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The Interplay of Economic, Climatic and Cultural Change Investigated Through Isotopic Analyses of Bone Tissue: The Case of Sardinia 4000-1900 BC

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The Interplay of Economic, Climatic and Cultural Change Investigated Through Isotopic Analyses of Bone Tissue: The Case of Sardinia 4000-1900 BC

by

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A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy
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Note to Reader

The original of this document contains color that is necessary for understanding the data. The original dissertation is on file with the USF Library in Tampa, Florida.
To my family, present and past,
including the unknown prehistoric people whose lives I try to understand
as one of the ways to understand ourselves
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The Interplay of Economic, Climatic and Cultural Change Investigated through Isotopic Analyses of Bone Tissue: The Case of Sardinia 4000-1900 BC

Luca Lai

ABSTRACT

With the broader aim of reconstructing long-term resource use and ecological history for better policy making in times of environmental change, this study is an attempt to decode the mutual effects of human subsistence practices, climate and socio-cultural organization in Sardinia between 4000 and 1900 BC. Was economy changing due to climate change? Was the environment changing due to economic practices? And how were economic practices and socio-cultural factors interacting? The answer is complex, and some convergence of complex systems theory, historical ecology and agency supports this. Diet, at the interface of all of these as fulfilling biological needs constrained by available resources, while being inextricably affected by ethnicity, age, class, gender roles, varies according to unceasingly changing variables.

Stable isotopic analyses of human bone tissues were used to build a quantitative dataset, and then integrate this with all the other proxies. The use of bone apatite besides collagen enhanced the dietary reconstruction and the contextual production of paleoclimatic data. The application of correction methods to ensure that dietary signature is distinguished from environmental noise enhanced inter-site comparability, making it possible to outline broad trends over time.

The results confirm the negligible role of seafood already documented in western Mediterranean late prehistoric groups. The long-held opinion that local Copper Age and especially Early Bronze Age societies relied more on herding than the Neolithic ones is not
supported by the data: contribution of plant foods actually increased. Certainly the data do not indicate any heavier reliance on meat or milk and dairy. Considering the limited data from zooarchaeology, material culture and landscape archaeology, the possible economic intensification could more likely be related to changes in power relations, gender roles and their construction through symbolically charged material culture. The two dry climatic events detected through δ18O values in accordance with previous independent studies seem to have had a role in triggering change, and such change followed specific routes based on the particular historical milieu.
Preface

The journey that brought me to this work has begun several years ago, when random readings and cartoons sparked my interest in archaeology. The road has not been straight, however. After studying classical literature and ancient history while cultivating my interest in pre-columbian complex societies, I got progressively interested in the prehistory of my own homeland, Sardinia. After studying English and contacting Dr. Tykot to explore options and possibilities, in the Fall of 2001 a new option was open by the fellowship provided by the Assessorato alla Pubblica Istruzione etc. of the Autonomous Region of Sardinia. Everything was at that point ready to start my PhD. My first expression of gratitude therefore goes to the Sardinian Region for providing the financial means to further my education at the University of South Florida, and to Sig. Massimo Lallai, in charge of the pertinent office, for his assistance, never only professional but always courteous.

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Chapter 1. Introduction

This dissertation is an investigation into economy and diet in prehistoric Sardinia (Western Mediterranean, politically part of the Italian Republic) and aims at contributing to our understanding of how they changed over time, in the context of a mutual relationship with the natural and cultural environment, between the Late Neolithic and Early Bronze Age. In rough absolute chronology the target period spans ca. 4000-1900 BC. Within the limits imposed by the current level of information we possess, the research presented here consisted of both an examination of prior evidence, and the production of new data, in order to evaluate models of development, or trajectories of socio-economic change, found in the literature. Such models provide different interpretive keys for the change in material culture patterns, and attribute such change to different causes, from technological to socio-political and – to a lesser extent - environmental. Quantitative stable isotopic data on human diet and climatic conditions have been produced according to a question-driven sampling strategy tailored to address specific questions that emerge in the archaeological literature. The discussion, rather than dealing only with the results, consists of a synthesis that attempts to integrate these new data with prior, mostly qualitative or semi-quantitative data, in order to ascertain the nature and extent of change, and suggest the possible underlying dynamics to be tested by future research.

Sardinia between the Late Neolithic and Early Bronze Age has long being the subject of archaeological research due to its architecture, both underground and above ground, mirroring the two aspects of Neolithic monumental tradition: rock-carved tombs and ritual sites on one hand, and megalithic structures on the other (Contu 1997; Webster 1996). This has been recognized throughout the Mediterranean and Western Europe at least at some point as reflecting the beginning of social complexity, and islands have represented a preferential focus, contributing, along with the Pacific islands, to the definition of the domain of “island
archaeology” (Evans 1973; Patton 1996). However, the meaning of many such phenomena in social terms has been, and still is, at the center of contrasting readings. Such a processual view, grounded on mild or radical environmental and geographic determinism, has increasingly been attacked, rejected, or corrected (Boomert and Bright 2006; Broodbank 2000: 6-35; Patton 1996: 24-33). The growing awareness that natural processes applicable to plants and non-human animals had little direct usefulness in studying human societies, the role of historically-specific developments and of the cultural, not just physical, nature of insularity, are the most important points. Moreover, the dietary and economic changes underlying the changes in material culture are surprisingly poorly known, and the economic side of the theoretical reconstructions has had comparatively little factual evidence to be evaluated against.

This is not surprising for the Italian research tradition, which includes outstanding excavators and art historians but remained until recent years largely impermeable to broad theoretical orientations, with a few notable exceptions. Many reasons can be cited: language was certainly one, as relatively few academics mastered more than three languages, and often English was not one of them. A second factor, connected to the former, is the presence of nationally-based institutions with smaller tenure markets than the world-wide English-speaking commonwealth. Moreover, a strong tradition in art history, rooted in the extraordinary wealth of figurative works dating to Greco-Roman times, made the focus on artifacts easy and natural. Finally, underfunding in Mediterranean nations is a general structural factor depending on broad economic patterns that caused a constant disadvantage, especially in science-based approaches.

Among the many interpretive approaches used to decode social change from the archaeological record, managerial or exploitative models have explained monumentality as the architectural manifestation of rising inequality, emphasizing the social outcomes of technological innovations: the introduction of the oxen-drawn plow, dairying and wool exploitation, also coupled with differential productive potential in different environmental zones, would have favored uneven accumulation of wealth and of labor control (Chapman 1990; Webster 1990).

Alternative models instead stress the remarkable continuity in the resource pool, belittle the social implications of variation in material culture, and emphasize mobility and horizontal stratification rather than complexity and vertical inequality (Whittle 1996).
Climatic change as an active factor is for the most part overlooked, or mentioned as a possibility but dismissed due to unclear or weak evidence. This is largely due to the lack of communication and collaboration between traditional archaeology and paleoclimatology, and of researchers at the interface between the two, who would be able to profit from both types of information.

In fact, the record of climatic change over the western Mediterranean clearly shows a long-term shift toward drier conditions during the Middle-Late Holocene, with a drier phase centered on the 3rd millennium BC. This time seems also to have been punctuated by a few abrupt dry events, which have not been given the consideration they deserve, at least as contributing factors to the social change recognized in the archaeological record. Clear evidence for a faster pace of change and even cultural disruption and adjustments in probable coincidence with climate change has been documented in the Near East, but despite some chronological coincidence being pointed at (around 2300 BC: Chapman 2003; Webster 1996: 62), a similar type of evidence in the western Mediterranean has not been synthesized and incorporated into standard archaeological knowledge.

Tracing diet in prehistory is relevant beyond a simple descriptive nutritional interest. It is relevant to shed light on the economic background of social variation since it is a proxy for the broad basis of subsistence. Diet can also reveal changes in relations between age groups and genders. An important part of the present dissertation consists in creating a first dataset of $\delta^{13}C$ and $\delta^{15}N$ isotopic measurements on human bone tissues, to address some issues highlighted by scholars of Mediterranean prehistory: did the exploitation of marine resources have any importance at some point in time, or was it marginal as it appears in the rest of the Mediterranean basin from an increasing body of data – both artifacts and isotopes? Were there any organizational changes from more sedentary, lowland-based farming communities to more mobile herding groups, focusing on the highlands and relying on milk and dairy products, as landscape occupation and material culture seem to indicate? If data are actually compatible with such a change, was this in any meaningful way correlated with climate change so that a causal link can be hypothesized, or was it instead socio-cultural dynamics that determined the variation in the archaeological record? In this regard, besides the critical analysis of paleoenvironmental and paleoclimatic data for the Western Mediterranean, $\delta^{18}O$ values measured on the same skeletal remains as the dietary analyses,
despite some interpretive uncertainties, provided a means to evaluate the correspondence with previously known broad climatic patterns.

In summary, this dissertation presents the results of the effort to address these three interconnected aspects: 1) collecting and critically assessing the prior evidence for socio-economic and climatic change; 2) documenting diet and climate through stable isotopes; 3) incorporating holistically the old and new data in a synthetic outline. While this is a proximate scope, one indirect scope is to give a contribution to the history of political ecology of Sardinia and the Western Mediterranean, and in this way understand the complex relationship between humans and environment in order to inform sustainable policies for the future.

From a cross-cultural and applied perspective, this is important in order to predict the consequences of human responses – or non-responses! - to climate change in fragile environments worldwide, and help to document and understand sustainability and non-sustainability in the past as in the present. Although heuristically useful, broad cross-cultural generalizations, typical of processualism (e.g. Boserup 1965; Steward 1959), were tainted with deterministic explanations overemphasizing environment and technology over specific cultural and historical determinants. From the reaction to environmental determinism permeating much of research until the 1970s came the reconsideration of culturally specific factors and the mechanisms they could reflect (Shennan 1987), after the historical domain had already been converging towards the use of a natural-cultural integrated approach with the French Annales school (Burke 1990). A detailed knowledge of contextualized cultural adaptations to changing climate in the past is especially relevant in our times of global warming, when we are starting to experience the warnings of major climatic transitions caused by the greenhouse effect, predicted to yield huge consequences on human societies.

Under this light, the research presented here is also inspired by approaches within a wider historical ecology framework, as outlined by Crumley and others (Crumley 1994; Fowler and Hardesty 2001), with some important differences. Such approaches were applied in fact to periods relatively well documented by literary sources in both the environmental and socio-cultural domains. Studying Sardinia in the 4th and 3rd millennium BC has the same aims of investigating holistically long-term change and broad patterns, but presents the challenges of climatic conditions documented only by more or less direct proxies measured and analyzed in comparatively recent times, and belief systems and social and economic
organization reconstructed only through material remains. This makes reconstructions coarser, with rare exceptions in the circum-Mediterranean world (Pétrequin, et al. 1998), but extends the potential breadth of our knowledge of the human-environment relationship several millennia back in time, increasing the ability to recognize long-term, persisting or reoccurring patterns (Braudel 1985).

Given this necessary premise, the following pages reflect the different stages of research. Chapter 2 gives a succinct background on the present-day geography and climate of Sardinia, and summarizes the main phases of the island’s history up to now, to make the reader familiar with the context, and based on historical sources in order to underline the interaction of geographic and historic factors and how these shaped the degree and type of relations that the island had with the surrounding mainlands. This can, in fact, illuminate our understanding of the potential situations that could have been in place in the past, helping to interpret the archaeological record. Chapter 3 provides an analysis of paleoclimatic and paleoenvironmental studies on the surrounding western Mediterranean areas, in order to infer conditions that are likely to have been in place in Sardinia as well, during the period under examination. Chapter 4 provides a critical overview of the material culture documented for the several phases studied, from pottery and lithics to architecture and funerary ritual, which provides a definition and the limitations of the cultural units that are used to discuss the subject of this dissertation. Particular emphasis is placed on chronology, and on indicators of social and organizational change in anthropological terms. This supplies a more specific framework that enables to reliably compare trajectories of cultural change with those detected in the other two domains of environment and economy. Chapter 5 examines in detail the extant evidence for dietary and economic change, from biotic remains to osteology and patterns of landscape occupation. All the relatively scarce evidence is evaluated and general tentative trends are outlined, with the aim of identifying the main hypotheses and research questions which are partially addressed through biochemistry in the following chapters. Chapter 6 presents the project that supplied new isotopic data. Principles, potential and limitations of carbon, nitrogen and oxygen stable isopy are first illustrated, followed by the operative description of the project, from sampling strategy to contextual information regarding the chosen collections. Chapter 7 presents the results of stable isotopic analyses, starting with preservation assessment and basic evaluation of the data. Chapter 8 opens with the correction of isotopic data in order to make them comparable between sites, continues
with the discussion of the isotopic results in dietary and climatic terms. All the pertinent available proxies are integrated in order to provide specific answers to the proposed research questions. Finally, an overall interpretation of the interaction between the environmental, economic and cultural element in shaping the ecological history of Sardinia between 4000 and 1900 BC is attempted. Finally, chapter 9 summarizes the main conclusions of this study and recommends directions for future research.
Chapter 2. Background

2.1. Geographic, Environmental and Historical Background

Sardinia is a large island, about 24,090 km\(^2\) (roughly the size of New Hampshire), located in the center of the west Mediterranean (Figure 1), almost equally distant from the Italian peninsula and from Tunisia (ca. 170-180 km), and especially close to the island of Corsica, a natural bridge toward the European mainland (Figure 2). The largest plains are located on the western half of the island, while the majority of the landscape is made up of hills, with a few areas in the central-eastern highlands over 1,000 m asl, and several steep ranges and gorges that make transportation difficult (Figure 3). Climate is presently characterized by mean annual temperatures of 10°C to 18°C, and precipitation of 400-1000 mm (Pracchi and Terrosu Asole 1971), a short rainy season in the winter, and a long dry summer which favors the occurrence of highly destructive fires. Prevalent winds are from the northwest, which is also where moist clouds come from, depending on the eastward winds from the Atlantic (westerlies).

Throughout documented prehistory and history (Table 1), Sardinia’s several outward connections reflect its central location, with cultural and political links and trade connections shifting between central-northern Italy, the Iberian peninsula and Tunisia, and additional ones to southern France, the Balearics, southern Italy, and Sicily (Contu 1997; Day, et al. 1997; Meloni 1990). Its insularity is reflected, on the other hand, by unique biogeographic elements, most important of which is the extinction of large mammals by pre-Neolithic times, the strong presence of species or subspecies not found elsewhere (Vigne 1992), long periods of relative cultural isolation and drift (Rowland 2001), and today in the unique elements of the local language, Sardinian (Blasco Ferrer 2002), and in the genetic traits of its population, remarkably distinct from those of the surrounding mainlands (Francalacci, et al. 2003; Fraumene, et al. 2003).
Figure 1. Location of Sardinia in the Central-Western Mediterranean. Map created with cartographic materials courteously provided by Primap Software.

Figure 2. Location of Sardinia with close up of the basins around the island. Map created with cartographic materials courteously provided by Primap Software.
Figure 3. Physical map of Sardinia showing main orographic features, coastal lagoons as of the mid-1800s, and names of some of the main historic regions and cities mentioned in the text. Map by the author, based on cartographic material from S.A.R. Sardegna consortium, with kind permission.
Table 1. Chronological table of Sardinian prehistory’s cultural phases in the time span considered in this study. Calibrated radiocarbon dates are after Tykot (1994), with a few modifications involving the hypothesized different duration of Copper Age cultures across the island.

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<th>Calibrated years BC</th>
<th>Chrono-cultural phase</th>
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While the Paleolithic occupation of the island is debated, the first stable colonization is connected with the introduction of domesticated animals and plants in the Early Neolithic (Cherry 1990). This phase is characterized by so-called cardial impressed pottery, a decorative style obtained by impressing the rim of Cardium shells on the ceramic paste.
before firing, which is common to a wide area between the Tyrrhenian Sea and the Spanish shores. During the Early through Late Neolithic, the presence of one of the largest obsidian sources of the western Mediterranean has put Sardinia in an archaeologically visible contact with wide areas: the distribution of Sardinian obsidian spreads as far as southern France, northern Spain, and central and northern Italy (Tykot 2002a, b; Tykot, et al. 1999). The participation in wide maritime spheres of interaction is witnessed also by other items, such as polished stone hatchets and large lithic rings/bracelets of uncertain purpose, circulating in the Early Neolithic and probably through the Middle Neolithic (D'Amico 1998; Pétrequin, et al. 1997; Tanda 1977). On the other hand, ceramic style, the best documented kind of artifact evidence, starts to acquire more regional features already within the Early Neolithic, which has been characterized by Tanda (1995a) in three aspects, with shapes and decoration that become increasingly peculiar to Sardinia (Contu 1997: 79-84, 178-197). By the Late Neolithic (4th millennium BC), pottery shows standardized decorative motifs that are typical and distinct from the European mainland. Contact with southern France and central-northern Italy is still documented by obsidian, although the intensity cannot be assessed due to the lack of indicators for transport of perishable goods.

While obsidian frequency declines, ceramic styles during the Copper Age show multiple similarities, occasionally quite stringent, documenting Sardinia’s full participation in the web of routes connecting the whole western Mediterranean, very likely in coincidence with the spread of metallurgy. The Early Copper Age pottery of northern Sardinia (1st half of 3rd millennium BC) appears closer to central and northern Italy (Basoli and Foschi Nieddu 1993), while later Copper Age material culture (Monte Claro phase, centuries across mid-3rd millennium BC) shows similarities with southern France and Sicily (Lilliu 1988a: 155-157). Walled settlements are also features in common with southern France and Iberia (Moravetti 1998a, 2001), and other peculiar traits found in southern Sardinia, such as burnished pottery and leaf-shaped copper blades, seem to reflect participation in more east-oriented cultural contexts. The presence of Bell Beaker elements (ca. 2500-2200 BC) is parallel to those widespread in continental Europe (Nicolis and Mottes 1998; Waldren and Kennard 1987). Two phases have been identified, with an earlier emphasis on similarities with the Mediterranean West and Northwest and later on stronger parallels with the Alpine and Italian area (Ferrarese Ceruti 1989: 59-66) Interestingly, Corsica appears to be touched only marginally by the Bell Beaker style (Lemercier, et al. in press), which may be due to lack of
research or reflect a late and peripheral inclusion in the Bell Beaker routes between the Northern Mediterranean and Sardinia, which were likely related to traffic in metal goods. The links witnessed by typical Beaker pottery decoration evolve and continue in the Early Bronze Age (ca. 2200-1900 BC), when material culture in general is similar to that of the Polada culture of northern Italy (Lilliu 1988a: 301-312), although daggers of Iberian type are also frequent at the transition into the Middle Bronze Age (ca. 1900-1300 BC). The wealth of copper sources in Sardinia might have been an important attractive element around this intermediate period.

More complex relations and intense trade is instead documented in the Late and Final Bronze Age (ca. 1300-1000 BC), when Mycenaean pottery, though in relatively small quantities, is found at several locations, along with a high density of metal objects and ingots, particularly of Cypriot origin towards the end of the Bronze Age (Knapp 2000; Lo Schiavo 1995). At the same time, Sardinian pottery is found on Lipari and Crete, witnessing to the island’s insertion in Mediterranean-wide trade networks involving not only metal but also perishable goods, identifiable as the new prestige consumables, i.e. wine and olive oil (Hamilakis 1999; Riley 1999).

In the Iron Age, evidence for indigenous export shrinks again within the Western Mediterranean, with preferential connections of Northeast Sardinia with Etruria (Lo Schiavo 2002), in central Italy, and the establishment of Phoenician trade posts on the southern and western coasts of Sardinia. These represent the first examples of truly urban communities, and within a few centuries virtually monopolize the traffic between the interior and the outside world, in the context of a colonial division of the Western Mediterranean into areas controlled by Etruscans, Greeks and Phoenicians (Bernardini, et al. 2000; Tronchetti 1988).

The unification of the Western Phoenician cities under Carthage and the creation of the first expansionist empire in the area strongly ties Sardinia to North Africa both economically and culturally, a pattern that remains up until the Middle Ages. Carthage conquers all lowlands by ca. 500 BC, and begins the utilization for cereal monocropping of the most fertile lands. The Roman take-over of the coastal cities in 238/37 BC did not extinguish the strong Punic identity, which lasted for centuries (Mastino 1995). After several uprisings and genocidal campaigns in the mountains lasting over two centuries, Sardinia was virtually romanized by the 1st century AD, and became fully part of the large Mediterranean-wide economic system of the classical world. This also coincides with the most intense
human presence in the landscape since the Late Bronze Age, and the establishment of landholdings with the use of slave labor (Meloni 1990). Not much more than place names of the pre-Roman languages survive, although in the central highlands such pre-Indoeuropean linguistic fossils have been documented in frequencies among the highest in Europe (Wolf 1998).

The link with present-day Tunisia in North Africa was maintained towards the decline of the imperial power, and during the occupation of the Vandals between the 5th and 6th centuries AD. Following the example of the Romans, who deported to Sardinia thousands of Jews, the Vandals deported into the island heretic bishops and political opponents, marking in this way an important phase in the diffusion of Christianity (Artizzu 1992). For another century and a half, after the Byzantine troops regained control of the island (AD 535), Sardinia was politically dependent on Tunisia, while being open to eastern culture. Islamic expansion reached North Africa in the early 8th century, breaking the millennial relation with Sardinia.

The Arab conquest of Sicily in AD 826 and the Islamic control of the Western Mediterranean made navigation and connections with the European mainland less intense. Byzantine authority became only nominal, but nonetheless important in the legitimization of the indigenous rulers who led the resistance to the many attempted invasions. While very few Greek words are found in Sardinian, many religious traditions and churches date to this period (Corrias and Cosentino 2002), and settlement remained dispersed in small hamlets, growing out of the late Roman farming enterprises, with slavery replaced by servitude. The alliance with Pisa and Genoa in the fight against North African raids favored the opening to external trade in the 11th century AD, and the intermarriage of local dynasties with high ranking families from Tuscany and Liguria. The allegiance to the Roman Church was also cemented through donations to monastic orders centered in central Italy, northern Italy and southern France.

The Kingdom of Aragona, with capital Barcelona, in Catalonia, entered the picture in order to gain control of trade routes to the East, and between AD 1323 and 1409 was able to defeat both external Italian competitors and the last indigenous kingdom of Arborea, with capital Oristano on the west coast (Casula 1983). Sardinian society experienced a dramatic demographic collapse due to war and disease, which likely contributed to easing the way to Iberian cultural hegemony (Ferrante and Mattone 2004). Sardinian cities controlled by
Catalans maintained regular trade connections with Barcelona, Genoa, Naples and to a lesser extent, Marseille, while in the countryside feudalism was instituted for the first time at a time when in continental Europe it had virtually disappeared.

Sardinia was under Catalan and subsequently Spanish rule until the early 1700s, and became heavily hispanic in many aspects of spirituality and tradition (Murgia 2000); Spanish is also the language that most heavily influenced the Sardinian vocabulary, remaining the prestige tongue of the nobles and the higher clergy until the early 1800s (Sorgia 1982). In 1720 the island was assigned by treaty to the Dukes of Savoy, based in northern Italy; this state annexed within approximately 150 years most of the territories that then became Italy. Among the important socio-economic points worth mentioning are the 1820s and 1830s reforms aimed at abolishing feudalism and creating private property, in an island where most land was still held and managed in common by each community (Le Lannou 1941: 157-167; Scaraffia 1984), and the investments in industrial-scale, modern mining in the late 1800s up to the mid-20th century, mostly in the Southwest, overlapping with the areas where prehistoric Bell Beaker occupation is densest.

The brief outline of Sardinian external relations through 8,000 years highlights the role of geographic centrality, which allowed multiple links with several surrounding mainlands and islands, during different periods or at the same time, and the important role that specific historical conditions played in shaping cultural change. At the same time, this did not prevent the establishment and maintenance of original cultural traits, which depending on the theoretical orientation may be attributed to insularity and isolation (Rowland 2001), or interpreted as acts of ‘creation of identity’. Among such original traits, many of which were codified in the Middle Ages by Queen Eleonora (14th century), is the legal condition of women, who inherited property as did their male siblings, and the clear recognition of rape as a crime against an individual (Casula 1994). Evidence of parallel descent reckoning, scarcely documented in Europe, appears from archival documents in the Middle Ages and up to the 17th century, where the transmission of the last name to women was matrilineal (Murru Corriga 1993).

Today, the language itself, which became officially allowed by the Italian government only in 1997, along with specific cultural and religious traditions, is a remarkable testimony of a unique cultural trajectory, where a complex interplay of
geography, external and internal economic dynamics, and agency seems to have constantly favored or permitted the expression of ‘otherness’.

2.2. Theoretical Background and Objectives

Studies specifically addressing economy and diet between the end of the Neolithic and the Early Bronze Age are surprisingly few. Mediterranean societies are overall considered to have been fully dependent on farming and animal husbandry (Sherratt 1994), but the particular patterns within the Neolithic resource pool, and the integration with hunting and gathering, are highly variable. In Sardinia, the first human presence documented on the highlands dates to this time (Tykot, et al. 1999). It seems clear that over wide areas of Europe there was enough surplus labor for construction of megaliths. In Sardinia, more than to the building of megalithic structures, this was applied to the carving and decoration of rock-cut tombs, so-called domus de janas, typical of the Ozieri culture and its later tradition (ca. 4000-2500 BC), which reached in some cases a high degree of complexity, with tens of rooms, abstract paintings and reliefs, and the reproduction of houses for the living (Tanda 1984, 1992a). What is uncertain is what this involves in economic terms. Subsistence was based on farming cereals and legumes, and tending ovicaprines, cattle and pigs. In several areas of western Europe there was demographic growth from the Late Neolithic, with the expansion of some settlements which has been related to the intensification of production (Knapp and van Dommelen 2002; Malone 2003; Robb 1999). Instead, in Early Copper Age Sardinia (ca. 3200-2500 BC) we see contraction in the absolute number of sites, their location at higher average elevation, and the almost total disappearance of evidence for open-air settlements: elements of material culture have been recovered mostly in burials (Atzeni 1995). Also, a few outstanding sites represent local social and ritual trajectories (same phenomenon found elsewhere in the 3rd millennium western Mediterranean: Robb 2001a: 190), with megalithic tombs and circles, concentrations of statue-menhirs with unique symbolic markers, and the pyramid-temple of Monte d’Accoddi (Atzeni 1989a, 1994; Atzeni and Cocco 1989; Perra 1994; Tiné and Traverso 1992b).

In the Monte Claro phase, which appears in many aspects of material culture foreign to the local tradition, dated through pottery style and stratigraphic contexts to the Later Copper Age (at ca. 2700: Tykot 1994), there is a focus on lowlands in the South, and
nucleation of settlements and the rise of fortified/ritual sites on hilltops in the North (Castaldi 1999; Moravetti 2000). Similar developments have been connected in Europe to the ‘secondary products revolution’, a concept that underlines the effects of the spread of technological innovations such as the wheel, the ox-drawn plow, and the exploitation of dairy products (Patton 1996: 59-62; Sherratt 1983, 1994). This package would have opened up new opportunities for differentiation, due to increased outputs and the presence of means of production that could not be maintained by all families or groups. For Sardinia, these dynamics have been suggested as the key to a certain degree of differentiation in the Copper Age: to sustain a household in lower-productivity areas, a peasant would need to depend on plow and draft oxen from wealthier families, so favoring the increase of inequality (Lewthwaite 1986). In reality, while exploitation of secondary products has been clearly documented in central-eastern Europe, in the Mediterranean Balkans the evidence is unclear, with older cattle possibly representing use for traction or just wealth accumulation in creating large herds, whereas ovicaprids were exploited for meat (Greenfield 1988; Greenfield and Fowler 2005). Moreover, besides the problem of the diversity in the material culture indicating distinct phases within the Sardinian 3rd millennium (often lumped into a generic ‘Copper Age’), complexity itself is not to be taken for granted: monumental structures are the main alleged indicator of social complexity, while burial customs, the other element that may reveal differentiation, are largely collective.

As in Sardinia, higher architectural complexity is found at some point in the Copper and Early Bronze Age in Iberia (Chapman 1990; Lillios 1995); in southern France, similar enclosed settlements have been interpreted as fully sedentary, fortified centers of power indicating intensification and competition (Gutherz and Jallot 1999; Lewthwaite 1982); in Malta, construction of large ritual and burial sites and specialized artworks also implies some concentration of labor (Malone and Stoddart 1998; Stoddart, et al. 1993). These phenomena have been mostly explained through Marxist and functionalist models, whereby the need for leadership or the opportunity to gain control are key factors in social differentiation processes (Earle 1987; Renfrew 1972).

In managerial models, the dry Mediterranean climate would have required, in arid areas such as south-eastern Spain, intensification of production to increase outputs and meet the needs of a growing population. Elites would have emerged to keep the order necessary for water management, or to make long-term investments in tree crops, as grains are more prone
to failure due to weather unpredictability (Chapman 1990; Vicent García 1995). For Marxian theorists, the new practices were the opportunity for ‘aggrandizers’ to exploit the community by tying it to reliance on olive and vine cultivation, and to themselves (Gilman 1981; Johnson and Earle 1987; Lull 1984; Ramos 1981). It has been observed, however, that such tree crops and water storage/irrigation facilities involve a substantial material and organizational power that must logically come before the ability to mobilize labor (Webster 1990; see parallel problems in Mesoamerican archaeology with irrigation management: Wells 2006: 269-270).

On empirical grounds, as concerns Sardinia, we do not know anything about tree crops before the Middle Bronze Age (Bakels 2002).

On a similar line between processualism and social theory, others ascribe the rise of patron-client systems and inequality in Sardinia (Hernando Gonzalo 1997; Webster 1996: 52-61) to different productivity potential, circumscription, and high-risk environmental contexts (Carneiro 1970; Webster 1990). In island ecosystems, key subjects for processual archaeologists (Patton 1996), monumental architecture has also been interpreted as the mirror of ritual intensification during chronic crises (Bahn and Flenley 1992; Stoddart, et al. 1993). Sardinian prehistoric cultures in the Final Copper (ca. 2500-2200 BC) and Early Bronze Ages (ca. 2200-1900 BC) are again known mostly from burials, with scarce evidence of living sites (Atzeni 1996a; Atzeni and Santoni 1989). The Bell Beaker style has therefore been interpreted as a new fashion of prestige markers to be displayed mostly at funerary rituals. The Early Bronze Age has attracted more attention, since it is identified as the formative phase of the following Nuragic culture. While many local archaeologists place the rise of complexity in the Early Bronze Age after the Copper Age cultures which are generally viewed as simpler (Lilliu 1988a: 358; he believed though that nuraghi dated to the Early Bronze Age; Tanda 2002; Ugas 1999), some also recognize signs of more social complexity in the Copper Age (Lilliu 1988a: 143, 244; 1988b). Webster (1996: 81-84) definitely argues for a society organized in autonomous households lasting through the Middle Bronze Age; others identify a first phase with household-based organization focused on lowlands and cereal monocropping, and a second phase, named Sant’Iroxi, with some signs of differentiation, which is transitional toward the Middle Bronze Age when this would have mostly occurred (Perra 1997).

The competing dietary and social model for Sardinian prehistory emphasizes continuity, with no significant changes from the Neolithic to the Iron Age (Lazrus 1999). A
similar mixed farming economy would have been in place during the Neolithic as well as the Copper and Bronze Ages, where the broad subsistence base would include sheep, goat, cattle, pig, wheat, barley and legumes, integrated with some gathering, fishing, and hunting of Prolagus sardus (a rodent now extinct), wild boar and deer. This diversity is considered incompatible with the reliance on a single food category that would be expected if a dramatic shift between agriculture and pastoralism had occurred. Any archaeological evidence in this direction (in settlement patterns, burial practices and symbolic expressions) is considered scarce. Social organization would have never involved more than moderate and temporary differentiation throughout the period (Lazrus 1999). This is in line with historicist and post-processual models applied to wider European prehistory, which stress mobility (Whittle 1996), tribal politics, agency, change in gender roles (Robb 1994a, 1999), and identity-building (Broodbank 2000 for the Aegean; Robb 2001a; Tusa 1998 for Malta) as driving forces. The enclosures found across western Europe are interpreted as areas for ritual gathering rather than fortresses, sites used repeatedly by mobile groups to keep communal identity and use rights in the land. Evidence for climate change is considered inconclusive (Whittle 1996: 322-354).

It has been underlined that the simplistic tetra-partite model of band-tribe-chiefdom-state largely based on the Pacific islands (Sahlins 1963) is an acceptable generalization but is inadequate to explain the complexity of tribal social organization. One reading of the central Mediterranean evidence based on more recent ethnographic work is by Robb (1999), who identifies in the Late to Final Neolithic transition in the Western Mediterranean the evolution of great-person societies into big-man societies. Big men enjoy a more generalized acquired status related to wealth and leadership, which become generalized prestige characteristics opposed to particular, horizontal or egalitarian roles based on unconvertible skills or spiritual qualities. Males also seem to gain a position of dominance as opposed to complementary and more balanced roles (Robb 1994a, 1997). A related consequence, in this case not inherent or necessary but historically generated, would be an augmented strife to acquire prestige items, which necessitates more surplus wealth and therefore intensification of production (Lillios 1995, 1997). At the root of intensification, rather than economy, would be the ritual need to acquire goods of extraordinary quality, or quantity (Spielmann 2002), for events which can become an opportunity for a socially acceptable gain of prestige and/or wealth (Wells 2007). In contexts where this was not environmentally viable for lack of land or scarce soil
productivity, as in small islands, intensification may have led to some degree of centralization and/or social disruption, according to historically specific trajectories (Robb 2001a). According to these models, it is a change in social and cultural behaviors that would affect economy and in turn environment, rather than the opposite.

Whether or not dynamics were similar over vast regions of the western Mediterranean, which is unlikely, the most profitable research agenda would seem that of collecting data on ritual and economic mechanisms within their environmental contexts, in regional units, in order to detect common causal relationships. From this perspective, Sardinia is one relevant piece of the wider goal outlined above: detecting the mutual relationships among natural and cultural factors, with economy at the interface between the two, while keeping our interpretative efforts as much as possible open to explanations that holistically integrate environmental change, economic processes, and socio-cultural dynamics (Sherratt 1991, 1997b; Thomas 1987).

As briefly mentioned in chapter 1, one of the lines of inquiry that this study takes inspiration from is the historical ecology framework, as outlined in Crumley (1994) and others. It was also underlined how similar tendencies where the holistic convergence of nature and culture can be recognized in historic studies. In the present work, the interpretive perspective for the understanding of change draws from Pauketat’s (2001) historicism-processualism, defined as a new paradigm, but also from van der Leeuw and Aschan-Leygonie’s (2000) complex systems approach on socio-natural dynamics. Pauketat’s discussion is useful to elucidate the main points that are relevant for the interpretation of the data analyzed. Even in some Neo-Darwinist approaches there is a convergence of some parts of such theoretical currents with post-processualism as concerns the emphasis on practice and conscious or implicit historicism, in that material culture is viewed as a product of previous traditions on which socially negotiated choices are applied, in turn shaping future developments. It has been pointed out (Pauketat 2001; Robb 2007: 5-7) that there are authors who define their theoretical orientation as “agency”, but in reality give in their interpretation preeminent role to individual decision-making and a strife for success and prestige as intrinsic human qualities. It is important to underline that intentionality, present in every act of replication of practices, is not the same as strategy or tactics. It corresponds rather to the “habitus”, or the realm of the “doxic” in Bourdieu’s (1977) terms: unconscious, spontaneous, practical, belonging to the domain of common sense. Pauketat (2001: 79-81) calls for the
documentation and understanding of the “genealogy of practices” as the context for the unceasing renegotiation of tradition. Rather than searching for universals by means of deductive logical process, the documentation of several micro-scale historical processes and their proximate causes are considered the basis for a better understanding of ultimate causation by means of induction profiting from large datasets. What is considered important is “the traditions of practice, the genealogies of production, and the proximate details of how things changed […] toward more encompassing – dare I say ultimate – explanations of the cumulative effects of practice” (Pauketat 2001: 81). The potential – or inevitability – of unintended consequences of any given practice, whether in the short or long term, is a concept used in social anthropology to describe cultural dynamics where the choice of action, on an individual and collective level, contributes to changing but also to reproducing preexisting structures with effects that were unwanted or unpredicted by actors (Joyce 2004; Robb 2001b; 2007: 5-7).

The same definition of “unintended consequences” is also commonly used by environmentalists to interpret practices that have an impact on the environment: van der Leeuw and Aschan-Leygonie (2000: 13) similarly point out that each human practice applies forces to the environment that have the potential to issue unpredicted effects. Furthermore, the more transformations and effects are long-term, the less likely they are to be perceived by human societies, even if they are leading to future problems. The embeddedness of the perceptions of crises or environmental change, besides theory, is confirmed ethnographically. It has been observed, for instance, that the perception of environmental degradation due to overgrazing is better where rainfall is regular, whereas in areas periodically affected by long droughts the effect of herds is easily conflated into and confused with the effect of lack of rain (Bollig and Schulte 1999), or that intentionality at the collective level may be absent or different from intentionality and profitability at the household or individual level, determining gaps and unintended consequences (McPeak 2005).

Considering some concepts used by the Complex Systems and Agency theorists mentioned above, it appears that despite the different underlying general basis, and the focus on more socio-cultural change versus environmental, “socio-natural” change, the concept is rather convergent, and not at all new. In a general form, it is found for instance in 16th-century politician and diplomat Guicciardini (1977), who in disagreement with his more influential friend Machiavelli, emphasized with disappointment that the specific historical
conditions of each and every given situation made systematic prediction and repeatability impossible. Van der Leeuw and Aschan-Leygonie (2000: 11) define “institutions” as “flow structures – essentially temporary manifestations of the movement of matter, energy and information”. This is one definition in scientific words of human practices, meaning things that humans do, but following Levi Strauss in clarifying that these are symbolically defined in each context. This is not, therefore, different from “practices” as defined in agency, in their dependence on the constraints of preexisting habitus, and in their generative property.

There are further elements widely shared in today’s theoretical panorama that can be found to be in common to agency theory, for instance as discussed by Joyce and Lopiparo (2005) and complex systems as discussed by van der Leeuw and Aschan-Legonye (2000): one is the emphasis on action, dynamic change, and relations, which incorporates what we perceive or traditionally define as structure, or systems, rather than being a separate entity. Since all human practices determine change, even if momentarily or archaeologically imperceptible, and whether it is intended or unintended, logical consequence is that every system, or apparently normative structure, is in motion and continuous becoming. The perspective used and the effort made in this study is accordingly that of describing dynamic realities, even if description of material culture may appear otherwise, and even if, for the sake of making change understandable, it may be necessary to describe situations synchronically as if they were artificially frozen. In reality, the concept of system, although connected in most archaeologists’ minds with the processualism of the 1970s, is still a useful tool to refer to several factors bound together in such a way that a change in one element affects the others. The existence of factors that do not respond to the laws of physics due to their arbitrary, symbolic nature (Robb 1998) and of cultural entities that are not integrated but can be devoid of (perceptible) effects does not erase, but only limits to some extent, and makes more dynamic, the validity and usefulness of the concept itself.

The perspective used here makes an effort to overcome the bridges and dichotomies between science-based and social theory-based approaches. As underlined above, most scholars aligned with post-processual criticisms of previous environmental determinism tend to deal with prehistoric politics, symbolic archaeology and ritual, and are generally inclined to overlook environmental factors in explaining, or rather describing, historical processes, probably regardless of the quality of environmental data that we have available for much of the Holocene, which is mostly ambiguous, patchy and admittedly inadequate for use by
archaeologists (Bintliff 2002; Dincauze 2000: 23-27). This, coupled with the historically-specific lens that characterizes most post-processualists, has also the consequence that there is very little connection that can directly or implicitly bear upon the current management of resources, which is regrettable. This is not intrinsic in practice theory, where the ultimate goal of finding general patterns in long-term human practices is not rejected a priori (Pauketat 2001: 81), but in concrete terms it tends to be postponed indefinitely, in a way somewhat similar to the indefinite postponing of the study of the so-called “superstructure” on the part of classic processualists. In this study, an attempt is made to verify the existence and reliability of information regarding climate and environmental change, and analyze such variation by considering its interaction with human practices as part of a whole. However, the focus is not on landscape itself (Crumley 1994; Gunn, et al. 2004), instead landscape is only one of the many proxies that are taken into consideration to interpret change in the human-made material record in terms of social and cultural change of people.

To be able to evaluate the interplay of elements, on one side I analyzed and synthesized data on climate and environment between 4000 and 1900 BC (see next chapter), on another I used existing data on culture and society, and finally I addressed economy and diet by both analyzing and synthesizing previous data from several research domains, and by producing a meaningful dataset of relevant stable isotopic values on skeletal remains. Human practices such as those related to food production and consumption are located at the interface of humans and everything else: the liminality embodied in the act of eating and drinking (Hamilakis 2000) makes it an ideal target as precisely one of the “flows”, or relational acts, which are themselves reflexive, reproductive and generative, constantly reinforcing and changing in various degrees the structures where they are situated and which they are part of. The cycle involving food and drink, of which consumption is an element together with production, distribution, and processing, impacts soils, vegetal and animal communities, creating through practice a cultural world, with the addition of other practices not directly related to diet. Along with change, such practices introduce both intended, proximate consequences, and non intended, longer-term effects (van der Leeuw and Aschan-Leygonie 2000).

As regards the origin of changes in culture (Figure 4), whereas theoretical orientations in the past have been leaning towards either general, climatic/environmental, natural causes – in the 1960s and 1970s – or preferably cultural/agency-based, human-
Figure 4. Flow diagrams to illustrate the relationships among Interacting domains in explaining change according to different paradigms. The third, considering that most domains interact both ways, with either direction potentially being stronger in different historically specific situations, is the one adopted in this study. On the right, the chapters roughly corresponding to the different domains as organized in this work.

induced causes – in the 1980s and early 1990s. The key concepts used in the anthropology of human-environment interaction were adaptation, where variation depended on people.
adjusting to nature in time and space, and then sustainability, where nature was thwarted and made cultural by people in ways that could be conducive or not to long-term maintenance of social entities (van der Leeuw and Redman 2002). Despite strong residual adaptationist generalizations that seem a new presentation of older processual attitudes, the approach that focuses on resilience using complex systems theory attempts to tackle the variability and broad range of potential factors that interact at any point in time, at different scales and in different ways (Redman and Kinzig 2003), in shaping what we perceive as change. In this study, the aspect relating to the attempt to find generalizations and applying models of change is not adopted: on this issue, the considerations regarding practice theory and historicism-processualism as briefly outlined above (Pauketat 2001) are valid. A more contextual look at the evidence available for the study area intends to reconstruct the dynamics of its particular historical ecology, with a lens that is as much as possible balanced and unbiased toward climatic, environmental and cultural causation as they interacted at different scales, pace, and ways, each potentially gaining somewhat stronger role in different situations.
Chapter 3. Climatic and Environmental Change in the Western Mediterranean Basin and in Sardinia ca. 4000-1900 BC

3.1. Introduction

As explained in depth in the introduction to this dissertation, the wide scope of my research is to understand the relationship between environmental, economic and cultural change, and to find correlations that may be interpreted as causal links between these three factors. To overcome dichotomies between natural and cultural determinism we must acknowledge that all cultural and natural phenomena are tightly intertwined. The direct effect of both sets of factors, although they may and do vary, cannot be expressed meaningfully by either/or statements, but appears to be better represented as a continuum between two extremes, which are rarely if ever found as such.

The essential outline of the theoretical position underlying this study in chapter 2 served the purpose of making clear some important points relating to the interaction of human impact and climatic conditions in shaping a changing environment. The climatic conditions function as constraints for the potential variation available to human agency, which is responsible for much of the characteristics of the cultural environment. The practices that transform both the natural (vegetal, animal, pedological) and cultural reality are culturally embedded, so that intended and unintended consequences are all elements to take into account (Robb 2007: 5-7; van der Leeuw and Aschan-Leygonie 2000: 13). Change is brought about unceasingly by acting, while at the same time contributing to the maintenance of contextual socio-cultural structures. Understanding the interaction among different elements, whether they are economic, symbolic, environmental, or climatic, is the goal of this study, and it is assumed (van der Leeuw and Aschan-Leygonie 2000: 19) that change will depend on the magnitude and intensity of change in some factors relative to others, the speed
and duration of different phases, and the scale considered. Long-term dynamics can intermingle with short-term events called perturbations (with a rather environmentally-oriented language), which include cultural stimuli and practices unrelated to activities pertaining to subsistence (and here these distinctions are used as units of analysis, not as intrinsically distinct domains: Robb 1998). The preeminence of some factors over others is assumed to change in single situations, depending on the elements cited above such as magnitude, duration etc.

In the past several decades the focus of research has been mostly on material culture, belief systems as represented by material culture and, to a lesser extent, social organization. Climatic information regarding specific localities on the island is lacking instead, so that a climatic reconstruction that is reliable and sufficiently detailed and articulated in phases is necessary.

Unfortunately, there have been no studies done that specifically involve the environmental conditions of Sardinia in the mid-to-late Holocene timeslice from 4000 to 1900 BC. This is due to the scarcity of structures, funds and professional skills necessary for all the disciplines that address climatic and environmental reconstruction in prehistoric times. There is up to now no palynology laboratory on the island, and none of the university departments has research teams involved in it. Comparing sites studied in Sardinia with the adjacent areas (Figure 5) underlines the large gap it represents in the western Mediterranean record.

With these premises, in this chapter I have reviewed the most important and up-to-date literature on climatic and environmental conditions, examining several contributions to the recording and explanation of climatic and/or environmental conditions in the regions surrounding Sardinia. This was done with the aim of putting together information in order to identify whether there are trends and phases that are common to the entire area and can therefore be inferred to affect Sardinia, in the same period ca. 4000 and 1900 BC. For this purpose, these are the main questions: was there any detectable climatic and environmental change? If so, is it possible to define chronologically, in an accurate and meaningful way, these different phases? Is it possible to quantify these changes in terms of temperature, humidity, and their seasonality? Also, what was the role of humans in contributing to the transformation of the environment?
Figure 5. Map showing the distribution of Mediterranean sites mentioned in the text, which have been discussed for the reconstruction of paleoenvironmental and paleoclimatic conditions in Sardinia, 4000-1900 BC.

3.2. Sources and Methods

Scholars have several methods at their disposal for paleoenvironmental reconstruction, which match the different available proxies. According to the chronological scale we are interested in, not all the known proxies yield the same information potential. Here I am interested in meso- and microscale ranges, and particularly in patterns spanning from several thousands of years to centuries. Ideally, the best situation would be having information at a much smaller scale, even to the year or the season, but this contrasts with the absolute chronology of Sardinian and of most of Western Mediterranean prehistory. In fact, the scale of radiocarbon dating is millennial or centennial – at least without sequences allowing the use of Bayesian statistics. As a matter of fact, tree-ring dating of archaeological
phases, possible for instance on waterlogged remains in the Alps or northern Europe, is truly exceptional in Mediterranean areas, so that having a higher-resolution environmental sequence without a comparable cultural sequence would be of limited use to identify relations between the two.

Generally, existing proxies include geomorphological features, morphology of sediments and soils on land and in lakes, faunal, macro- and microbotanical remains, tree rings, corals, historical record, and ice cores (Dincauze 2000: 176-87). Among these, ice cores are a viable approach on high mountains, but they never yield long sequences as in arctic regions. Tree rings in the western Mediterranean do not preserve as well as in more northern latitudes due to temperature and higher seasonal variation, and those available have not been studied extensively. Historical records are not useful for phases at least a thousand years earlier than the first appearance of writing in the 9th century BC (Phoenician inscriptions) or the first truly historic accounts by Greek (6th century BC) or Latin (2nd century BC) writers.

A systematic discussion of the principles and ways to extract paleoenvironmental information from all these diverse materials is not included in the scope of this dissertation, therefore for this purpose I recommend consulting more specific literature. Here I will only briefly discuss pollen analysis and its main limitations, as they have been pinpointed in the context of the reconstruction of vegetation history within the western Mediterranean context. This is done here for the sheer reason that palynology makes up the majority of our evidence.

Most general caveats and limitations concerning the interpretation of pollen data stem from the diverse nature of pollen deposition through different agents and for different species: some are airborne over long distances while others are carried mostly by insects within a short radius from the plant source, some are self-pollinating and their flower does not even open. Some taxa produce large quantities of pollen grains, while others relatively few, so that their representation in the archaeological record, affected also by differential preservation, is severely biased. Moreover, only some plants can be identified at the genus level, most grasses for instance cannot be recognized beyond the family level. These are the reasons why ancient assemblages, more than being interpreted singularly, are compared to modern ones (Pearsall 2001: 336-44).

Concerning the Mediterranean, some examples are the overrepresentation of the Pinus genus (pine), whose species produce large amounts of pollen, and the Cedrus genus
(cedar), both windborne over wide areas, as opposed to the underrepresentation of the *Fabaceae* family (pulses or legumes). Pollen of the latter, despite these plants being intensely cultivated, is hardly found more frequent than 1% of any given total pollen count. Legumes are instead revealed by the pollen of *Cuscuta* (dodder), a parasite, and by remains of insects that live on them, like species of the *Curculionidae* family. Glacier melting can liberate pollen that will mix with, and distort, the sequences of the lake where it is transported. Depositional processes have also been identified, where due to the particle size, some taxa are represented better than others in clayey deposits rather than in muddy ones, or the other way around (Andrieu, et al. 1997). All this warns us against taking one or a few sequences as representative without accounting for these mechanisms. Unfortunately in many works dealing with paleoenvironmental proxies, whether it is pollen analysis or different methods, this is instead common. While rejecting a priori a large amount of data would be unwise, it is safer to formulate conclusions only on a substantial body of evidence spanning wide areas.

As is clear from the following analysis of available data, I relied mostly on well-dated sequences, whether they are pollen, charcoal, oxygen isotopes, magnetic susceptibility and so on, and gave more importance to datasets that were comparable. In some cases I attempted to read the diagrams in more detail than did the authors themselves, just considering that I was interested in portions of sequences, while the majority of the papers dealt with longer-term change. The diversity in the information provided, and the style, depend on the focus. Some articles contained good descriptions of vegetation changes that may have applied to Sardinia, others had good chronological data useful to detect specific environmental phases.

All radiocarbon dates were calibrated whenever possible. They are cited whenever possible as uncalibrated years BP with relative calibrated date. Dates BC are calibrated in the present work with Calib.5.0.5, which is one among the several calibration programs internationally recommended (Weninger, et al. 2005), and are in brackets. Dates that appear as calibrated in previous works but whose raw dates were not reported, as well as calibrated dates BP cited in the original works, are in parentheses. The cases where the dates are reported already calibrated with the 1999 calibration curve (Stuiver, et al. 1998) with no BP dates are also indicated.
3.3. Analysis of the Evidence by Area

3.3.1. Mediterranean France

France is a country with a well established school of palynology; numerous cores have provided data regarding the vegetation cover in the Holocene. Other approaches to paleoenvironmental reconstruction are anthracology (Carcailliet 1998; Heinz 1991; Heinz and Thiebault 1998), a specific branch within the study of plant macroremains that deals with charcoal, which is shedding new light on the early beginnings of human impact on the territory through fire (Quilès, et al. 2002), and the study of sedimentation in riverbeds (Bichet, et al. 1999), lakes (Magny, et al. 2001), and coasts (Dubar and Anthony 1995; Morhange, et al. 2001).

The pollen evidence has been critically manipulated and reinterpreted in the last decade by the research team led by Guy Jalut (2000; 1997) to homogenize and make sense of several studies involving single cores or sites. Specific parameters were used with the purpose of tracing the shift from temperate to Mediterranean and from Mediterranean to steppic conditions: the ratio of deciduous and broad leaved trees vs. sclerophyllous trees, and the ratio of sclerophyllous trees vs. Chenopodiaceae. The datasets from the sites were reorganized, and diagrams produced according to these variables. All climatic types are defined accurately and used consistently, so that thresholds between different environmental stages could be systematically established (Jalut, et al. 2000: 256-63). Modern pollen distribution along two longitudinal transects was documented, in order to compare consistently the prehistoric database with a control reference. Sites included in the study were also purposefully selected: only coastal sites, to avoid contamination by Supra-mediterranean species (from higher elevations), and only sites with small drainage basins, to reduce input of waterborne pollen, both concerns that are rarely present in the literature, and which may negatively affect precision of meaningful counts (Jalut, et al. 2000: 256-68).

Jalut and coworkers provide the first documentation of a gradual expansion northwards of the Mediterranean climate zone during the Middle and Late Holocene, opposed to the rapid contemporaneous installation model (Prentice, et al. 1996). According to their findings, it took several thousand years for a fully Mediterranean vegetation to cover the whole latitudinal span between southeastern Spain and southern France. South of 39°N, the environment would have been Mediterranean already around 10000 BP, while at La Trémie,
in Provence, only around 2800 BP. Etang de Berre, a site included in the first preliminary article (Jalut, et al. 1997) and later expunged, shows Mediterranean vegetation as defined according to their criteria not earlier than 1000 BP.

Based on data from four sites on the French Mediterranean coast (La Trémie, Marsillargues, Capestang and Canet St. Nazaire: Bernard 1971; Jalut 1995; Planchais 1982, 1985; Planchais and Duzer 1978), Jalut and coworkers were able to identify several aridification phases (Figure 6). Since here I consider specifically the period covered in the

![Figure 6. Pollen diagrams from southern France: La Trémie, Marsillargues, Capestang and Canet-St.-Nazaire. Reprinted with modifications from Palaeogeography, Palaeoclimatology, Palaeoecology, vol. 160, G. Jalut et al., Holocene climatic changes in the Western Mediterranean, from south-east France to south-east Spain, pp. 263-266, Figs. 4-7, ©2000, with permission from Elsevier. The period ca. 4000-1900 BC is shaded in gray for each sequence.](image-url)
present dissertation, the relevant phase is mostly A.3 occurring around ca. 4500-4000 BP, or 3300-2200 cal. BP (Jalut, et al. 2000), which is dated by radiocarbon dates at La Trémie (about 4050 ± 100 BP, mid-3rd millennium BC) and Capestan (before or around 4010 ± 100 BP, first half to mid-3rd millennium BC), and correlated with a long aridification phase recorded at Marsillargues and Canet-St. Nazaire.

One of the problems facing paleoclimatologists and archaeologists desiring a fruitful mutual exchange of information is the different target scale for environmental reconstruction. Often, palynologists work on a timescale closer to geological times than cultural times, so that the chronological resolution turns out to be of limited use to understand its relations with culture change (Dincauze 2000: 23-7). Therefore, besides this phase A.3, considered by the authors as a major one, I tentatively identified four possible additional aridification phases, which I called E, B, D, and C (see figure 6). Phase E, identifiable clearly at Canet-St. Nazaire, could be tentatively placed around 3050-2950 cal BC based on a date that follows it (4200 ± 90 BP). Such identification and date are possibly confirmed at Marsillargues (earlier and up to 4460 ± 100 BP), less clearly at Capestan. Phase D is best dated at Marsillargues at about 3550-3450 cal BC (wiggle right after the radiocarbon date 4760 ± 100), and clearly visible at Canet-St. Nazaire between phases C and B. Phase B can be identified at Canet-St. Nazaire between E and D, so around 3350-3250 BC. Visually, it seems it could correspond to a drop in humidity and temporary sub-Mediterranean vegetation in the Marsillargues diagram. Finally, aridification phase C seems to have occurred around 3850-3750 cal BC (bracketed between 5240 ± 50 BP, date of the precedent peak at Capestan, and 4880 ± 80 BP at Canet-St. Nazaire). A similar pattern of alternating dry-wet phases in the same period has been detected through lake level changes at Lake Constance (Magny and Haas 2004).

Apparently, the following major dry phase recorded in Mediterranean Spain, dated around 3700-3300 BP (ca. 2350-1450 cal BC), did not correspond to any fast vegetation change along the French coast (Jalut, et al. 2000; 1997). To the east, Provence, as shown by the pollen sequence of La Trémie, had sub-Mediterranean conditions throughout the 4th and 3rd millennia BC. In the west, the Gulf of Lion benefited from the moist and cooler westerly winds coming through the corridor between the Pyrenees and the Massif Central, so that the
climate was generally oceanic. The threshold of sub-Mediterranean conditions was reached a few times and for very short lengths of time (Jalut, et al. 2000).

Anthracology, the discipline concerned with the study of charcoal, has been giving a substantial contribution to the documentation of prehistoric vegetation and environment. Several sites in the eastern Pyrenees have been studied by Heinz and coworkers (Heinz 1991; Heinz, et al. 2004; Heinz and Thiebault 1998), and provide stratigraphically controlled diagrams of vegetation change, although the degree to which such change is anthropogenic or climate-related is not quantifiable. At Font Juvénal, about 500 m asl (Figure 7), there was during the Late Neolithic and Copper Age a steady decline in deciduous oak and increase in genus *Buxus* (boxwood) and garrigue (the typical shrubby vegetal community, similar to

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<th>Phases based on charcoal analysis</th>
<th>Cultural period</th>
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<td><em>C14yr B.P. Dating</em></td>
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**Figure 7.** Charcoal diagram from Font Juvénal. Reprinted with modifications from Quaternary Research, vol. 50, C. Heinz and S. Thiebault, Characterization and palaeoecological significance of archaeological charcoal assemblages during Late and Post-glacial phases in southern France, p. 63, Fig. 2, ©1998, with permission from Elsevier. The period ca. 4000-1900 BC is shaded in gray, with the 4th millennium in lighter gray.
Italian *macchia*), but still forested environment with diversity of species associated with deciduous oak after 4800 ± 150 BP [3760-3370 cal BC 1σ]. The lowest presence of deciduous oak, highest frequency of shrubs and *Quercus ilex* (evergreen oak) dates after 4190 ± 90 BP [2890-2620 cal BC 1σ] (Heinz and Thiebault 1998).

At Montou, 270 m asl (Figure 8), there is as well a decline in oak, but here it involves evergreen as well as deciduous oak, with a remarkable drop from the centuries of the Late Neolithic around 4000 BC to the Copper Age layer (Heinz, et al. 2004). In the Copper Age there is also an increase in the genus *Buxus* (boxwood), but especially *Rhamnus-Phyllirea* (mock privet) and *Cistus* (rockrose), adapted to warm and dry conditions. The latter is a shrub that, besides being typical of Mediterranean environments, often indicates human

Figure 8. Charcoal diagram from Montou. Reprinted with modifications from Heinz et al. 2004, p. 624, Fig. 2, in *The Holocene*, ©2004, with kind permission from Sage Publications. The period ca. 4000-1900 BC is shaded in gray.
clearing since it sprouts easily after burning. What is important, though, is that the decrease in *Quercus*, both deciduous and evergreen, and the increase in heath (*Erica*), strawberry tree (*Arbutus*) and rockrose (*Cistus*), had already started in the Late Neolithic layer.

The evidence fits a picture of replacement due to climate change, with the contribution of human impact. It is only in the Early Bronze Age that human impact is visible in the increase of *Olea*, due to the beginning of its cultivation, as shown by the ratio of wild vs. cultivated specimens, which declines from 1 in the Late Neolithic to 0.7 in the Early Bronze Age, and by the ratio young vs. old wood (indicating management), which rises from 0.5 to 0.8 (Heinz, et al. 2004). This also matches well the turning point in the vegetation type detected through pollen, with several genera not specifically related to human activity but to relatively dry conditions (*Pistacia*, *Erica*, *Phyllirea*) peaking between 4880 and 4200 BP [ca. 3700-2700 cal BC], while deciduous oak is still abundant. Evergreen oak and rockrose, markers of cleared, secondary forest, take over afterwards (Planchais 1985).

Fires are documented in the highland region of the Causse between 4805 ± 50 BP and 2990 ± 60 BP [4th through 2nd millennium cal BC], where pine trees dominated the forest (Quilès, et al. 2002), and on the western valleys of the Alps (Carcaillet and Brun 2000). At St.-Michel-de-Maurienne and Aussois, the record of fires thickens in the 4th millennium BP [mid-3rd to mid-2nd millennium cal BC], a period when the forests seem to have been largely made up of pine trees as well (Carcaillet 1998).

Based on the above evidence for fires and on methodological grounds, there are critics of the climatic reconstructions done through statistical manipulation of pollen sequences. The method used by Jalut and colleagues (2000; 1997) to standardize data has been put under serious critique: the use of the ratios of deciduous and broad leaf trees vs. sclerophyllous plants would reflect the advantage given to sclerophyllous families, plants with hard leaves adapted to dry environments, by human agency rather than by climate change. The use of average annual temperature and precipitation to define climatic thresholds may admittedly be inaccurate, since the main characteristic of Mediterranean climate is instead the uneven distribution of them, with long summer droughts. The charcoal record is considered by some to be the key point to show that fire, not dryness, would be responsible for the spread of sclerophyllous plants and the replacement of deciduous forest (Pons and Quézel 1998).
Related to the effects of both climatic change towards drier conditions, and the use of fire to clear the landscape, is the change in river and coastal sedimentation. According to Bichet and colleagues, a reversal can be detected between Atlantic and Sub-boreal periods: up to the subboreal, high lake levels would correspond to thicker and coarser sediments, and vice-versa low levels would signify thinner and finer-textured sediments; afterwards, the opposite (Bichet, et al. 1999). Based on this association, from the coastal sediment record of the Baie des Anges, near Nice, it was possible to reconstruct the existence of wet and temperate conditions 8000 to 5000 BP (ca. 7000 to 3800 cal BC: the so-called ‘climatic optimum’). From ca. 6000 BP [ca. 4800 cal BC] the forest cover upstream begins to thin, and after 5000 BP [ca. 3800 cal BC] deciduous oak is replaced by pine, selected for by a drier climate and possibly by burning. Increasingly irregular precipitations caused episodic high-energy streams, recorded in the accumulation of coarse sediments. On the coasts, malacology, the study of mollusk shells, confirms a shift from seawater to fresh and brackish water species, indicating lagoons and marshes due to gravel barriers and the infilling of former marine shallow bays (Blanc 1993; Dubar and Anthony 1995). In the highlands, infilling volume has been calculated for the watershed of Lake Challeixon, showing higher rates starting in the Late Atlantic up to ca. 3400 BC and particularly in the Subboreal (although this lumps together 2600 years, up to ca. 800 BC): at this location, conifers replace deciduous forest around 3400 BC, roughly corresponding to the macrobotanical record, and signs of palustrine waters appear for the first time (Bichet, et al. 1999). Blanc attempted to draw a climatic outline of Provence prehistory through sediment analysis and integration of proxies: the Atlantic (8000-5000 BP, up to the 1st half of the 4th millennium cal BC) is assessed as hot to very hot (2-4°C higher than modern temperatures), characterized by the peak of progradation of the Rhône delta. Erosional crises in the streams would characterize the interface between Atlantic and Subboreal. The following period (5000-4750 to 3000-2750 BP, or mid-4th to early 1st millennium cal BC) would have temperate/hot conditions, with alternating humid and dry phases (see also Magny and Haas 2004). Characteristic of the Sub-boreal period would also be the regression of cliffs, brief erosive events, more deposition of colluvium and the infilling of bays and bottom valleys (Blanc 1993). This occurred in continuous interaction with sea level changes: sea level rose up to about 2000 BC on the French Mediterranean coast, with a negligible role of tectonics (Lambeck and Bard 2000).
3.3.2. Mediterranean Spain

In Spain, botanical remains, including mostly pollen, but also non-pollen microfossils and charcoal, have been analyzed at many locations, providing a relatively good knowledge of vegetation changes, at least for certain areas. A great amount of data have been produced in the last decade by José Carrión in collaboration with several scholars (Carrión, et al. 2001a; Carrión, et al. 2001b; Carrión and Navarro 2002; Carrión, et al. 2000a; Carrión, et al. 2000b; Carrión, et al. 2003). At San Rafael (36°20'N, 10 m asl, Almería), from 7100 ± 50 BP [ca. 6000 cal BC] through 4430 ± 100 BP [around 3000 cal BC], there is a drop of *Artemisia* sp. and grasses in general, and higher frequency of *Corylus* sp., deciduous oak, and particularly evergreen oak. Around this date, trees decline sensibly while *Artemisia* dominates largely the assemblage, indicating drier conditions and/or human impact. *Asteraceae* in general and the microfossil *Pseudoschizea* point to increased aridity, the latter being an aquatic plant that thrives in desiccating basins (Carrión and Navarro 2002; Pantaleón-Cano, et al. 2003). Similarly, at Navarrès (39°06'N, 225 m asl), at about 5930 ± 80 BP [from ca. 5000 BC] there is great increase in evergreen oak, decrease in *Pinus* and *Artemisia*, and among the indicators of limnological change, an explosion of *Polyadosporites*, markers of stagnant waters and extension of peats and marshes (Carrión, et al. 2001b; Carrión and Navarro 2002). Basin desiccation parallels data from Southern Italy and Southern France over a thousand years later, appearing compatible with the progressive spread northward of aridity that has been suggested (Caldara, et al. 2002; Dubar and Anthony 1995), to which fire and grazing must be considered as contributing to shape both plant communities and water drainage.

At Cañada de la Cruz (38°04'N, 1595 m asl), a turning point with the establishment of a xerophytic component (adapted to dry conditions), *Juniperus* sp. and *Ephedra* sp., parallel to the almost total disappearance of trees (pine, oak) and shrubs present before, is extremely well dated by three very close radiocarbon dates around the event: 3385 ± 30 BP, 3370 ± 20 BP, 3350 ± 40 BP (Figure 9). These dates place the shift between 1750 and 1550 cal BC (Carrión, et al. 2001b; Carrión and Navarro 2002), so clearly after the period I am concerned with. This seems important, because it means that this site at over 1500 m asl experienced wetter conditions throughout the early-mid-Holocene (Carrión, et al. 2001b), while at lower
elevations weather was remarkably dry throughout the Copper Age. This may explain why there has been a widespread shift of site location towards the highlands, which in Sardinia do not have a record of human presence earlier than ca. 4000-3200 BC (Ozieri phase), their importance being emphasized only after 3200 BC.

At Sierra del Gádor (36°54’N, 1530 m asl), another site in southern Spain at about the same altitude, there is a similar pattern; in this case, between 4000 and 1900 BC there is an invasion of deciduous oak from lower elevations, probably provoked by an increase in temperature and consistent humidity, differently from the dry lowlands, where at least from 2200 BC aridity was enhanced by the effects of fires (Carrión, et al. 2003). At Villaverde (38°48’N, 870 m asl, Pinus forest is dominant (~60%) in the first half of the 6th millennium cal BC (6670 ± 70 BP), when other tree species appear (Figure 10). The intrusion of oak
indicates moister and warmer temperatures. At 5140 ± 60 BP [beginning 4th millennium cal BC] *Pinus* is lower than 30%, and deciduous oak expands rapidly becoming the dominant species, with important presence of hazel, ash and alder. In the second part of the sequence that is bracketed by the date 3240 ± 50 BP [mid-2nd millennium cal BC], from around 3000 cal BC, evergreen oak takes over, marking the onset of drier conditions, accompanied by *Artemisia, Juniperus* and xerophytic taxa that expand up from the lowlands with increased aridity (Carrión, et al. 2001a; Carrión and Navarro 2002). Differently from southern France and Corsica, *Olea* was apparently present early on after glacial times on the coasts of Spain, and as soon as the climatic conditions changed, it spread consistently, along with the rest of drought-resistant trees and shrubs (Pantaleón-Cano, et al. 2003). Furthermore, the non-pollen microfossil diagram shows a distinct peak of density probably not longer than half a century, centered on the mid-3rd millennium BC, and possibly lasting a few centuries. This indicates lowered lake-level and eutrophic environment (Carrión and Navarro 2002).
Such a dry event correlates well with the dry spell identified all over the Mediterranean and better identified in the Near East (Bryson and Bryson 1997; Weiss 1997). A confirmation of the general trend towards aridity from the early-mid to late Holocene, yet with a coarse chronology, comes also from the analysis of isotopic discrimination of $^{13}$C during grain infilling of barley and wheat, compared with modern samples (Araus, et al. 1997a; Araus, et al. 1997b; Araus, et al. 2003).

The previously cited work by Jalut and coworkers tracks the spread of Mediterranean conditions northward; Southeastern Spain (Figure 11) is peculiar in that vegetation was already Mediterranean before Neolithic times (Burjachs and Riera 1995). South of 40°N latitude, Mediterranean climate was established very early: at Salinas (38°31'N), conditions were Mediterranean throughout the sequence starting around 10000 years BP. An irregular arid period spans the sequence around 6090-5650 cal BP [ca. 4300-3600 cal BC]; wetter periods are recorded at 4810-4240 cal BP [ca. 2900-2200 cal BC] and between these two dates. Between 3980 and 3670 BP [ca. 2350-1700 cal BC], there is indication of a prolonged dry event – or of its long-term effects – which again corresponds clearly with the aridification.
phase documented over wide areas (Burjachs and Riera 1995; Jalut, et al. 2000). Finally, the Cabo de Gata sequence (37°47'N, figure 11), on the Almerian coast, shows as well as Salinas a Mediterranean climate already established in pre-Neolithic times. A drop in the ratio sclerophyllous taxa/Chenopodiaceae right after 3570 ± 60 [ca 2100-1750 cal BC] (Jalut, et al. 2000) rather than just drought might be an example of delayed, abrupt threshold crossing of the ecosystem into grassland (Scheffer, et al. 2001), likely enhanced by human impact through soil overuse, fires, and possible deforestation related to metallurgy as shown by increasing evidence in the western Mediterranean. This time and area corresponds in fact to the peak of the Early Bronze Age Argaric culture, characterized by a powerful rise in metal manufacture.

Mediterranean conditions would have been established at the two sites of Besos and Cubelles (Figure 12), both in the Northeast and less than 100 km apart, with a relatively long interval: at the southern site during the 1\textsuperscript{st} half of the 4\textsuperscript{th} millennium BC, at the northern one only in the mid-2\textsuperscript{nd} millennium BC. Here as in the whole western Mediterranean area, several aridification events of broad extent have been recorded: A.3, 4500-4200 BP (around 3400-

![Figure 12. Pollen diagrams from Catalonia (northeastern Spain): Besos and Cubelles. Reprinted with modifications from Palaeogeography, Palaeoclimatology, Palaeoecology, vol. 160, G. Jalut et al., Holocene climatic changes in the Western Mediterranean, from south-east France to south-east Spain, pp. 267-268, Figs. 8-9, ©2000, with permission from Elsevier. The period ca. 4000-1900 BC is shaded in gray for both sequences.](image-url)
2600 cal BC), would mark the beginning of the shift towards a Mediterranean climate north of 40°N, which is considered connected to an increase of 2°C in the sea surface temperature of the Mediterranean. A large mass of data are compared to these results, pointing to a threshold period for the major shift at around 4500 BP [ca. 3400-2800 cal BC] (Jalut, et al. 2000: 281-3). Looking at the diagram more closely, at Besos (41°24’N) the chronology has similarly low resolution; the period 4000-1900 cal BC, when climate conditions become Mediterranean, is bracketed between 6870 ± 100 BP [1\textsuperscript{st} half of the 6\textsuperscript{th} millennium cal BC] and 3250 ± 50 BP [ca. 1650-1400 cal BC], and is therefore not useful for comparative purposes. The Cubelles diagram (41°12’N) shows drier conditions at 5040 ± 70 BP [ca. 4000-3700 cal BC] before a humid peak that makes the vegetation temporarily Submediterranean (compare again Magny and Haas 2004), then a decrease in humidity and constant ratios in the following centuries up to 3680 ± 80 BP [ca. 2350-1750 cal BC], when there is possibly a mildly dry event matching the major phenomena found in the Levant (Jalut, et al. 2000; Riera i Mora 1994; Riera i Mora and Esteban Amat 1994).

In the lake level record, the Iberian Peninsula (Figure 13) as North Africa seems to experience a major shift toward drier conditions between 5000-4000 BP (early 4\textsuperscript{th}-mid 3\textsuperscript{rd} millennium cal BC). Unfortunately, the number of lakes considered is scarce (only 4 for the Iberian Peninsula versus 72-76 for North Africa) (Magny, et al. 2002).

![Figure 13. Lake level diagram from the Iberian peninsula. Reprinted with modifications from Palaeogeography, Palaeoclimatology, Palaeoecology, vol. 186, M. Magny et al., Assessment of the impact of climate and anthropogenic factors on Holocene Mediterranean vegetation in Europe on the basis of palaeohydrological records, p. 50, Fig. 1, ©2002, with permission from Elsevier. The period of interest ca. 4000-1900 cal BC is comprised between the mid-5\textsuperscript{th} and the mid-3\textsuperscript{rd} millennium BP, or timeslices 5 to 3.](image-url)
3.3.3. Mediterranean Italy

In Italy, the best record of vegetation changes has been collected in the middle section of the peninsula, due to the many volcanic lakes which preserved sediments yielding much environmental information. A key synthetic work on conditions in Middle to Late Holocene Italy (Magri 1997) considered the traditional arboreal pollen (AP) vs. non-arboreal pollen (NAP) ratio from seven lacustrine sequences along the peninsula summarizes the identifiable trends; further evidence comes from magnetism (Brandt, et al. 1999), sediment history (Ramrath, et al. 2000; Ramrath, et al. 1999a; Ramrath, et al. 1999b), oxygen isotopes (Tuccimei, et al. 2003), and, for sea surface temperature, from alkenones (Rimbu, et al. 2004).

Lago Grande di Monticchio, in Southern Italy, did not yield any absolute date, so that environmental reconstruction is not well anchored to any timeline that is archaeologically relevant (Watts, et al. 1996). Similar limited information comes from Agoraie di Fondo and Padule; therefore, here I discuss mainly the sites in Latium, central Italy. At Valle di Castiglione (44 m asl), AP is relatively scarce, but increasing at 5280 ± 65 BP [ca. 4300-3900 cal BC] and 4490 ± 65 BP [ca. 3400-3000 cal BC]. After reaching the highest proportion, with strong presence of *Fagus* (beech) indicative of rather wet conditions, tree frequency starts decreasing some time before the date 3480 ± 50 BP [ca. 2000-1700 cal BC], with the lowest level some time afterwards.

At Lago di Vico, 510 m asl (Figure 14), AP is around 85% from 5354 ± 75 BP [4330-4040 cal BC 1σ] onwards, with a decrease in two steps down to 75% and 65%, corresponding to radiocarbon dates 4135 ± 75 BP [ca. 2900-2500 cal BC] and 3710 ± 50 BP [2278-1954 cal BC 2σ] (after Magri and Sadori 1995); this two-stepped drop may correspond to the aridification phase A.3 in France (Jalut, et al. 2000) and possibly with the phase E that I tentatively identified at Canet-St.-Nazaire (figure. 6). Lago Lungo (371 m asl) does not have but one radiocarbon date at the end of the sequence, 3680 ± 70 BP [2284-1887 cal BC 2σ], which corresponds though to the lowest ratio of tree versus grass pollen, and to a severe reduction of oak (Calderoni, et al. 1994), parallel to Lago di Vico itself and matching the evidence from the Levant. Finally, Lagaccione (350 m asl) shows a similar pattern, with a very high percentage of AP up to 4350 ± 75 BP [3335-2779 cal BC 2σ], one first drop of arboreal pollen with a date around 3750 ± 80 BP [2457-1951 cal BC 2σ] that seems to stop
for some time, where *Quercus* is high and *Fagus* severely decreased, and finally a further, sharp low peak possibly within a few centuries afterwards (Magri 1989; 1997: 520-3). These two drops may coincide again with drier phases A.3 and E mentioned above for Mediterranean France.

The 4th millennium seems to start with dense forests at these sites in Latium, central Italy, except at Valle di Castiglione where this is likely due to altitude (only 44 m asl, as opposed to the altitude of the other three, between 350 and 510 m asl), where probably rainfall was lower, and consequently tree cover more sparse. The two more detailed and better dated sequences, Lago di Vico and Lagaccione, show similar patterns of dense forest until a noticeable reduction of arboreal pollen takes place starting around 2300-1900 cal BC, in two steps that seem to coincide with each other, with arid phases in Southern France, and with the wider trends mentioned above. Sediments data and lower lake levels also match the indication for a remarkable dry phase in the same period. Such events do not appear to have occurred at the northern sites of Lago Padule and Agoraie di Fondo, in the northern
Apennine, again due to altitude (both lie over 1000 m asl), which mitigated the effects that decline in rainfall can generate in lowlands (Magri 1997), as indicated at Cañada de la Cruz in Spain. Furthermore, the appearance at Lago di Vico of the of Cedrus sp. pollen, related to strong southerly winds at about 2250 cal BC, points to the dependence of climate on air masses centered in North Africa. These winds, among other factors, might have contributed to the desiccation of soils and the environmental disruption documented by the reduction in arboreal pollen; similar association of low pollen concentration and Cedrus presence has been observed as well in France (Andrieu, et al. 1997; Magri and Parra 2002).

The growth of organisms associated with specific environmental conditions in lakes has also been used as an environmental proxy: during the interval ca. 7250 to 3650 cal BC, organic-rich diatoms were deposited at Lago di Mezzano. Two phases of lower organic carbon were identified within this interval, of which one (P2) around 4850-4250 cal BC is characterized by a decrease in biogenic parameters, and finds its best correlate in Tunisia (see below). From 5000 cal BP [ca. 3000 cal BC], the shift in sedimentation pattern indicates abrupt climate aridification, from very wet to dry, and some cooling (Ramrath, et al. 2000), data that have been correlated with the abrupt event recorded in Tunisia (Zielhofer, et al. 2004).

One recent study at Buca della Renella provides an even more specific and explicit proof of an anomalous dry spell that hit Tuscany at ~2200 BC, from the profile of several proxies including δ¹³C and δ¹⁸O measured in a speleothem. In this profile, another peak in aridity, milder than this, is also recorded at ~4700 BC (Drysdale, et al. 2006), which the authors connect with a similar date and event recorded at Soreq Cave, in Israel (Bar-Matthews, et al. 1997).

The same general pattern is recorded also in Apulia, southeastern Italy, but possibly aridification started here at an earlier time; study of sediments in the Salpi lagoon indicated wetter conditions in the Middle Neolithic. It would be at the end of this phase that the climatic deterioration would start, with an arid phase characterized by scarce rainfall and high temperatures that was so remarkable that the whole coastal area fell under semi-desert conditions (Boenzi, et al. 2001; Caldara, et al. 2002). Erosion due to the absence of vegetation increased sediment infilling rates, made the lagoon smaller and shallower, until it turned it into a sabkha, a flat, desiccated biome typical of Middle Eastern areas characterized by compact and highly saline soil. While later phases at the site of Coppa Nevigata have
better chronological resolution (Caldara and Simone 2005), it is unfortunate that such a good sediments history is very poorly dated, with a single aridification phase documented between the Late Neolithic and Middle Bronze Age (Caldara, et al. 2002). A still similar pattern has been recorded in the plain south of Salerno, Campania, where during the Copper Age a profound environmental crisis (which followed signs of volcanic activity, not necessarily in any kind of causal relationship) led to a massive series of cut-and-fill events, with large quantities of sediments colluviated toward the coast and the suggested coastal progradation and formation of marshes and stagnant-water lagoons (Di Maio, et al. 2003).

Information on sea surface temperature comes from core AD91-17, located between Apulia and Albania. The sequence begins at about 17°C at 4000 BC, then temperature decreased to 16°C until the mid-3rd millennium BC, and rises slightly around 2000 BC, confirming at least the bipartite character of this section of the Holocene (Rimbu, et al. 2004).

3.3.4. North Africa, Sicily and Surrounding Islands

The most investigated record for paleoenvironmental reconstruction in North Africa is probably the oscillation in lake level (Figure 15). While relatively few studies concern the Mediterranean belt of Africa, a large database has been created and synthesized with Saharan lakes across the continent, building upon previous data collections, particularly the Oxford lake level data bank, OLLDB (Damnati 2000). After a moist period, an ‘unstable phase’ where some lakes became shallower is identified around 7000-6000 BP [ca. 6000-4700 cal BC]. The ‘last fluvial phase’ followed, where most lakes began to decrease from the early 5th millennium BC, to become increasingly drier from the 1st half of the 4th millennium BC (Damnati 2000). Generally, the whole period between 9000 and 4500 BP [end of 9th-end of 4th millennium cal BC] was much more conducive to human life than it has ever been later: the water bodies supported molluscs, fish, and savannah mammals, all nutritional resources that disappeared afterwards. The decrease in precipitation between 10000-5000 BP and today has been estimated for the paleo-lake Chad area to be roughly 300 mm (Damnati 2000; Kutzbach 1980).

The Western Libyan Sahara has been investigated by an interdisciplinary Italian-Libyan team, integrating several methods: a relatively wet phase lasted up to the early 4th millennium BC: in the area there were lakes, swamps, savannah vegetation, and this
water left its trace in the sediments. Lake levels rose gradually, peaking during the early 5th millennium BC, when moisture started decreasing. There is a break in the radiocarbon dates sequence at the end of the 6th millennium BC, which has been interpreted as a possible dry phase which caused the break in human occupation; afterwards, erosion, wind deposits inside shelters and caves, and the collapse of shelter roofs indicate progressive aridification (Cremaschi and Di Lernia 1999).

As regards specifically the Mediterranean belt, at Lake Tigalmamine (Morocco) the isotopic evidence and the shallow-water diatoms indicate evaporation and increased salinity due to lowered water level during the 5th and the 1st half of the 4th millennium cal BC (Lamb,
et al. 1995). In Algeria at Sebkha Mellala, a lacustrine episode is revealed in the early 5th millennium cal BC through the analysis of sediments (Damnati 2000; Gasse and Fontes 1992): all phenomena point to a Mediterranean wet phase. In northern Tunisia, in the Medjerda Valley (Zielhofer, et al. 2004), which is the north African investigated location closest to Sardinia, sediment deposition between approximately 4650 and 4050 cal BC has been interpreted as a sign of drier conditions and connected to similar evidence at Lago di Mezzano in central Italy (Ramrath, et al. 2000; Ramrath, et al. 1999a; Ramrath, et al. 1999b). Afterwards, from ca. 4050 to 2850 cal BC, sedimentation is stable, until an abrupt event, defined as a “climatic collapse”, is recorded at about 2800-2700 cal BC, when drier conditions generated increased sediment and the end of soil formation; according to the authors (Zielhofer, et al. 2004), this would be a punctuated event representing the response of the environmental system to increased insolation, following a model of alternative steady-states and “hysteresis” occurring between them (see also Higgins, et al. 2002; Mastrandrea and Schneider 2001). At another location in Tunisia, the Chott Rharsa basin, a later arid phase, starting around 2400 cal BC, has been identified (Swezey, et al. 1999).

In the lake level record, the major drop is in the period between 5000-4000 BP, corresponding to early 4th -mid 3rd millennium BC (Figure 16), which confirms the trend highlighted above (Magny, et al. 2002). Variation in sea surface temperature investigated through alkenones (Rimbu, et al. 2004), yielded results from the southern belt of the western

![Figure 16. Lake level diagram from North Africa. Reprinted with modifications from Palaeogeography, Palaeoclimatology, Palaeoecology, vol. 186, M. Magny et al., Assessment of the impact of climate and anthropogenic factors on Holocene Mediterranean vegetation in Europe on the basis of palaeohydrological records, p. 50, Fig. 1, ©2002, with permission from Elsevier. The period of interest ca. 4000-1900 BC is comprised between the mid-5th and the mid-3rd millennium BP, or timeslices 5 to 3.](image)
Mediterranean. Core RL11, located between Sicily, Malta and Greece, shows a temperature in the Ionian Sea starting at ~22°C at 4000 cal BC, rising to almost 24°C around 3000-2500 cal BC, and dropping constantly almost until 1000 cal BC at 18.5°C. Core MD95-2043, located in the Alboran sea, near Gibraltar, starts at almost 19.5°C at 4000 cal BC, declines to ~18.3°C at 3500 cal BC, and after 3000 cal BC peaks at 19.3°C (see table X, after Rimbu, et al. 2004).

Not much research has been done regarding Holocene climate change in Sicily and the surrounding islands (Giraudi 2004; Madonia, et al. 2003; Sadori and Narcisi 2001), while even worse and of no use for the scope of this study is the little research done on Malta (Hunt 1997). On the southern island of Lampedusa, between Sicily and Tunisia, the Atlantic period is characterized by deposition of fine silts. This process was interrupted at about 4010 ± 40 BP [mid-3rd millennium BC], when sediments became coarse, pointing to instability and soil disruption. The accumulation of wind-borne dust rich in quartz (foreign to the local geology) increased from the 1st half of the 4th millennium cal BC, and such dust accumulation corresponds to moister conditions and glacier advance in the Alps and the Apennines (Giraudi 2004). In Sicily, at Lago di Pergusa, the formation of muds and decline in the rates of sediment accumulation are interpreted as decreasing humidity from the 6th millennium cal BC onwards. Overall aridity increased up to remarkably dry conditions from the late 2nd millennium cal BC. The pollen zone ending right after 7475 ± 65 BP [6447-6228 cal BC 2σ] reveals a forest (high arboreal pollen levels) dominated by deciduous and evergreen oak (40-61% and 12-25% respectively), but very important is also, at this early stage, the presence of Olea (olive), Pistacia (mastic and terebinth), and Vitis (vine), which in Corsica appear only thousands of years later. Afterwards, warm and wet optimum is indicated by the peak in arboreal pollen (94%), followed by two drops to the minimum across 4400 ± 105 BP [3369-2764 cal BC 2σ] (Sadori and Narcisi 2001). The role of climate is, however, again likely mixed with human impact.

3.3.5. Western Mediterranean Islands: Balearics and Corsica

Corsica and the Balearic Islands are undoubtedly the two most important places that need to considered in the absence of data coming directly from Sardinia. This is due, for Corsica, to its geographic proximity to Sardinia and to its role as a natural bridge with the
Italian peninsula and the European continental landmass, which makes it the likely intermediary for the spread of species to and from the island. The Balearics are important because their latitude is fully included in Sardinia’s latitudinal range, so that at least it is possible to get an idea of possible climatic clines in a south-north direction using them as a proxy.

Paleoenvironmental reconstruction on the different islands has been given uneven attention by researchers: Corsica shows in fact a remarkable example of an island quite well-known from a palynology standpoint, mostly thanks to Maurice Reille. Cores have been taken from over 25 sites, with a good coverage of all the environmental zones of the island, many of which included Holocene sequences and specifically the period of interest for my dissertation (Reille 1984, 1988, 1992, 1997; Reille, et al. 1999a, b; Reille, et al. 1997). Corsica can therefore provide powerful analogies to infer possible developments on Sardinia as far as vegetation is concerned, with the necessary caution to account for human vs. climatic impact and for the latitudinal difference that makes Corsica more temperate and moist.

The vegetation pattern appears to be, in the Atlantic period (up to the 1st half of the 4th millennium cal BC), bipartite: on the eastern plains, *Taxus* (yew), *Tilia* spp. (lime or linden) and deciduous oak are the most frequent trees, while the evergreen oak is absent, as well as genera *Pistacia, Olea, Myrtus, Phyllirea. Erica* sp. (heath) was confined to the warmer spots. This means that most of the typically Mediterranean kinds of shrubs were not present yet. On the other hand, on the much steeper western flanks and northern Cape areas, pristine forests of heath and strawberry trees characterized the vegetation landscape. At an altitude of over 1500 m, black pine (*Pinus laricio*) and even fir (*Abies*) constituted the majority of arboreal cover.

In the Subboreal, from the second half of the 4th to the beginning of 3rd millennium cal BC, evergreen oak expanded, replacing deciduous oak, heath and strawberry tree. In the thick oak forest previously dominant on the coasts, new species that are today widespread, as mastic, terebinth, wild olive, and mock privet, make their first appearance. At higher elevations, black pines undergo as well major expansion (Reille 1984, 1988, 1992): all such phenomena can be related to a progressively drier climate.

More in detail, at the site of Crovani on the northwestern coast, a major expansion of evergreen oak occurred around 4300 ± 120 BP [3262-2679 cal BC, 1σ]. At this site, right
after the date 3820 ± 140 BP [2468-2045 cal BC, 1σ], there is a hiatus in the deposition of organic sediments, with a sterile sandy layer (Reille 1992), which might be an indication of faster erosion, parallel to phenomena studied in coastal France. At Saleccia, two radiocarbon dates, 5690 ± 140 BP [4688-4372 cal BC, 1σ] on the bottom and 5160 ± 100 BP [4217-3798 cal BC, 1σ] on the top of the pollen ‘zone b’, bracket the end of the Atlantic period: this phase shows strong presence of heath (*Erica arborea*), not much evergreen oak, and consistent presence of strawberry tree (*Arbutus*). The presence of rockrose and asphodel (*Asphodelus*) is a sign of human clearance, since these are the first pioneer plants that colonize impoverished soils. The fact that evergreen oak did not spread yet is interpreted as proof of its absence from the natural vegetation until the late Atlantic. A typically Mediterranean shrub such as *Myrtus* (myrtle) is absent up to historic times (Reille 1992: 372). ‘Zone c’ is dated after 5160 ± 100 BP [4217-3798 cal BC, 1σ] and before 3730 ± 110 BP [2292-1973 cal BC, 1σ], and corresponds to the Subboreal, characterized again by the trends described above, the spread of evergreen oak being the most relevant (Reille 1992).

A very good record of vegetation changes has been retrieved from cores at the Lac de Creno, in the mountainous center of Corsica, at 1310 m asl. During the Atlantic, preceding the timespan of interest, there is a replacement of yew (*Taxus*) by heath (*Erica arborea*), with increasing temperature corresponding to the climatic optimum, while *Tilia*, boxwood, and *Ulmus* (elm) decrease. The first appearance of beech also indicates increased humidity in the first half of the 7th millennium BC (zone i). After a temporary decline of heath and alder, and the increase of yew and black pine (*Pinus nigra laricio*), possibly due to cooler conditions, a “major event” is recorded between ca. 6285 ± 155-150 and 5419 ± 80-75 BP [between ca. 5500-4000 BC], which involved the appearance and establishment of *Arbutus*, whereas evergreen oak is still insignificant, less than 1% (Reille, et al. 1999a, b). This phase represented the peak of deciduous oak which replaced yew on high elevations, while evergreen oak in the early 4th millennium BC extends at the expense of heath at lower elevations. Reille connects this ‘major event’ to human impact, due to the presence of plantain (*Plantago lanceolata*), rockrose (*Cistus*) and asphodel (*Asphodelus*), all indicators of human impact on the landscape, and of buckwheat (*Rumex*), indicating ruderalization, which disappears afterwards. Unfortunately the chronology becomes coarser during the key timespan of the 4th and 3rd millennia BC, when evergreen oak takes over partially replacing heath and deciduous oak, and so establishing a type of vegetation that resembles the current
Mediterranean one. This can therefore be taken as a sign of climatic conditions with enhanced seasonal difference and longer summer drought (‘zone l’ of Lac de Creno, estimated by Reille to have lasted approximately 3000 years around 4465 ± 125 BP [3349-2944 cal BC, 1σ] (Reille 1988; Reille, et al. 1999a). During this period, while shrubs like *Pistacia* (mastic and terebinth), *Phyllirea* (mock privet), and *Olea* (olive) become established on the dry lowlands (Reille 1988), the charcoal evidence does not seem to support the suggested importance of fire until the Iron Age (Carcailliet, et al. 1997), differently from Southern France where such evidence dates as early as the Late Neolithic (Carcailliet 1998).

On the island of Minorca, among the pollen sequences considered, two are radiocarbon dated, and the other two are generally well compatible (Yll, et al. 1997). At Algendar, during phase ‘a’, dating to before 4940 ± 50 BP [3911-3639 cal BC 2σ], boxwood (*Buxus*) and hazel (*Corylus*) dominated the forest. Remarkably abundant were also juniper (*Juniperus* sp.) and ephedra (*Ephedra* sp.), besides both deciduous and evergreen oak. The frequency of *Typha* sp. (cattail) indicates extensive coastal marshes. In the phase lasting up to 4090 ± 60 BP [2872-2489 cal BC 2σ], olive trees appear and increase; heath, alder, mock privet and evergreen oak spread, while boxwood and hazel decrease: these changes point to the beginning of Mediterranean conditions with longer summer droughts. *Plantago* (plantain) starts but expands only in the end of the phase, when conversely *Juniperus* (juniper) decreases, which is likely connected with human activity. During this phase, there is also a very high frequency of Apiaceae, which quickly disappear shortly after. This family includes thousands of species, among which the genus *Ferula*, which includes pioneer species very common in present-day Sardinia that colonize impoverished soils (compare with *Rumex* and *Asphodelus* in Corsica). Abruptly, in the second half of the 3rd millennium BC, juniper and boxwood almost disappear, and hazel declines. Selection against boxwood and hazel may be connected to higher seasonal variability and lower precipitation, but also coincides with the first stable colonization of the islands. The survival of hygrophyllous taxa (adapted to high moisture) only in the northern mountain range has been explained with the possible formation of mists. Replacement of boxwood by olive and heath is unique to the Balearics, and such olive tree pollen has been interpreted as belonging to the wild variety, *Olea europaea* subspecies *sylvestris*. This is based on historical information regarding the introduction of cultivated olive trees by the Moors in the late Middle Ages (Yll, et al. 1997).
At the same time in Corsica a similar trend to aridification is instead characterized by the replacement of heath by evergreen oak (Reille 1988).

The sequence at Cala’n Porter (Figure 17) follows a relatively similar pattern. One event that could date to a few hundred years before 5120 ± 60 BP [4042-3776 cal BC 2σ] causes on one hand Plantago, Asteraceae and Poaceae, and especially olive, to increase; on the other, it makes deciduous and evergreen oak and hazel decrease sensibly, and juniper and boxwood to almost disappear. Pollen diagrams are dominated by olive and grasses until 4450 ± 50 BP [3339-2929 cal BC 2σ], with Polygonum (a kind of buckwheat) very high in the first half; this plant grows on sandy soils, and may therefore indicate soil degradation depending on aridity and loss of vegetal cover. Afterwards, even most grasses decline (only Poaceae recover), while olive trees become the characterizing element of the vegetal landscape (Yll, et al. 1997).

Figure 17. Pollen diagram from Cala’n Porter, Minorca, Balearic Islands. Reprinted with modifications from Quaternary Research, vol. 48, E-I. Yll et al., Palynological evidence for climatic change and human activity during the Holocene on Minorca (Balearic Islands), p. 343, Fig. 4, ©1997, with permission from Elsevier. The period ca. 4000-1900 BC is shaded in gray.
At the site of Alcudia (39°51’N), on the island of Mallorca, the situation is similar. In the Atlantic period, juniper and ephedra are found on the sandy coasts, hazel and alder along streams, and there were widespread forests of heath, evergreen oak, mastic, and particularly deciduous oak and boxwood. After 6270 ± 70 BP [5463-5038 cal BC 2σ], shrub species such as *Olea, Pistacia* and trees like pines replace most of junipers and ephedra. On higher elevations, boxwood disappears, deciduous oak decreases, and beech increases. Mastic/terebinth and evergreen oak spread, particularly towards the end of the phase, which is around the 1st millennium cal BC. The presence of rockrose (*Cistus*) also becomes more consistent, and as in Corsica, there is a great expansion of evergreen oak at the expense of the deciduous species (Burjachs, et al. 1994). All these vegetation changes are symptoms of gradually longer summer droughts since the 5th millennium BC, according to the reconstruction by Jalut and colleagues, who detected the first establishment of Mediterranean conditions by the early 6th millennium BC (Jalut, et al. 2000).

3.4. Discussion. Trends, Events, and Their Nature

3.4.1. Was There Any Long-Term Climate Change 4000-1900 BC in the Western Mediterranean?

Since the evidence is highly diverse in methods and study areas, and the purpose of this chapter is to compare evidence from different areas to infer trends in the geographic center, by necessity I draw most of my generalizations from the studies that involved wide areas. This is also coupled by attention to century-scale shifts, which as I explained above are very important for archaeologists but do not represent the main concern of paleoclimatologists.

As is clear from the results of the survey, one of the key studies is that by Jalut et al. (2000). They devised a rigorous and sound methodology, which while not lacking reasons for criticisms, makes their findings widely accepted and cited. It accounted for several biases commonly not considered, and allowed the tracing of patterns over a broad area and over different latitudes in a systematic way. Magny et al. (2002), in their synthetic work focusing on hydrology, bring together many available proxies (Figure 18), and accept the identified aridification phases. What they disagree upon concerns the correspondence of dry phases
with high lake levels and glacier expansion. They point out the problem of comparing calibrated dates of pollen sequences with uncalibrated dates of glacier data, concluding that the correspondence is rather between arid phases, low lake levels, and glacier retreats as documented in previous studies (Magny 2001; 2004; Magny, et al. 2003a; 2003b).

A general trend toward aridification is clear over the 4000-1900 BC period we are interested in. On the other hand, the chronological correspondence is in my opinion not much better by using all calibrated dates. Although it is of course more rigorous methodologically, it does not make things clearer because dating resolution is still too coarse. Jalut et al.’s (2000) aridification phases in some cases even overlap with each other, so they can
potentially match almost every phenomenon one likes. It is clear that due to such problems of resolution, finding correspondences is very hard at the small scale. This also affects the complexity of accounting for climatic patterns at the local level. However, two important points have been acknowledged: first, that there was a general division of the Holocene into two halves worldwide (warmer/wetter vs. cooler/drier?) (Roberts, et al. 2001); and second, that the existence and identity of arid phases, despite their coarse chronology needing improvements, are recognized in several cases.

Looking at a variety of different proxies, the reality of significant climatic changes that do not depend at all on human impact is clear, and has been connected to changes in summer insolation of the northern hemisphere and global warming, which caused south-north displacements of the monsoonal zone and of the westerly winds that bring rain to the Mediterranean and the Levant (Damnati 2000; Magny and Haas 2004; Weiss 1997). These displacements and climatic changes were generated, as they are now, by displacements of the boundaries between resulting climatic zones, or ecotones. While the Mediterranean zone is hot and dry in the summer and wet only in the winter, the Oceanic/Atlantic zone is cooler and more moist (Crumley 1993); Sardinia’s location is remarkably central, so that a shift of a few hundred km, comparatively small at the global scale, does generate significant and possibly rapid change in precipitation and temperature patterns. Such movement has been described as pulsating, and it may involve, when high pressures prevail, a weakened westerly jetstream, so that the moisture coming from the Atlantic does not release rains on the Mediterranean basin. When thresholds are crossed that are relevant for hydrology and ecosystems in general (Starkel 1997), environmental change can be profound, as can be seen in vegetation communities. It is also apparent that besides the general trend from the climatic optimum in the 5th millennium until historic times (after the 9th-7th century BC), the most substantial climatic and environmental change in the Western Mediterranean area did occur specifically during the 3rd millennium.

3.4.2. Assessing Human vs. Climatic Impact

The issue of whether the environmental evidence reflects climate change or human impact is a crucial question, and the debate is lively. On one side are those who recognize a primary role of climate independent from human agency, which is not considered as relevant
up to historic times (Jalut, et al. 2000; Jalut, et al. 1997). On the other side there are those who identify human impact as the primary factor for the recorded evidence since the establishment of Neolithic economies (Carcaillat 1998; Carcaillat, et al. 1997; Pons and Quézel 1998).

Anthracology and AMS dating have been used to address this problem. Carcaillat (1998) argues that if two areas within the same altitudinal belt, and only 10 km apart, show remarkably different patterns of fires, this means that fires are not of natural origin, but set by humans. Along this line, the recorded pattern supports an origin independent from wide climatic change. On the other hand, 34 AMS dates for a period spanning 7000 years (from 6715 ± 95 BP to 75 ± 55 BP: about one sample every 200 years) seem quite few to infer real patterns. Each date may represent a small fire rather than forest fire, while conversely the scattered dates show a large uncertainty and possible randomness of patterns. Also, the possibility of lightning-generated fires is overlooked, and very difficult to determine. Assessing frequency and extension of fire events seems to require a much more intense sampling.

Pons and Quézel (1998: 758-9) point out how over the last 100 years, with the decrease in human management of the countryside, deciduous oaks have shown a constant expansion (over twice as large an area) in southern France. They argue that changes appear to not be contemporaneous, and so reflect factors other than climate. As an example of paradoxical conclusions, they cite La Trémie and Berre. These two sites are hardly 40 km apart, they are located within the same ecological context, but Mediterranean climate, based on pollen records, would have appeared about 1800 years apart (Jalut, et al. 1997; Berre was expunged from Jalut et al. 2000). This would indicate that human impact is responsible for this variation, not climate, and such explanation would be confirmed by the contextual appearance of indicators of human activity: pioneer plants that colonize disturbed soils and others that thrive in soils with high concentration of nitrates.

Even acknowledging the importance of general climate change as reconstructed by Jalut and coworkers, it must be considered that fires would have been responsible for major vegetation changes, not by simply destroying the forest, but by altering the competition among species, favoring evergreen versus deciduous oak (Figure 19), in a chronologically irregular and to a certain extent reversible way (Carcaillat 1998; Pons and Quézel 1998). In coastal Corsica, fires would have destroyed the specific factors inhibiting the spread of evergreen oak: the
dense clusters of heath and pine, the layer of humus, and nitrogen mineralization. As a proof that this does not depend on drier climate, there would be the establishment of species such as *Acer* (maple) and *Fraxinus* (ash) which are not related to arid conditions (Carcaillet, et al. 1997: 92). A counterargument to this is also that the increase in erosion and the formation of bodies of stagnant water would have created new moist ecological niches (Caldara, et al. 2002; Dubar and Anthony 1995). Similar arguments for a selective pressure of fire have been made about *Pistacia*, *Phyllirea* and *Olea* (Reille 1992), and for highland Corsica about *Pinus nigra* and *Taxus* (Reille, et al. 1999a).

In some contexts it is less controversial that plant communities changed in response to much higher aridity. Radical differences in vegetation took place in the Balearics “before human impact began […] , changes were then accelerated by human activity” only later (Yll, et al. 1997: 343-6). Other examples of vegetation change independent from human presence come from Southeastern Spain (Jalut, et al. 2000: 285): climate must have been the main trigger for change in Almeria, since no undisputed palynological evidence exists of human impact on the landscape, even in areas with high density of settlement (Pantaleón-Cano, et al. 2003). The dichotomy human vs. climate is interestingly present also in the fact that in the presence of anthropogenic indicators, important pollen variation is attributed to humans, even
though climate can have an effect, and in fact does, on environments that have been already modified. Therefore, even such markers mean human presence, but not necessarily that active impact is responsible for all the recorded variation.

The difference of these positions is not in absolute terms, but in the emphasis. While Jalut, Magny, Yll and coworkers identify major climate changes that modify the environment with limited and occasional contribution of human practices, Carcailllet, Pons and Quézel, and Reille see climate change as a possible factor speeding up major changes brought about by human deforestation by fire, cultivation, and pastoral practices. Some scholars are actually modeling environmental change taking into account both factors (Carrión and Navarro 2002; Carrión, et al. 2003). Similar polarization mirrors closely the interpretation of erosion in relation to human settlement across the Mediterranean from a more archaeological perspective, along the opposite lines exemplified by Vita-Finzi and Van Andel, but a model of mutual feedbacks seems more likely to have been at work in most cases (Bintliff 2002).

The constant problem is the extent to which we can identify correlation with causality. Comparing the intensity of human occupation and the erosion events, for instance, there is always the dilemma that “two major human-induced processes were likely to be at work […]. First, rapid settlement expansion across the countryside, associated with clearance of wood or scrub and heavy soil disturbance, could lead to soil erosion and thence stream alluviation. Second, the reverse procedure – abandonment of a formerly heavily populated countryside – might cause slope failure with abandonment of terrace maintenance” (Bintliff 2002: 419). The problem is further complicated by two mechanisms: sharp climate changes may be detected in areas where they cause some parameters to cross thresholds that are relevant for the ecosystem, while elsewhere the same temperature/rainfall change may not be ecologically significant (Starkel 1997); climatic and/or human impact can initiate processes that result in sensible changes long after their occurrence, sometimes in sudden and radical ways, if equilibrium is maintained by alternative states (Scheffer, et al. 2001).

3.4.3. Chronology and Nature of Climatic Events

The most comprehensive contribution to the identification of climatic phases in the western Mediterranean during post-glacial times defines several aridification phases, two of which are within the range of interest for this dissertation (Jalut, et al. 2000). Besides these
dates, which are rather coarse and even overlap, likely because of phenomena described above, further evidence of specific dry phases comes from measurements of magnetic susceptibility (Ellwood, et al. 1996; Ellwood, et al. 1997). Combining two sequences from Spain (El Mirón 1) and Albania (Konispol), three arid periods were detected, two of which correspond with those detected through pollen analysis: SE-7, ca. 4255 to 3675 cal BC, SE-5, ca. 3583-3069 cal BC, SE-3, ca. 2880-1997 cal BC (Ellwood, et al. 2001; all dates are already calibrated with the 1999 curve, without raw dates available).

The dry phase SE-7 at the end of the 5th- start of the 4th millennium finds correspondence in central-northern Italy (Tuccimei, et al. 2003), and especially in the southern belt of the Mediterranean: in Tunisia (Zielhofer, et al. 2004), in the Ionian Sea and near Gibraltar (Rimbu, et al. 2004). The phase SE-5 seems to correspond to the beginning of the accumulation of windborne dust sediments on Lampedusa after the mid-4th millennium BC (Giraudi 2004), whereas similar dates at northern latitudes correspond to remarkable instability, with swinging lake levels in the Jura massif, the beginning of pebble accumulation in the southern Alps (Magny 1999; Magny, et al. 2002), and three stormy events dated by tree rings at Lake Constance that affected the human occupation of the shores (Magny and Haas 2004). Similar instability has been found in northern-central Italy in the oxygen isotope record (Tuccimei, et al. 2003), a clear rainy peak is recorded at Cubelles (Catalonia) after the mid-4th millennium (Jalut, et al. 2000: 274-5), and the wiggles in pollen sequences from southern France discussed above could as well be related. Such instability has even been traced at a global scale, mostly as drier, and often as cooler conditions.

Good agreement in chronology connects the long dry phase SE-3, identified between ca. 3000 and 1900 BC in most areas, beginning with a dry event around 3000 BC, reflected by a drop in arboreal pollen at San Rafael, Spain, and Pergusa, Sicily (Carrión, et al. 2001b; Carrión and Navarro 2002; Sadori and Narcisi 2001), and by a dry spell at Tigalmamine, Morocco (Lamb, et al. 1995). This long dry phase has been documented in central Italy by pollen sequences, sedimentation evidence and oxygen isotopes (Magri 1997, 1999; Magri and Sadori 1995; Ramrath, et al. 2000; Tuccimei, et al. 2003); in southern France and the Alps, through lake levels and glacier retreat (Magny, et al. 2002); in the belt between northern Spain and Albania, through interpolation of magnetic susceptibility profiles (Ellwood, et al. 2001); and in North Africa, through sediment micromorphology (Zielhofer, et al. 2004). This time seems to have witnessed a change in air mass circulation patterns, due
to the migration northward of the polar front. There was a shift from a more regular precipitation regime related to southerly circulation and monsoonal-type summer rains, to stronger influence of westerly wet air masses, which were likely to be seasonally constrained by high pressure systems in the southern Mediterranean belt.

From palynological evidence in central Italy (Magri 1997) and on the western coast of the Mediterranean, it seems that this long phase could have contained two periods separated by milder conditions around the middle of the millennium (between phases A.3 and A.4 in Jalut, et al. 2000); the first coincides with the sudden ‘collapse’ detected in Tunisia, which is interpreted as a punctuated event in response to increased insolation (Scheffer, et al. 2001; Zielhofer, et al. 2004), documented also in central Italy (Ramrath, et al. 2000) and therefore very probably involving Sardinia as well. The second aridification phase, besides the pollen evidence, is also recorded in low lake levels in the Alps (Magny, et al. 2002), a warm phase detected through alkenones in the southern Adriatic Sea (Rimbu, et al. 2004), windborne dust on Lampedusa (Giraudi 2004) and elsewhere, and a large body of evidence for the Eastern Mediterranean and beyond, that has been summarized and discussed elsewhere (Bryson and Bryson 1997; Dalfés, et al. 1997; Weiss 1997).

Reconstructing the details of climatic change in terms of temperature and humidity is complex. Many scholars do not even mention the problem, although it is clear that in some cases there is an implicit idea that drier corresponds to warmer, which not necessarily is the case. In general terms, it seems accepted that both temperature and rainfall were higher in the Atlantic; in southern France, this has been estimated as 2-4°C higher than the present-day annual average (Blanc 1993). The shift towards drier conditions characterizing the late 4th and 3rd millennia would have been coupled by a few degrees in both sea surface (Jalut, et al. 2000: 281-283; Rimbu, et al. 2004) and atmospheric temperature, although their interaction and the consequences for Mediterranean climate are not known in enough detail. For certain areas of Saharan Africa before ca. 3500 BC, precipitation has been estimated to have been about 300 mm more than today, but this cannot be applied as such to the Mediterranean area (Damnati 2000). It only gives an indication confirming the generally moister conditions widely documented in Europe. Even smaller changes could have made a difference between the 5th and 3rd millennium, and especially in a threshold area they would have been ecologically significant (Starkel 1997; Thornes 1995), but this is even more likely since there is evidence of major events in the 3rd millennium.
3.5. Conclusion. What Can Be Inferred about Environmental Change in Sardinia

I draw here a few conclusions from the evidence I have analyzed and discussed (Table 2). The 4th millennium BC was drier and cooler than the millennium before and wetter than the millennium after, representing the crucial transition from temperate and humid to Mediterranean conditions characterized by increased seasonality and summer droughts. A warmer and drier phase occurred around the centuries around 4000 BC in the whole area. A time of storms and weather instability around 3600-3200 BC (Magny and Haas 2004), apparently wetter than before and after, and which is documented in the northern area of the western Mediterranean, may have involved Sardinia at least in the northern area.

A generally arid period, lasting over a thousand years, characterized the 3rd millennium BC as compared to the one before and to the centuries just after. Within this period, two particularly dry (and warm?) phases occurred. The first, centered around ca. 2900-2700 BC, which seems to have been dramatic in North Africa, is likely to have affected Sardinia, and particularly the southern lowlands. The second, centered around 2400-2000 BC, was probably the most severe ever experienced by local human groups up to that point, which might be connected to the widespread evidence of break in settlement continuity in the Western Mediterranean that has been pointed out (Webster 1996: 62). It has been documented widely, over a belt stretching from the Atlantic Ocean to areas beyond the Near East, and quite well at Lago di Vico (Magri 1997; Magri and Sadori 1995).

It is important to note that altitude and geography played an important role in affecting the local variation of environmental conditions. As shown by several pollen sequences, the higher the elevation, the less the vegetation suffered from aridification. Similar to data from the Apennines, the diagram of Cañada de la Cruz (Carrión and Navarro 2002), at over 1500 m asl, shows a warm and wet phase throughout the timespan examined, up to the mid-2nd millennium BC, which means that since the more fertile lowlands were, as are now, also more susceptible to severe drought in arid phases (Thornes 1995), the dynamics of settlement and resource exploitation must have been adjusted, either by mobility or by a process of selection in favor of the communities occupying the most advantageous regions. This may explain why there seems to have been a proportional increase in human presence in
Table 2. Tentative reconstruction of likely climatic phases in Sardinia between the late 5th and the early 2nd millennium BC, with relative references and chronology of cultural phases as identified in the literature and chronologically defined by Tykot (1994)

<table>
<thead>
<tr>
<th>Date cal BC</th>
<th>Climatic phases</th>
<th>References</th>
<th>Chronology (modified from Tykot 1994)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4500</td>
<td>Warm and rainy (December rain, Brama, Gypbal, Beqal and atlantic)</td>
<td>(Falai et al. 2000, Baro i Moia di Esteban 1984: Calabria, California)</td>
<td>L'Anghina</td>
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<tr>
<td>4400</td>
<td></td>
<td>(Falai et al. 2000; Baro i Moia di Esteban 1984: Calabria, California)</td>
<td>L'Anghina</td>
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<tr>
<td>4300</td>
<td></td>
<td>(Falai et al. 2000; Baro i Moia di Esteban 1984: Calabria, California)</td>
<td>L'Anghina</td>
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<tr>
<td>4200</td>
<td></td>
<td>(Falai et al. 2000; Baro i Moia di Esteban 1984: Calabria, California)</td>
<td>L'Anghina</td>
</tr>
<tr>
<td>4100</td>
<td></td>
<td>(Falai et al. 2000; Baro i Moia di Esteban 1984: Calabria, California)</td>
<td>L'Anghina</td>
</tr>
<tr>
<td>4000</td>
<td>Moderately rainy (winter monsoon)</td>
<td>(Falai et al. 2000; Baro i Moia di Esteban 1984: Calabria, California)</td>
<td>L'Anghina</td>
</tr>
<tr>
<td>3900</td>
<td></td>
<td>(Falai et al. 2000; Baro i Moia di Esteban 1984: Calabria, California)</td>
<td>L'Anghina</td>
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<td>3800</td>
<td></td>
<td>(Falai et al. 2000; Baro i Moia di Esteban 1984: Calabria, California)</td>
<td>L'Anghina</td>
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<tr>
<td>3700</td>
<td></td>
<td>(Falai et al. 2000; Baro i Moia di Esteban 1984: Calabria, California)</td>
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<tr>
<td>3600</td>
<td></td>
<td>(Falai et al. 2000; Baro i Moia di Esteban 1984: Calabria, California)</td>
<td>L'Anghina</td>
</tr>
<tr>
<td>3500</td>
<td>Possibly rainier in Northern Sardinia?</td>
<td>(Maggini di Haas 2004, Western Alps)</td>
<td>L'Anghina</td>
</tr>
<tr>
<td>3400</td>
<td></td>
<td>(Maggini di Haas 2004, Western Alps)</td>
<td>L'Anghina</td>
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<tr>
<td>3300</td>
<td></td>
<td>(Maggini di Haas 2004, Western Alps)</td>
<td>L'Anghina</td>
</tr>
<tr>
<td>3200</td>
<td>Moderately rainy</td>
<td>(Falai et al. 2000; Baro i Moia di Esteban 1984: Calabria, California)</td>
<td>L'Anghina</td>
</tr>
<tr>
<td>3100</td>
<td></td>
<td>(Falai et al. 2000; Baro i Moia di Esteban 1984: Calabria, California)</td>
<td>L'Anghina</td>
</tr>
<tr>
<td>3000</td>
<td>Very dry (Evergreen oak, Gingko)</td>
<td>(Falai et al. 2000; Baro i Moia di Esteban 1984: Calabria, California)</td>
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<td>2900</td>
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<td>(Falai et al. 2000; Baro i Moia di Esteban 1984: Calabria, California)</td>
<td>L'Anghina</td>
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<tr>
<td>2800</td>
<td></td>
<td>(Falai et al. 2000; Baro i Moia di Esteban 1984: Calabria, California)</td>
<td>L'Anghina</td>
</tr>
<tr>
<td>2700</td>
<td>Moderately rainy</td>
<td>(Falai et al. 2000; Baro i Moia di Esteban 1984: Calabria, California)</td>
<td>L'Anghina</td>
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<tr>
<td>2600</td>
<td></td>
<td>(Falai et al. 2000; Baro i Moia di Esteban 1984: Calabria, California)</td>
<td>L'Anghina</td>
</tr>
<tr>
<td>2500</td>
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<td>(Falai et al. 2000; Baro i Moia di Esteban 1984: Calabria, California)</td>
<td>L'Anghina</td>
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<tr>
<td>2400</td>
<td></td>
<td>(Falai et al. 2000; Baro i Moia di Esteban 1984: Calabria, California)</td>
<td>L'Anghina</td>
</tr>
<tr>
<td>2300</td>
<td>Very dry</td>
<td>(Falai et al. 2000; Baro i Moia di Esteban 1984: Calabria, California)</td>
<td>L'Anghina</td>
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<tr>
<td>2200</td>
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<td>(Falai et al. 2000; Baro i Moia di Esteban 1984: Calabria, California)</td>
<td>L'Anghina</td>
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<tr>
<td>2100</td>
<td></td>
<td>(Falai et al. 2000; Baro i Moia di Esteban 1984: Calabria, California)</td>
<td>L'Anghina</td>
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<tr>
<td>2000</td>
<td>Moderately rainy</td>
<td>(Falai et al. 2000; Baro i Moia di Esteban 1984: Calabria, California)</td>
<td>L'Anghina</td>
</tr>
<tr>
<td>1900</td>
<td></td>
<td>(Falai et al. 2000; Baro i Moia di Esteban 1984: Calabria, California)</td>
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<tr>
<td>1800</td>
<td></td>
<td>(Falai et al. 2000; Baro i Moia di Esteban 1984: Calabria, California)</td>
<td>L'Anghina</td>
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<tr>
<td>1700</td>
<td></td>
<td>(Falai et al. 2000; Baro i Moia di Esteban 1984: Calabria, California)</td>
<td>L'Anghina</td>
</tr>
</tbody>
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the Sardinian highlands, which were virtually uninhabited earlier than 4000-3200 BC (Ozieri phase), and came to be preferred after 3200 BC.
These climatic changes resulted in the alteration of the ecosystem, which was particularly severe in the lowlands, selecting species well adapted to summer droughts that were until then confined to coasts and sandy soils. Since there is no palynological evidence so far, it is only possible to infer, based on Corsica and the Balearics, that forests of deciduous oak, heath and strawberry tree were dominant in the early 4th millennium on the northwestern and central-eastern mountains, with boxwood and hazel also present. The southern and western plains were probably covered by deciduous oak, possibly yew and linden, with juniper only in the arid coasts. The typical Mediterranean shrubby vegetation, made up by wild olive, mastic, privet, myrtle and especially evergreen oak, could have been present in glacial times in refugia in the extreme south, but the fact that their arrival to Corsica was quite late may indicate that Corsica and Sardinia were acting like cul-de-sacs for the spread of these species after the last glacial maximum. They would have spread northward up to Tuscany and southern France, and then south. Genetic evidence of present-day evergreen oak (*Quercus ilex* species), in fact, points to an origin from the Italian peninsula (Lumaret, et al. 2002), and this may imply that it was scarcely or not present in Sardinia as in Corsica (Reille 1992) before the Atlantic, and marginal until the 3rd millennium BC.

During the 3rd millennium BC the establishment of drier conditions and longer summer droughts, enhanced by fire, likely accelerated the spread of specific species more resistant to drought and burning. The actual dynamics of species competition, which were different in the Balearics and Corsica, will remain unknown until pollen sequences will be obtained and analyzed. By purely geographic arguments I would think about evergreen oak replacing boxwood, hazel and heath, as in Corsica but earlier than in Corsica, and on the same south-north gradient. If the increase in *Olea* in the Balearics may be connected to the stable colonization of the islands by the Bell Beaker groups around 2500 BC, it seems reasonable to think that the contemporaneous presence of Bell Beakers in Sardinia and their marginal presence in Corsica (Lemercier, et al. in press) could likely reflect the establishment of different agricultural practices including the management or planting of tree crops, detected and studied in the northwestern Mediterranean. While temperate deciduous forests were getting thinner, in the drier lowlands of the Campidano and Sulcis wide extensions of shrubs and grasses dominated the landscape, in certain areas probably close to pre-desert conditions as recorded at similar latitudes in
southeastern Spain and in Apulia (southeastern Italy) for the 3rd millennium BC. Weather instability in the 4th millennium and the following arid phase in the 3rd, enhanced by human impact through fire and grazing, likely caused soil erosion that first favored the definition of large coastal lagoons and then progressively infilled them with sediments, turning rich estuarine environments into marshes, with differentiated ecological outcomes. This process was probably coupled by a slight decrease in sea level: estimates for coastal Provence are on the order of 6-3 m lower than present-day at ~4000 BC, 3.5-1.5 m lower at ~2000 BC (Lambeck and Bard 2000). Due to the complex intersection with uplift and subsidence, there is a great variation the western Mediterranean: specific estimates for Sardinia (Figure 20) are around 12-8 m below current sea level at 4000 BC, and 6-4 m at 2000 BC (Lambeck, et al. 2004). On the Aegean coasts, though, a more articulated curve has been recorded, apparently not influenced by tectonic movements, by which sea level would have been equal to present-day at ca. 4000-3000 BC but dropped during the 3rd and 2nd millennia BC, to reach its lowest level in the second half of the 2nd, ca. 2 m below, before rising up to today (Kayan 1997). Beyond these details, what is clear is that phenomena of erosion and infilling were more intense in the end of the 3rd millennium, during an unprecedented arid phase, which probably precipitated an environmental crisis already favored by cultivation of steep slopes, long-term grazing, deforestation and burning. This is likely to have created problems, involving poorer

![Figure 20. Sea-level change in northern Sardinia. Reprinted from Quaternary Science Reviews, vol. 23, K. Lambeck et al., Sea-level change along the Italian coast for the past 10,000 yr. p. 1584, Fig. 3.e, ©2004, with permission from Elsevier.](image-url)
harvests, scarcer water and pasture for the flocks, and scarcer water for people. Additionally, the possible establishment of malaria (Brown 1997), especially in the lowlands, which is commonly attributed to later times, would have prevented the exploitation of some well-drained fertile areas. In fact, in case of drought the most sensible ecological systems are those with substantial biomass, whereas vegetation communities adapted to dry soils will likely be more resilient (Thornes 1995: 365), as can also be observed today: the areas at higher risk of desertification for global warming are the fertile lowlands of the South (Sardegna 1995-2007).

The human perception of what was happening for centuries or millennia is a fundamental aspect. It has been underlined that the more gradual phenomena are the less likely they will be perceived as a threat even though they affect negatively vegetal communities and natural resources in general (van der Leeuw and Redman 2002: 9). Especially in case certain practices were actually advantageous and disadvantageous at different social levels, the unintended effects could have been just inevitable. This has been suggested for herd accumulation, which makes sense at the household level but is detrimental for the progressive impoverishment of vegetal communities and soils by overgrazing that it favors (McPeak 2005). The different directions that such practices were leading to, including possible responses such as the regulation of resource exploitation, social and organizational adjustments, the adoption of technological innovations in food production (e.g. tree crops, more resistant to unpredictable weather) are not foreseeable based on general models but depend on the historically specific forces at play, all embedded in, and producing, environmental and cultural change. It seems likely, as documented in other areas of the Mediterranean (Maggi 2004), that drier periods may have induced, gradually or exceptionally, movement to the highlands with the flocks to have reliable water sources and grazing grounds. Furthermore, clearing through fire to create this pasture and fields, documented in France, Spain and elsewhere (Carcaillet 1998; Carcailllet, et al. 1997; Carrión, et al. 2003; Maggi 1998) is likely to have deprived the slopes of thin fertile soils which in turn discouraged farming because of low outputs and encouraged the intensification of herding. Increases in grazing due to herd accumulation may have prevented the recreation of forests and sped up soil erosion, in a series of negative feedbacks which, coupled with
unfavorable settings such as poor soils and particularly sharp and severe arid events, may have led to ecosystem degradation and collapse. These possible trajectories are considered in the remaining sections of this dissertation, particularly through stable isotopes, which can provide an efficacious independent assessment of climate variation and of reliance on vegetal versus animal products.
Chapter 4. Change in Material Culture and Social Organization in Sardinia 4000-1900 BC

4.1. Introduction

The plan of this dissertation involves the integration of information coming from three broad domains. This chapter represents the variation in material culture and its possible meanings in cultural and organizational terms. This is the most qualitative but also the best known of the three, since it has been the subject of archaeological investigation since the beginnings of prehistoric archaeology in Sardinia. This means that the sheer amount of data available is by far the largest. I will not refer here to these raw data; instead I will make use of the main synthetic works, with some degree of integration only when there are substantial updates, or specific points to be made regarding more limited topics, such as specific categories of material culture or symbols.

Detailed synthetic works on Sardinian prehistory before the Bronze Age are only available in Italian. In English, are worth mentioning the introductory section of Rowland’s (2001) book on Ancient and Medieval Sardinia summarizes prehistoric cultural history, and Webster’s A Prehistory of Sardinia (1996). The latter is the only work with a prehistoric and anthropological focus covering pre-Nuragic times, even if only as an introduction to the Bronze Age. Therefore, the main sources of raw data and descriptions will be Lilliu’s La civiltà dei sardi (1988a, reprinted in 2004), and Contu’s La Sardegna preistorica e nuragica (1997), with integrations where appropriate. The first is almost two decades old and outdated in many aspects, but the collection of data and the general framework is still a good reference, particularly as concerns ceramics, which is the main discriminant in what came to be defined as ‘cultures’ in the scholarly tradition.
Decades of research in the fields of ethnography and archaeology have shown that there is no necessary relationship between ethnicity and specific aspects of material culture. Only elements that are themselves structurally defining for identity will have this connection. For periods that are *sans documents* and are far back in time, reconstructing this is at best extremely difficult, if not impossible (Fowler and Hardesty 2001). It will be sufficient here to emphasize that ethnic identities may not, and likely did not, correspond to the archaeological constructs we work with, while only a consistent association of several elements of material culture and cultural symbols may increase the likelihood of actually reflecting a cultural ‘unit’. For the reasons just explained, this will be an overall view on material culture, with a special attention to geography and chronology, rather than typological details for their own sake. The locations mentioned in this chapter can be found on the general map of sites (Figure 21).

4.2. Ceramic Groups and the Definition of Archaeological Cultures

4.2.1. Ozieri

The culture named Ozieri (or San Michele di Ozieri) is characterized by specific ceramic shapes and decoration. It appears to have evolved from Middle Neolithic tradition, with a transitional phase, named San Ciriaco, which has been recognized at several locations in western and southwestern Sardinia. After the first finds it was suggested that this may be a local aspect. It is now clear that the style’s distribution covers most of the island, including Gallura in the northeast (Antona 2003; Lugliè 2003; Molinari 2002; Usai 2005a).

As several aspects of lithics, settlements, and architecture are shared with previous and subsequent phases, pottery is truly the nature of the Ozieri culture. Lilliu divided the pottery types according to form and decoration into three groups, although one, painted pottery, is now attributed to the Sub-Ozieri aspect of the same tradition, which is chronologically considered part of the Copper Age (Melis 2000d: 47-48). There is no evidence for wheel-made vessels, firing is highly variable, but never very high temperature, and clays reflect local sources, never reaching the finesse of Middle Neolithic vessels (Contu 1997: 184). Among the non-decorated types are collared vessels and carinated bowls,
Figure 21. General map of all sites mentioned in chapter 4. Map by the author, based on cartographic material from S.A.R. Sardegna consortium, with kind permission.
including the footed version (tripod). This latter shape is very common, with frequencies that do not have parallels anywhere else in the western Mediterranean, and can be rather large (diameter 23 cm, height 17 cm). It has been compared with western types, especially from southern France (Lilliu 1988a: 100-101). Handles are often minimal or absent in tripods, replaced by holes for suspension around the rim (Contu 1997: 182). In the earliest Ozieri phase at Cuccuru s’Arriu (Cabras, west coast), undecorated amphorae and cups are also associated with large spoons (Contu 1997: 180).

Most distinctive are, however, the decorated vessels (Figure 22), which are found with little local differences over most of the island. Typical are the collared amphora, the so-called vaso a cestello, a basket-shaped open vessel with flat bottom and concave walls also called kalathos, and the pyxis, a closed form with flat bottom and concave walls as well. These last two types are very standardized and common, usually decorated, and very distinctive, and the second seems more rare in the final phase of transition into the Copper

Figure 22. Examples of typical Ozieri decorated pottery (~4000-3400 BC). Reprinted with modifications from Lilliu 1999, pp. 95, 113, 117, 119, Figs. 113, 131-132, 137-138, 140, ©1999, with kind permission from Carlo Delfino publisher.
Age (Santoni 1989). Generally, there is a prevalence for flat-bottomed, open shapes, with few flasks and bottle-shaped containers (Contu 1997: 184).

Decoration is rarely painted, but it displays techniques that replace the filled-empty effect of painting (“achromous dichromy”): excisions (rare) and incisions, which are sometimes filled with white or red material. Striated, pinched and punctated motifs are either free or within geometric partitions, often covering the whole surface of the vessel and the inside. Among such motifs are the star, spirals, flower-shaped figures and zig-zags (Contu 1997: 179-186; Lilliu 1988a: 105-111). Occasionally bovine heads and human stick figurines appear as part of this decoration (Contu 1997: 188-196). When these diagnostic sherds are present, the identification of this culture is quite straightforward, which may cause its overrepresentation when dealing with highly fragmented surface finds. Specific to Sardinia, the features of the Ozieri style do not appear as such elsewhere: its distribution is virtually limited to the island, with a significant exception in a few potsherds found in downtown Florence (Tykot 1999: 74).

4.2.2. Post-Ozieri Tradition

I include here in the Post-Ozieri tradition the phases that have been identified as the evolution of the Ozieri style within a framework of continuity, labeled traditionally as Sub-Ozieri, Filigosa and Abealzu (Figure 23). The articulation and classification of ceramic evidence has improved remarkably in the last two decades. Lilliu (1988a: 131-146) considered the beginning of what is now known as Sub-Ozieri as part of the Ozieri style, and the following period a different unit, defined “Abealzu-Filigosa”. He suggested the existence of some differences in the two aspects Abealzu and Filigosa, but recognized the overall identity of the culture, and since clear stratigraphies were still lacking, he believed Abealzu to be an earlier phase. Later, it became clear that the aspects truly represented somewhat different phases, and Contu found a basic distinctive element in the presence of flasks and bottles with a handle on one side and two grips, or rough knobs, on the opposite side (Contu 1997: 302).

The milestone in documenting and understanding the real nature of these ‘cultures’ is the contribution by Melis (2000d), who collected and classified typologically all the known materials from these phases, using statistics to find relevant associations of shapes and
decoration in order to understand and evaluate change over time. What she found is a large overlap in associations, which points to a gradual change in ceramic production (Melis 2000d: 49). Several groups were generated where types were found exclusively, while others had elements of the previous and following groups. She was therefore able to outline trends in this continuous flow of modifications: technology in group A (tentatively identified with Sub-Ozieri) is close to Ozieri, technologically the finest of the group. Exclusive to this phase is red-on-white painted ware, low pans, and a still high frequency of tripods; also, there are a few carinated shapes, and still typically Ozieri basket-shaped vessels.

In the ‘interface’ groups AB (Sub-Ozieri/Filigosa transition) there is a high proportion of carinated bowls, while pans disappear. Group B has few exclusive types, but scratched decoration appears, to continue in the following phases; in group ABC, carinated cups become more frequent than bowls, and plastic decoration begins. Group BC (labeled as Filigosa I) still shows high frequency of carinated cups (41%), and a remarkable increase of miniature vessels. In group C (labeled Filigosa II) there is a proportional decrease in cups and bowls, whereas beakers become quite common (16%), accompanied by jugs (8%); at the same time, typically Ozieri shapes like tripods decrease.
Groups CD and D (defined as transitional between Filigosa and Abealzu), have rather few common types: beakers, tall-necked vessels, or flasks (Melis 2000d: 51-55), which in the previous qualitative literature are considered typically “Abealzu”. Miniature vessels increase in frequency, a trend associated with the increasing proportion of burial sites versus open-air settlements. The remaining groups CE and E (the latter labeled as Abealzu) are represented by very few types and sites, so that they formally describe a statistically coherent group but do not seem to represent widespread cultural markers: one single hut near the temple of Monte d’Accoddi contained several of these unique types (Melis 2000d: 55).

As for general long-term trends, simple forms were found to be very common in the first groups and to be much rarer after phase C (Filigosa II). There is a similar sequential trend for carinated bowls and cups, and for tripods, which decrease sensibly after C. Inversely, there is an increase in beakers, mugs, jugs, amphorae and long-necked vessels. Large jars are more common in the earlier phase and in the later ones (Sub-Ozieri and Abealzu: but again, the second represents mostly a single hut at Monte d’Accoddi). They are instead scarce in the intermediate phases (Melis 2000d: 55-60). Decoration drops after the Sub-Ozieri phase, and rather than incised and impressed it is mostly dry-scratched and plastic, with an exception for cupules (Contu 1997: 273; cfr. Lilliu 1988a: 135; Melis 2000d: 60). Besides unique examples from Monte d’Accoddi, painted wares are limited to a few sites within a limited area around Cagliari, namely Terramaini (Pirri), and su Coddu (Selargius), and Monte Olladiri (Monastir), the latter possibly Late Neolithic (Lilliu 1988a: 118; Melis 2000d: 48; Ugas, et al. 1989: 239-243). In this phase there is an increased general comparability with ceramic styles of the Italian peninsula, namely the Rinaldone culture, which may be an indication of enhanced communication and contacts between the island and the European mainland (Basoli and Foschi Nieddu 1993; Contu 1997: 315-316).

As for geography and site types, it must be highlighted how most Sub-Ozieri (group A) sites are located in the south, and mostly in lowlands, while the proportion is more balanced in the group B, it is reversed from group C onwards, with most sites in the northern half of the island. Starting from phase BC, the Sub-Ozieri assemblages of the southern lowlands disappear (Melis 2000d: 60). These trends, rather than merely reflecting a shift in settlement patterns from lowlands to highlands, are likely to be related to spatial variation in ceramic styles, and the phases might have a partially overlapping chronology. Such an interpretation may be supported by the new AMS dates presented in this dissertation, where
Sub-Ozieri pottery at Cannas di Sotto and Filigosa pottery at Santa Caterina di Pittinuri appear to be partially contemporaneous.

Given such a picture, is there really a point in naming these cultures as if they had some separate identity, especially those that appear as largely arbitrary entities created based on single assemblages all but representative of generalized phenomena? I exemplified the point in a barchart (Figure 24), where several sites are represented with indication of the types belonging to each of Melis’ systematically defined phases. The assemblage from the eponymous site Abealzu turns out to be rather more “Filigosa”, whereas Serra Cannigas, Santa Caterina-upper layer and other assemblages are more ‘Abealzu’ than the assemblage from Abealzu itself. This points out a source of confusion and inconsistency that traditional nomenclature perpetuates and that I believe specialists of material culture and pottery should address. This is why I hereafter prefer to use ‘Post-Ozieri’ as a comprehensive term for Sub-Ozieri, Filigosa and Abealzu (~3400-2400 BC), while keeping the single phase’s denominations when necessary or when the sources mention them as such.

Figure 24. Chart of relative frequency of ceramic type groups at Sardinian Early Copper Age select sites (data after Melis 2000). Note that types represented at Abealzu are mostly belonging to BC and C groups, which are nevertheless labeled ‘Filigosa’.
4.2.3. Monte Claro

Whereas the Post-Ozieri pottery tradition has been dissected into several archaeological ‘units’, interestingly Monte Claro pottery (~2700-2300 BC) has been constantly defined as one, despite since the beginning a remarkable differentiation was underlined in stylistic features in different geographic zones. From three to five aspects were identified, often referred to according to the four provinces of the island, with the addition of the Southwest (Depalmas 1989; Ferrarese Ceruti 1989: 57-59; Lilliu 1988a: 166-177).

Fairly distinctive aspects are that of the Cagliari area (Figure 25), mostly known from burials in the eponymous Monte Claro-sa Duchessa necropolis in Cagliari; that of the Oristano area, mainly represented by the well-studied assemblages at Simaxis; that of Biriai (Oliena, Nuoro), a large settlement; and that of the Sassari-Alghero area in the north. Lilliu

![Figure 25. Some examples of typical Monte Claro pottery from southern Sardinia (~2700-2300 BC). Reprinted with modifications from Lilliu 1999, pp. 128, 129, Figs. 151, 154, 155, ©1999, with kind permission from Carlo Delfino publisher, and from Ferrarese Ceruti 1989, pp. 61-62, 65, Figs. 3-4, 6, ©1989, with kind permission from Banco di Sardegna S.p.A.](image-url)
distinguished the Mogoro group, with features intermediate between the Cagliari and the Oristano area. Depalmas (1989), instead, sampled more sites and separated into groups according to the four provinces, so that the Cagliari area and the Southwest are together.

Paste quality and color, and surface color, inclusions and so on are all variable, reflecting local manufacturing, but quality seems generally finer than preceding and following phases (Lilliu 1988a: 167-174). Decoration is characterized by straight parallel grooves covering portions of the vessel horizontally or vertically, or both, but several other techniques are represented in combination, with remarkable variation. Vessel shapes are also highly variable, but generally more rigid than before, and with wider flat bottom (Ferrarese Ceruti 1989: 57). The relative frequency of ceramic types also varies, characterizing assemblages across the island very distinctively. During this phase we find the largest jars of the whole Sardinian prehistory before the Middle Bronze Age. The highest frequency of grooved pottery is found in the Cagliari province (Cagliari and the Southwest), and common shapes are buckets (*situlae*), large jars (*dolia*), tripods, and low platters (Depalmas 1989; Usai 1989b, 1991; Usai 1996). Along with grooves, striations are more common in the North, where shapes are less rectilinear and the paste is more refined (Lilliu 1988a: 176-177; Moravetti 2002: 76). Incisions are particularly common in the Oristano area, impressions are frequent in the Center and South, and a peculiar leaflet motif is particularly frequent at Biriai in the East (Castaldi 1999: 239-274; Depalmas 1989: 44-54). Among other shapes, vessels with outward neck and a ledge inward, traditionally labeled as ‘milk boilers’, are more frequent at Biriai, in the western lowlands near Mogoro and Oristano, and in the Southwest (Lilliu 1988a: 171-174; Usai 1997; Usai and Santoni 1998).

The relative similarity of assemblages among sites of the central belt across the width of Sardinia has induced Depalmas (1989: 55) to define three, rather than four or five, regional aspects. Evidence has been recognized for a further local aspect in the Southwest, where middle- and large-size containers with internal rim dominate the assemblages from open-air settlements (Usai and Santoni 1998), while in the mountainous area a possible borderline between the Cagliari and Biriai styles has been identified in the territory of Orroli (Sanges 1989).

Burnished surfaces on pottery are found almost only in grave goods around Cagliari, and its somewhat patchy Mediterranean-wide distribution includes, outside of Sardinia,
central Italy and especially Sicily (Lilliu 1988a: 179-180), making its presence unexpected, and pointing to possible contacts between Southern Sardinia and Sicily or even farther East. Other comparisons for the grooved treatment of vessels have been drawn especially with pottery of the contemporary Fontbouïsse culture of Southern France. With such an evidence for high variation, if Monte Claro is used as a meaningful unit in Sardinian archaeology this is probably just because its difference from any other ceramic group is more than its internal differentiations. The main problem is still that of verifying, defining and then explaining the terms, essence and reasons of this “almost radical cut with the past” (Lilliu 1988a: 181). Certainly to the extent to which pottery similarities can be used as proxies for intensity of communication, Sardinia definitely seems to partake now in a wider western Mediterranean network than it previously did.

4.2.4. Bell Beaker

With the appearance of this ceramic style, Sardinia for the first time since the cardial Early Neolithic, over two thousand years earlier, shares the same decorations and shapes with wide areas of the Mediterranean and beyond. Sardinian Beaker pottery (Figure 26), whose comprehensive typological repertoire has been published relatively recently (Castia 1999: 7-35) is borrowed, and generally parallel, to the styles widespread in Central and Eastern Europe, France, Iberian and Italian peninsula, and the British Isles. While some specimens could have been imported, most are local imitations and variations of motifs of large diffusion. Key markers are the typical bell shaped beakers and the decoration, organized strictly in horizontal bands, that includes incisions and impressions made with or without a comb.

Different phases have been recognized on purely stylistic grounds, which have not been tested through absolute dating before the AMS dates presented in this dissertation. The corded ware pre-Beaker aspect is scarcely documented (one single find: Atzeni 1996a: 397), but both main Beaker groups, Mediterranean and Continental, are largely comparable with Sardinian examples (Lemercier, et al. in press). While traditionally gentle, round shapes were considered earlier and more angular and rigid profiles later, likely they did coexist in some contexts, also due to local variation, and in fact there are some late assemblages showing late,
non-decorated pottery with a trend toward more round profiles (Marinaru and Cuguttu, Alghero; Molimentos, Benetutti: Ferrarese Ceruti 1981a: lvii-lviii).

Keeping these caveats in mind, the second phase that has been identified, which is better represented (78% of all finds according to Lilliu 1988a: 199), finds comparisons mostly with areas in the western shores of the Mediterranean (Lemercier 2003, in press). Although very few assemblages (Marinaru, Filiestru) included sherds likely to have been imported, due to its close similarity to examples in Atlantic and Mediterranean France (Atzeni 1996a: 397; Ferrarese Ceruti 1981a: lviii), there are more generalized stylistic similarities with Beaker assemblages from France and Spain, and most stringent with Catalonia; typically vessels in this group do not have handles, and tripods are not very frequent (Atzeni 1996a: 397-400; Ferrarese Ceruti 1981a: lvii-lviii), while punctated decoration is more common than incision (Lilliu 1988a: 198).

A later Beaker aspect (~2500-2200 BC?) is marked by new shapes, as similar beakers and mugs are provided with handles, and small globular vessels with distinct neck appear. Bumps and pointed handles (Atzeni 1996a: 402) are also documented, including the elbow handle, which will remain a feature of post-Beaker cultures in northern Italy as in Sardinia.
The presence of handles, of *metopal* decoration – which indicates a decorations distributed in a horizontal band vertically divided in fields, like in Doric Greek temples – and the dramatic increase in polypod types (three- and four-footed vessels) are all elements close to examples from Austria and the Czech Republic, whereas they are foreign to western Mediterranean pottery (Ferrarese Ceruti 1981a: lxii). Decorated pottery is found also increasingly associated with undecorated pottery, in a gradual transition into the virtually undecorated Early Bronze Age assemblages (Atzeni 1996a: 400-406). The three- and four-footed bowls characterizing this second phase are completely different from the long tradition of Neolithic-Copper Age polypods, and are shapes widespread in northern Italy and across the Alps in Central Europe (Ferrarese Ceruti 1981a: lviii).

Geographically, the later Beaker group seems to be more represented in the center and south, with relatively fewer examples in the Sassari-Alghero area, which may represent some local innovation on known types (Atzeni 1995: 134-139; Lilliu 1988a: 197), or an outcome of more intense interaction with central-European stylistic spheres.

### 4.2.5. Bonnanaro A

This aspect (Figure 27), also named Corona Moltana from the site where it was first identified in 1889, clearly shows its origin from the Beaker style, with the main innovation being its virtual absence of decoration, in a gradual transition possibly well represented in the Sardinian Southwest and in the Oristano area (Atzeni 1996a: 406-408; Ferrarese Ceruti 1981b: lxxii; Lilliu 1988a: 345, 351). Documented almost totally by burial assemblages, its best parallel is found in northern Italy, where the Polada culture shows very similar developments from common models. Stringent similarities are found with both phases Polada 1 (Lilliu 1988a: 318, 351) and 2 (Ceccanti 1980).

The quality of manufacture of artifacts pertaining to this style is generally quite low, and the vessel walls quite thick (Lilliu 1988a: 356). The single most important diagnostic shape is the tripod; as compared to the Beaker type it shows elongated feet, usually single-handed vessels, height almost as great as width whereas the Beaker antecedents were more open (Castia 1999: 37-94; Ferrarese Ceruti 1981b: lxxii-lxxiii; Lilliu 1988a: 351). The relatively abrupt disappearance of tripods in the following Middle Bronze Age phase (named sa Turricula), within a general context of continuity, points to a specific function. Carinated
bowls ranging from less than 10 to about 30 cm diameter are the most frequent type, possibly because of its being simple and non-specialized. The main differentiation is due to the slope of the vessel walls, from very low in the Early Bronze Age to almost vertical in the Middle Bronze Age (Ferrarese Ceruti 1981b: lxxii-lxxiii).

Besides the tripod, the presence of axe-shaped handles is another main marker of this period, in Sardinia as well as over a wide area that extends from the Alps down to Tuscany, which is where there may be the closest similarities (Ceccanti 1980)

4.3. Lithics, Bone, Other Items, and Trade

The data described from this section onwards are summarized in tabular format to provide a visual reference as a guide for reading and analyzing them (Table 3). Among the Ozieri lithic implements that probably did not survive past the Neolithic-Early Copper Age transition are stone vases. Although not very frequent, they have been found at several
Table 3. Prospectus of important trends in the change of key elements of material culture in Sardinian prehistory, ~4000-1900 BC

<table>
<thead>
<tr>
<th>Phase</th>
<th>Obsidian &amp; flint tools</th>
<th>Chopping/working tools</th>
<th>Grinding tools</th>
<th>Ceramic tripods</th>
<th>Other ceramic forms</th>
<th>Weaving implements</th>
<th>Metal items</th>
</tr>
</thead>
<tbody>
<tr>
<td>LN (Ozieri)</td>
<td>Microliths decrease and disappear</td>
<td>Hardstone axes decline</td>
<td>Frequent oval, flat grinding stones</td>
<td>Frequent cooking</td>
<td>Bowls</td>
<td>Loom weights, spindle-whorls</td>
<td>Incipient</td>
</tr>
<tr>
<td>4000-3200 BC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ECA (Post-Ozieri)</td>
<td>Peak in arrowheads and foliates</td>
<td>Increase in hoe-weights</td>
<td>More grinding stones, long and concave</td>
<td>Less (North)</td>
<td>+ jugs, bottles, beakers, strainers</td>
<td>+ frequent, complex, varied, large loom weights</td>
<td>+ ornaments: silver, copper (South)</td>
</tr>
<tr>
<td>3200-2500 BC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LCA (Monte Claro)</td>
<td>Knapping decline</td>
<td>Flaked adzes</td>
<td>Frequent (South)</td>
<td></td>
<td>+ large jars</td>
<td>Less metal overall + utilitarian, - silver, + tin</td>
<td></td>
</tr>
<tr>
<td>2700-2300 BC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beaker</td>
<td>Only arrowheads in burials</td>
<td>?</td>
<td>Frequent (serving)</td>
<td></td>
<td>+ beakers, serving vessels</td>
<td>Scarce (?)</td>
<td>+ utilitarian: knives, pins</td>
</tr>
<tr>
<td>2400-2200 BC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EBA</td>
<td>Hoe-weights ?</td>
<td>Fewer?</td>
<td>Frequent (drinking cups)</td>
<td></td>
<td>Beakers/ cups</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2200-1900 BC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

locations, which seem to cluster around the central western coast (Oristanese: at least five examples), with single finds in the north, south and eastern highlands. While Contu would assign most of them to the Middle Neolithic (Contu 1997: 201-203), they may well be of Ozieri age, and some contexts have been demonstrated to be Sub-Ozieri or Filigosa (Lugliè 1988, 1992; Melis 2000d: 71).

Besides a limited use of locally available various materials, most formal tools are made of obsidian and chert (Contu 1991), and their frequency varies depending on geographic proximity to the sources. While rich chert sources are located mostly in the North, obsidian originates only from Monte Arci near the central-western coast, which is of the four sources of the western Mediterranean along with Lipari, Palmarola and Pantelleria (Tykot 1997, 2002a). This explains the highest relative proportion of obsidian at sites in central and southern Sardinia, and its highest absolute quantity at sites close to the source (Figure 28). The relative frequency of different subsources within the Monte Arci obsidian source and the whole chaîne opératoire, are still being investigated. Current data are insufficient for a
conclusive overall reconstruction, because many assemblages come from surface collections at settlements with several phases of occupation, a problem affecting as well our knowledge of typological and technological change (Melis 2000d: 65). It seems that obsidian from SB sources, the most inconsistent as concerns quality and workability, is increasingly rare by Late Neolithic times, when SA and SC are preferred. At the site of Contraguda, recently excavated and radiocarbon dated (Boschian, et al. 2002), there is no SB obsidian (Lai, et al. 2006), and for some fairly standardized types reliably recovered in Ozieri layers, there is one instance of almost exclusive use of SA obsidian at Cuccuru s’Arriu, near Cabras (Lugliè and Sebis 2004). Obsidian from Sardinia is also found beyond the island shores, in Corsica, central and northern Italy and southern France, with a few specimens in Catalonia. This is evidence of a substantial trade connection, although the specific ways in which this material reached such distant areas is not well understood and certainly changed over time. Based on the current evidence, the main mechanism seems to be down-the-line exchange, from Sardinia to Corsica, and from Corsica to Tuscany, Liguria and beyond (Bietti, et al. 2004; Tykot, et al. 2005; Tykot, et al. 2003). On the other hand, there are some clues pointing to
different patterns of relative distribution among subsources that could indicate differential pathways. Obsidian SA, which is the subsource best represented in southern France, may have been transported through more direct maritime routes and may have carried social meanings more than just functional value (Binder and Courtin 1994; Robb and Tykot 2003).

Obsidian microliths, which were common since Early Neolithic times, decrease in frequency in the Ozieri phase, although average size of tools is usually small (Lilliu 1988a: 120). This phase is considered the peak in quantity and quality of obsidian tools; among the formal types are blades and arrowheads (Cappai, et al. 2004: 229). Arrowheads are more common in open-air settlements, less in burials, and rarely found in isolated findspots, which suggests they were standardized tools for frequent use (Lugliè and Sebis 2004). There is also some variation in their typology: foliate tools, pedunculated with or without notches (Ragucci and Usai 2004), often fully retouched, are common during the late Ozieri phase, and continue, possibly even increase, into the Sub-Ozieri (Melis 2000d: 67-69).

In the Early Copper Age of Post-Ozieri tradition there may have been a contraction in the circulation of obsidian, and in typological variation, with scrapers and drills rarer (Contu 1997: 213), although quality of tool-making shows continuity (Lilliu 1988a: 140; Melis 2000d: 69). An enhanced tool revitalization and reuse has also been documented at a Sub-Ozieri site in southern Sardinia, which has been seen as a symptom of a decrease in the procurement of raw material, and this confirms that its acquisition was not as easy as in the past (Cappai, et al. 2004). Chert usage was apparently discontinued, even at northern locations near the sources, where it previously represented over half of the assemblages (Melis 2000d: 67). Among the contexts that have been systematically studied and published, foliate points are considered the most distinctive element of this phase, especially in Melis’ groups C and D, which at least in the center and south of the island represent a later development along the lines of the Ozieri tradition (Melis 2000d: 67-68). While simple foliate points dominate the assemblage at Puisteris (central-western Sardinia, near Monte Arci, mostly Ozieri), notched points, with a tendency to more elongated profiles, are more frequent at several burial sites attributed to Filigosa and Abealzu cultures based on ceramic style (Atzeni 1985; Atzeni and Cocco 1989; Cocco and Usai 1988; Contu 1997: 211-212; Ragucci and Usai 2004).

In Monte Claro contexts of the later Copper Age, obsidian is still present but much decreased, with frequency still affected by proximity to the source. Blades and notched
arrowheads are the most common formal tools, and at one location close to a source, there seems to be a revival in chert use (Atzeni 1981: xlii; Contu 1997: 344-345; Lilliu 1988a: 160-161), which is part of a widespread trend underlying the presence of chert arrowheads and daggers at Bell Beaker burials in northern Sardinia and elsewhere in Europe (Ferrarese Ceruti 1981a: lxii). Obsidian and chert arrowheads, typically square-notched and pedunculated, are anyway the only kind of flaked stone tools still found in Bell Beaker contexts (Ferrarese Ceruti: 62; Lilliu 1988a: 189), and obsidian becomes really rare. The persistence of obsidian and chert for symbolic rather than functional reasons is demonstrated by its typology in the Early Bronze Age. While manufacture of formal, elaborate stone tools is virtually over, at Iscalitas, an Early Bronze Age burial pit recently excavated in southern Sardinia and included in our stable isotopic sample, simple flakes of obsidian, estimated to be per individual, were used as grave goods (Manunza 1998).

A specific stone tool type has been recognized in several large and roughly shaped adzes (Lilliu 1988a: 120), obtained by percussion from volcanic rocks, very common in the central-western lowlands and present also in the south. They have convincingly been attributed to the Sub-Ozieri and particularly Monte Claro phases (Lugliè 1999). Some of these adzes are similar to another category of tools, often found inside or in the vicinity of rock-carved tombs, and therefore considered to be carving picks (Contu 1997: 203; Lilliu 1988a: 141; Melis 2000d: 70).

Regarding the category of ground stone tools, and specifically grinding implements, only scanty and preliminary quantitative data are available for frequency and change in typology at one site (Neuville 1999). This is unfortunate, of course, because it would be very useful to understand changes in organizing and carrying out food production and preparation. Grinding stones were widespread throughout the sequence 4000-1900 BC, from Ozieri times onward, when the most common type is oval, flat on the grinding surface and convex in the bottom (Contu 1997: 203; Lilliu 1988a: 122). Conspicuous numbers are reported for some settlements in post-Ozieri Copper Age (su Coddu, sa Corona: Lilliu 1988a: 127, 141; Monte d’Accoddi: Melis 2000d: 69), although the data that can be safely referred to a single phase by stratigraphy are very limited (Melis 2000d: 67-69). In the Monte Claro phase, grinding implements appear to be very frequent, and generally larger than before (Atzeni 1981: xlii). They were commonly made of basalt or granite, constantly elliptical and elongated like New World metates, and range in size between 12 and 60 cm long by 5 to 23 cm. Their shape is
usually similar to that recorded at earlier times on Sardinia, but also, at least in settlements in the Campidano from Oristano to Cagliari, with both top and bottom flat-rectangular sections, and with concave, wide tops (Atzeni 1981: xlii; Contu 1997: 344-345; Lilliu 1988a: 164). At Biriai (Oliena), the only site where some systematic study on a small sample of grinding stones has been done, authentic middens of exhausted and broken *metates* can be seen tossed or reused in walls (Neuville 1999). As for the Beaker and Bonnanaro A phases, there is no mention of grinding stones in the literature, possibly related to the scarcity of open-air living sites: in fact, none is known for the Beaker phase (only sporadic sherds) and a few Bonnanaro A were discovered in the last twenty years (after Ferrarese Ceruti 1981b: lv-lvi).

Among these few sites, two fragmentary grindstones have been retrieved at Costa Tana (Santoni 1996), while from the isolated hut excavated at su Stangioni (Sardinian Southwest) only several pestles are reported but no grinding supports (Usai 1994: 242).

A type that has been interpreted mostly as utilitarian is the so called “*testa di mazza*”, or digging hoe, which is present but rare already in Neolithic Ozieri times. It becomes more common throughout the Copper Age phases, possibly during the Monte Claro phase (Contu 1997: 205, 344-345; Lilliu 1988a: 122, 140; Melis 2000d: 66). Their presence is also documented at the few investigated Early Bronze Age dwelling sites (Santoni 1996; Usai 1994), and are common during the Nuragic Bronze Age. Some scholars associate them with the polished-stone spheroid objects also found at several locations, which for their dimensions and refinement were more likely ornaments (Contu 1997: 207; Lilliu 1988a: 163-164). Apparently non-utilitarian were also the large polished stone rings of Early Neolithic tradition that are possibly found up to the Middle Neolithic, but definitely disappear in the Late Neolithic Ozieri culture (Contu 1997: 207; Tanda 1977).

The hardstone axes, from large to pendent-sized, already common, continue to be used in the Late Neolithic and Early Copper Age, although a gradual decrease in the amuletic type may have begun within the cultures of post-Ozieri tradition (Contu 1997: 207-208; Lilliu 1988a: 120-122, 140; Melis 2000d: 70; Moravetti 1989). The large, flaked, utilitarian type is still frequent in Monte Claro settlement contexts (Lilliu 1988a: 163-164), whereas the polished small specimens, differently from other areas of the Mediterranean (e.g. Portugal and Malta: Lillios 1997; Skeates 2002) are not very common in burials. The raw material for the polished small axes, mostly greenstone, was believed to be imported from the Alpine region, but alternative, local sources have been identified on the island, so that overseas
circulation may not have been necessarily involved as much. Nonetheless, at least the amulet-sized specimens are part of a common code of western Mediterranean material culture that is still alive during the Bell Beaker period, at least at an early stage (Ferrarese Ceruti 1981a: lxiv-lxv), becoming scarce in the Early Bronze Age (Lilliu 1988a: 344), and disappearing afterwards.

A specific, standardized type of large stone axe, traditionally known as “battle axe” (so called from the first interpretation of such specimens in the context of the Corded Ware culture of Central Europe), which is very common in northern and central Italy during the Gaudo and Rinaldone cultures, has been documented at a few locations in Northern Sardinia, and particularly at the temple-site of Monte d’Accoddi (Contu 1997: 315-316). This may be a testimony of a circulation of ideas reflected by and generated through material culture, which was in place following a north-south pattern and is shown by the distribution of several other artifactual classes.

A few types of stone (and bone) tools are typical of the Final Copper and Early Bronze Age phases, which in Sardinia correspond to the Bell Beaker and Bonnanaro A phases (ca. 2500-1900 BC): the so-called brassards, or wrist-guards. They are small plaques with two or more holes, which have been interpreted as protective implements for the archer’s arm holding the bow while shooting arrows (hence the name, in French); there is no compelling evidence, though, that this was actually the case. They certainly had some symbolic importance, since they were buried with the dead, likely secured to the body and/or clothing through strings. In Sardinia, they are for the most part roughly rectangular, and have one face flat and the other slightly convex, with great variation in the details. Some have straight sides, some concave, some long sides straight and short convex, or vice-versa (Ferrarese Ceruti 1981b: lxii-lxiii; Lilliu 1988a: 190-191). Their average length seems to increase between the Beaker phase and the Bonnanaro A phase (longest specimens are 11.3 cm in the former, 14 cm in the latter: Contu 1997: 371). These details have also been compared to mainland Beaker specimens, to detect possible similarities and, by inference, trade connections. It seems that, while types often coexist, straight sides are more frequent in southern France (Lilliu 1988a: 191), whereas concave sides are typical of Central Europe (Ferrarese Ceruti 1981a: lviii). Also attributed to these contexts are turtle-shaped buttons and buttons with v-shaped perforation (Atzeni 1996a: 402; Ferrarese Ceruti 1981a: lxiv; but see Lilliu 1988a: 194-195).
Several elements, together with the change in pottery style preferences reflected by the revival of tripods in a different form, by metopal decoration, and other typical ornaments found in burials, contribute to the same reconstruction. In an earlier Bell Beaker phase, Sardinia was part of a cultural area having its center in the coastal western Mediterranean, particularly the Gulf of Lion between Catalonia and Languedoc-Roussillon. In a later Bell Beaker phase, the most intense communication seems to have shifted to central Europe, via northern Italy (Atzeni 1996a: 400-406; Ferrarese Ceruti 1981a: lxv), a link that remains strong in Early Bronze Age times, with the post-Beaker culture of Polada 1. It also seems that within Sardinia the earlier phase is more intensely represented in the northwest (Sassari-Alghero area), which is also the closest to the north-western Mediterranean shores, whereas the later phase with the development of more regional elements is best represented in the southwest (Atzeni 1995). It is also significant that the first Beaker phase is closer to the mainland models, while the second partakes of the general taste but has original stylistic outcomes: this would fit a model of direct overseas contact in the first phase, followed by a more mediated circulation of materials and people, possibly overland or through coastal sailing. However, in the second phase the scanty evidence from Corsica (Lemercier, et al. in press) suggests some more complex explanation.

Bone tools, for the most part simple and not specialized, are found in moderate numbers especially in settlements, and occasionally in tombs, throughout the period ca. 4000-1900 BC. Projectile points are documented in the Copper Age, along with common pins and various tools (Melis 2000d: 79), but items made from this material have not preserved as well, and have not received as much attention as pottery and lithics.

The miscellaneous category of ‘personal ornaments’ is documented at all times but in different quantities and materials, which include bone, shell, teeth, stone and metal. Beads, for the most part likely to be elements of necklaces and other personal items, are largely made of shell. Shells found at settlement sites are commonly interpreted as refuse, whereas those provided with suspension holes, or modified in shapes other than natural, commonly found in burial contexts, can be considered beads. They are not as common in the Ozieri phase, and even less along the post-Ozieri and Monte Claro assemblages (Contu 1997: 213, 278, 346). Many examples from the north, when they come from reused tombs and particularly if they were not excavated by modern standards over fifty years ago, cannot be assigned to one specific phase. It is especially in the last two phases under investigation, the
Bell Beaker and Bonnanaro A, that personal ornaments reach an unprecedented appreciation, with consequent archaeological representation, not recorded before, nor afterwards until historic times. This is in direct relationship with the Bell Beaker phenomenon; in southern France this sort of aesthetic taste is remarkable (Ferrarese Ceruti 1981a: lxiv; Lilliu 1988a: 192), and this is probably where the new way of perceiving and displaying one’s bodily image – in the tomb - originated. It is therefore presumably not due to chance that these bead assemblages appear wealthier in the Northwest (Lilliu 1988a: 193), which as discussed above has been recognized as the area where stylistic expressions more closely reflect Catalanian-French models.

Shell beads can be just perforated shells otherwise left untouched, or more defined shapes, and are both made from seashells and landsnails. Teeth can be human, but more often are wild boar tusks and fox or dog canines (Lilliu 1988a: 193). Atrophic deer canines are typical of the Early Bronze Age Bonnanaro A phase, representing another common element with the Polada I culture of northern Italy, and significantly their distribution is centered in the Sardinian South (Ferrarese Ceruti 1981b: lxxv; Lilliu 1988a: 345). Well-documented examples of such assemblages that include pottery, beads, metal and more are Padru Jossu (Ugas 1982b) and Iscalitas (Manunza 1998), which will be discussed more in detail in the description of the burial contexts of the individuals sampled for stable isotopic analyses.

4.4. Metal

The presence of metal items has been observed to increase generally as the traditional Neolithic stone tools decline. Specifically, the frequency of flaked implements made of obsidian and chert on the one hand, and of copper on the other, has been read in terms of an inversely proportional relationship, as if the decline of obsidian was caused by the spread of metalworking. Concerning Sardinia, the logical contradiction that stone tools had already been much scarcer while metal tools did not appear to be yet very common has been highlighted (Lilliu 1988a: 344). Along the assumption just mentioned, recycling of metal has been considered the cause for such apparent underrepresentation. In reality, metal circulation is poorly documented and even less is it understood in terms of the social mechanisms underlying such circulation and use. The patterns of metal presence seem to be complex rather than linear, as is clear from the trends briefly summarized below. An updated list of all
metal finds at prehistoric sites up to the Early-Middle Bronze Age transition has recently been published (Usai 2005b); this is the main reference for the following data.

Typologically, the diversity of metal items varies remarkably over time. In Ozieri and Sub-Ozieri contexts, most broad categories of objects are already represented, even though sporadically or as single cases (Lo Schiavo 1989; Usai 2005b: 258-260), and mainly in the South: copper and silver rings and wires, copper pins, grains used as beads, silver foil, and knives. This demonstrates, despite the scarce numbers, knowledge of all main physical properties of such metals, and active experimentation of the basic metalworking techniques that imply this knowledge, even though Lilliu (1988a: 166) hypothesized that the defective technology in Monte Claro knives might be evidence for incipient metalworking several hundred years later.

While copper smelting is likely an innovation imported from outside, the early chronology and substantial diffusion of silver items (Figure 29), which declines with the rise of copper, seems an indigenous development. In the following phases of the Post-Ozieri tradition, the copper axe and the bracelet, both of copper and silver, are documented. Bracelets and rings are the most common metal item found in burials at this time, declining afterwards, when different ornaments come into fashion (Usai 2005b: 261-263). In this Early

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Figure 29. Barchart showing the relative frequency of different metals in the phases examined (raw data are after Usai L. 2005b), with number of artifacts on top of each column. In the last two phases, artifacts defined as copper, bronze-copper and bronze are grouped together, since no analyses have established real proportions. Note the importance of silver in the first phases and its decrease and disappearance by the Early Bronze Age, and the use of lead especially in the Monte Claro phase.
Copper Age phase we also have the first evidence for the working of lead, both in the form of clamps to repair broken pots and of smelting slag, whereas circumstantial evidence for earlier periods may be represented by similar holes for repair (Ugas 1993a).

A peculiar type of copper knife, leaf-shaped, long between 8 and 20 cm and with a thin tang, is associated with Monte Claro pottery and other material culture at several locations in the South, and is sharply different from the previous triangular knives/daggers with holes for rivets (Lami 1999). The latter have abundant parallels in the western Mediterranean area, first and foremost in the Rinaldone culture of Central Italy, which that the former type lacks. While there may be antecedents in unusual foliate points (Usai 2005b: 262), their best matches are interestingly found in the eastern Mediterranean (Lilliu 1988a: 166). In the Bell Beaker and Bonnanaro A phases, knife-dagger types realign with western models from Catalonia and France, and from central Europe and northern Italy. Their size, though, is reduced to no more than 15 cm, compared to both previous Sardinian specimens and to the mainland models (Ferrarese Ceruti 1981a: lxiii; Lilliu 1988a: 191-192).

While axes seem to be present but not common, items defined as pins and awls are found throughout, and in higher numbers especially after the mid-3rd millennium. In the Beaker phase, they are close to northwestern models, and particularly to southern France (Lilliu 1988a: 191-192). In the following Early Bronze Age, which in other aspects is strongly associated with the Alpine region, there are metal tools that find their best comparison in Argaric Spain, whereas nothing similar is found in Polada contexts of northern Italy (Lilliu 1988a: 343). This may be evidence of contacts following different routes and exchange partnerships for specific items, and/or autonomous local elaboration of aesthetic canons, although it may belong to a somewhat later phase of transition into the Middle Bronze Age.

Evidence of metalworking itself is provided by a few specimens interpreted as crucibles, all recovered in Post-Ozieri contexts (Contu 1997: 141; one possibly Monte Claro: Lilliu 1988a: 164). If similar items were used in the following centuries, as presumably was the case, evidently these were not markers that the value system of those communities considered appropriate to accompany the dead.
Looking at the general trend of the frequency of metal objects (Figure 30), some commonly held opinions about the development of metallurgy in Sardinia can be questioned: first, the gradual, progressive intensification in the use of metal. It appears that a first increase occurred in the Early Copper Age Post-Ozieri contexts. The Monte Claro phase, rather than representing the inevitable take-over of eastern folks bringing ‘superior’ metallurgical skills (as in Foschi Nieddu 2001), represents a decline in metal objects’ frequency. A second peak is to be connected with the Bell Beaker contexts, while the following phase is again a decline in the circulation of metal items.

If typology over time is considered (Figure 31), many types are sporadically represented, in minimal numbers, in the Ozieri and Sub-Ozieri periods. A dramatic increase in metal body ornaments occurs in the Filigosa-Abealzu contexts, mostly represented by rings and bracelets, with some sharp-edge tools and a few awls and pins. The latter become more common in the Monte Claro phase, which is partially contemporary with the chronology of Bell Beaker assemblages, and find large usage in this phase and during the

![Figure 30. Barchart showing the frequencies of metal artifacts by cultural phase in Sardinian prehistory, calculated as absolute number of items recorded (Usai L. 2005b) divided by time of duration of the phase, according to the current chronology (Tykot 1994). This is the index on the y axis, whereas absolute number of artifacts is on top of each column. It appears that metallurgy did not have a constant, progressive intensification as previous literature assumes, but a first increase in the Post-Ozieri contexts, and a second peak in the Bell Beaker contexts. The contexts with Monte Claro and Bonnanaro A pottery represent instead a recession in metal use](image-url)
Figure 31. Bar chart showing the number of different types of metal artifacts by cultural phase in Sardinian prehistory (raw data after Usai L. 2005b). Pins and awls seem to reflect a different clothing repertoire involving woven wool items and pins, as opposed to leather and linen accompanied by silver jewels as in the indigenous tradition.

Bonnanaro A phase. In the Beaker and Bonnanaro A assemblages, a higher proportion of knives-daggers are also documented, with a reduction in the overall diversity of types in the last period.

Items with no practical use, such as rings, bracelets, and rare metal foil, were the majority of recovered specimens during the Ozieri tradition phases (Figure 32). Associated with the appearance of Monte Claro pottery and the end of the long tradition of female figurines is a sharp proportional increase in copper sharp-edged tools and pins/awls. The Bell Beaker assemblages reflect similar ratios, with a further increase in the frequency of pins/awls and other personal items, which mirrors the elaboration of bodily appearance reflected in the large use of pendants and beads made of shell, stone, and bone. Finally, purely decorative items almost cease to be documented for the Bonnanaro A phase, which corresponds with the absence of decoration on pottery as well. These changes seem related
Figure 32. Barchart showing the relative frequencies of different types of metal artifacts by cultural phase grouped in broad categories. Raw data after Usai L. (2005b). Absolute number of artifacts is on top of each column. The groups are arbitrary to some degree, but they are working approximations, considered useful in order to visualize long-term trends. Blades are labeled as ‘war and sacrifice’ items rather than utilitarian, since most tools were still made of stone. ‘Utilitarian’ includes pins and awls, and ‘ornament’ all items with no obvious function as manual tools. Social, symbolic and practical meanings are of course attached to all types in different ways, and impossible to isolate to transformations in status symbols, or rather identity markers, as they are presumably connected to both the ways of displaying and constructing social inequality, but also different material instruments to define gender identities and roles, as shown by further elements described below. This and other lines of evidence will be used for a tentative outline of such developments in the synthesizing concluding section of this chapter and in the final integration in chapter 8.

4.5. Buildings and Architectural Remains

4.5.1. Settlements

Very little synthetic works appear in the literature concerning the settlements themselves, their type of location within landscape units or their architectural features in a comparative perspective. A short synthesis summarizes the data available for the Copper
Age, including both Post-Ozieri cultures and Monte Claro (Melis 2003a). The density of sites is important as an indicator of demography, if studied carefully taking into account potentially different patterns of concentration-dispersion versus absolute numbers, and of archaeological visibility. As explained above, some styles are easier to identify for a denser frequency of decorated, diagnostic pottery. Even if it is a simplification which does not consider many variables, a chart of the index obtained dividing the number of sites (as summarized in Lilliu 1988a) by the time each culture lasted (according to absolute chronology as in Tykot 1994) gives a rough visual estimate of these data (Figure 33).

The representation of different cultures in caves, burials and open-air sites, based on current knowledge, is remarkably varied in different periods. While caves may have been in some instances ceremonial, burial and living sites, assuming the basic opposition between funerary/caves on one hand, and open-air on the other there was a sensible oscillation in the ratios (Figure 34). In reality, for Late Neolithic Ozieri there are no attempts after Lilliu (Lilliu 1988a) to take into account the huge mass of data obtained if the approximately 2500 rock-

![Figure 33. Barchart showing the density of sites by cultural phase. Raw data after Lilliu (1988), calculated as the total number of known sites divided by the time of duration of the phase, according to the current chronology (Tykot 1994). This index (on axis y) represents a working approximation, considered useful as a proxy for population density and/or population nucleation: in fact, it includes burials, open-air sites, cave sites. Consistent bias is due to the different decoration on pottery, which makes certain styles inherently easier to identify. See text for discussion.](image-url)
carved tombs, and the countless findspots of diagnostic pottery (Campus 1997; Dettori Campus 1989b; Lilliu 1988a: 73-82) are considered. Also, a number of caves could have been dwellings particularly in the last phases, which show scarce evidence of settled life.

The following Copper Age Filigosa and Abealzu phases are more represented by burials (Depalmas, et al. 1998: 357-363; Melis 2003a: 737), although several factors need to be considered. The identification and recognition of the Sub-Ozieri aspect is increasingly pointing out that many sites earlier labeled as Ozieri had longer spans of occupation into the Copper Age; moreover, a systematic bias must be taken into account, since Ozieri pottery is often decorated, making even the smallest sherd diagnostic, whereas Copper Age Post-Ozieri ceramic aspects can be reliably recognized from sherds of identifiable shape (rims, bottoms, handles). A similar bias concerns in the Later Copper-Early Bronze Age the identification of Monte Claro pottery in comparison with undecorated Bell Beaker and especially Bonnanaro A pottery. This may partially account for the scarce number of open-air sites attributed to Bonnanaro, which is characterized by almost totally undecorated pottery. Keeping this in mind, we can accept, until we have evidence to the contrary, at least the overall trends, while being aware that they may be overemphasized.
Architecturally speaking, the most typical feature of Ozieri and Sub-Ozieri settlements of the southern lowlands is the so-called *fondo di capanna*, or hut bottom. They appear as lenses of soil of different color with more or less dense elements of material culture, food refuse, and hearths. These have been traditionally interpreted as shallow pits that were covered by perishable walls and roofing. They are consistently round or oval, with a few possible sub-rectangular examples (Contu 1997: 109). This is the current reconstruction, since the only surviving evidence of roofing is the occasional find of clay with vegetal impressions. At su Coddu (Selargius), there is evidence that in the Sub-Ozieri phase pits were deeper than before (Ugas 2000; Ugas, et al. 1985; Usai 2005b: 258). There is no strong evidence for stone wall foundations in the southern lowlands: possibly some huts had them at some locations (Atzeni 1958). There is a slightly better documentation regarding houses with stone foundations likely belonging to the final Ozieri-Early Copper Age, which match the reconstructions based on the architectural elements reproduced in the *domus de janas* (Tanda and Depalmas 1997). These houses have a rectangular plan with a semicircular room where the entrance is placed. Several internal stone alignments partition it into several rooms. To this point, they have only been surveyed and mapped, not excavated, but a great deal of information is expected from them.

Several rectilinear huts have been investigated in the village around the temple of Monte d’Accoddi, where interestingly the lower layers showed at least one circular hut (Contu 1997: 304-306). A plan similar to those in Serra Linta, which possibly dates to a late aspect of Ozieri, was well documented in the Monte Claro village of Biriai (Oliena). There are also stone foundations, but different construction details. In this case, full excavation of several of these houses gave also material culture evidence of a very homogeneous phase (Castaldi 1999), which has been recognized elsewhere (Fadda 1997). As prior to this period, the upper structure must have been made of wood, planks and clay, probably with vegetal roofing. A circular hut with higher walls has been excavated at sa Corona, Villagreca-Nuraminis (Lilliu 1988a: 203), where Monte Claro pottery was found, but unfortunately no detailed excavation records have ever been published.

The building expression of the Monte Claro pottery users is divergent in the two halves of the island: in the center-south, there are more villages with no stone architecture, in the north there are stone foundations and megalithic walls surrounding some of the houses or special areas. These megalithic structures are commonly defined ‘fortifications’, based on the
traditional interpretation of the examples in France and Spain. Whether defense was the real concern, or rather some less strictly functional meaning, remains unexplored. In the Italian peninsula, a rise in weaponry symbolism has been found not to match trauma frequency in skeletal remains, and even if there was a clear positive correlation, there is not necessarily a single ‘right’ answer (Robb 1997, 1998). Certainly megalithic walls imply a great labor effort, as they can be over a hundred meters long, about 2-3 m thick and as high. They are built on a standard morphological feature, wide, roughly flat hilltops, stretching to enclose the side where the slope is gentler, while leaving untouched the naturally defended steeper side (Moravetti 1998a, 2001). At Monte Baranta (Olmedo), the only one that has been investigated and published (Moravetti 2000, 2002), no significant patterns have been recognized in the distribution of material items, but a megalithic circle defined by menhirs was right outside, in front of the wall, and a smaller, thick, tower-like enclosure was in the inner part of the walled area, near the edge of the ravine. It must be said that the sharp distinction within Monte Claro contexts between the southern Campidano lowlands with little stone architecture, opposed to the north with stone villages and walls, had to be corrected in light of the recent documentation of similar villages in the Southwest (Canino 1998; Usai 1997; Usai and Santoni 1998), where prior evidence consisted essentially in cave finds (Atzeni 1987).

No dwelling sites are known with substantial Bell Beaker cultural materials, and their partial chronological and geographic overlap, but not clear association with, the Monte Claro assemblages (only a few sherds have been found within Monte Claro settlements) points to a complex relationship between the two. Differently from other areas in southern France, where a differentiated acceptance of Bell Beaker objects has been well documented (Lemercier 1998, in press), no clear patterns have yet been pinpointed in Sardinia. The scarcity of finds in open-air sites has led to the inference that, rather than pottery for daily use, Beaker vessels may have been in Sardinia essentially an element of funerary custom (Ferrarese Ceruti 1981a: lv-lvii).

The picture was similar for the Bonnanaro A phase (Ferrarese Ceruti 1981b: lxvii-lxviii), until the 1980s and particularly the 1990s. Although a number of sites yielded materials that could possibly be attributed to the Early Bronze Age (Webster 1996: 66-67), no more than a few sites yielded stratigraphically reliable evidence of artifacts in a non-burial context. Besides the site of Matzeddu (Ugas 1992), Noeddos (Trump 1990: 3-18) yielded
radiocarbon dates covering the Early Bronze Age, although the relationship with the stone-built structures is not clear (Webster 1994). The site of Costa Tana was only tested (Santoni 1996), so that only one single-phase Bonnanaro A site has been excavated, at su Stangioni (Portoscuso). It was an isolated, roughly built, and irregularly rectangular hut, possibly with a cobbled area in an open space in front of it. Significantly, the excavators recovered the largest vessels known as yet for this ceramic aspect, which is otherwise known mainly from tombs (Usai 1994).

Here I am not considering the site type known as corridor-nuraghi or protonuraghi (Lilliu 1988a: 208-214), a name defining a stone platform with a corridor and one or more small rooms within the body of the structure, which are considered the architectural antecedent of the Bronze Age towered buildings known as nuraghi. While previously considered to date to the Early Bronze Age, there is growing evidence that the large majority date instead to the Middle Bronze Age, or in a few cases to the transitional phase known as Sant’Iroxi, otherwise known as Bonnanaro A2 (Perra 1997: 2-4; Ugas 1990; 1999: 139-140, 169-173). This phase is also not included in this dissertation.

4.5.2. Ceremonial Sites

Evidence for ceremonial sites during the Ozieri period is scarce. Besides caves, which were used for ritual purposes at least in some cases (Loria and Trump 1978), a possible example may be identified at Puisteris, Mogoro (Lilliu 1988a: 86): a simple slab-altar on the top of the hill where the village lies. It seems that in the 4th millennium the focal point of ritual activity was increasingly the burial area. Related to this is the sporadic presence of abnormally enlarged vestibular rooms within the funerary rock-carved structures, which is quite rare, and has been interpreted as possibly housing ceremonies beyond the usual cult of ancestors (Montessu, Villaperuccio); their size causes some archaeologists to refer to them as ‘chapel-tombs’ (Atzeni 1972), and of course rather than something more, this might indicate precisely how important for those communities the cult of the dead was.

A few cases of large scale ceremonial sites are found in the Copper Age: Monte d’Accoddi and the sanctuaries at the Monte Claro villages of Biriai and Monte Baranta. The first is a unique structure in the whole central-western Mediterranean; although some comparisons have been made, its clear otherness is exemplified by its being commonly
defined as a ‘ziggurat’. In fact, the closest examples for monumentality and spatial arrangement were, for Old World archaeologists, Near Eastern temples (Mesoamerican cases are probably more similar): a rectangular, truncated pyramid with a long access ramp and a temple on top. The scale is much smaller, though, and the stonework quite rough (Contu 1997: 287-302). Different construction phases were recognized, with an earlier, lower platform, replaced by a taller and wider one that contained the first, again in a sequence of incorporations as we see in the enlarging of Mesoamerican pyramids.

While the village, mostly Ozieri and Sub-Ozieri, has pottery dating back to the Early Neolithic, the phases of temple-building are attributed to the Filigosa phase, within the uninterrupted Post-Ozieri tradition. A village with menhirs, and an altar-slab existed before the temple, while at least one round hut, and several rectilinear huts with stone foundations were built all around the temple at later times, in the very final phase of the Post-Ozieri tradition. The sudden, apparently violent, end of occupation is shown by the remarkable preservation of the only excavated hut, which still contained all the utensils abandoned in situ (Contu 1997: 306-309; 2000: 55-56). While no further details are needed here, it is important to emphasize the uniqueness of this site (Tiné and Traverso 1992b). Also, it is significant that this site is in the middle of the Sardinian Northwest where the large majority of complex, elaborate, decorated domus de janas are concentrated, and where the highest number of perforated stone figurines (see below) were found. The association is presumably all but random, suggesting an increase in intensity and complexity of socio-cultural expressions.

In the following Monte Claro phase, the walled enclosures discussed above had presumably also a ceremonial function; unfortunately, nothing significant has been recovered at Monte Baranta, where only scarce sherds were retrieved: Moravetti (2000: 53-57) infers that occupation may have been very short after the building phase. The standing stone circles indicate formalized ritual activity; Castaldi (1999) believes that the one at Biriai may have been an astronomical calendar; interestingly, both at Monte Baranta and Biriai, some of the menhirs were brought to the site but never erected, which seems to support the idea that occupation was possibly relatively short, and construction itself may have stopped abruptly. Following these events, there is no more evidence for clearly ritual areas associated with Bell Beaker material culture, nor with Bonnanaro A.
4.5.3. Burial Sites

4.5.3.1. Rock-Carved Tombs

From this section onwards, a reference scheme representing a synthetic summary is provided (Table 4). Architectural remains in Neolithic and Early Copper Age Sardinia are for the largest portion made up of burials (Contu 1997: 115). This is probably due to practical reasons: the materials used in constructing dwellings were mostly perishable, with a few exceptions. The relationship between open-air sites and tombs becomes more articulated geographically and possibly chronologically for the Later Copper Age users of Monte Claro pottery, with more evidence for domestic stone architecture. Bell Beaker and Bonnanaro A cultural materials are for the most part again recovered in burial contexts.

The most important type of burial that had intense and widespread diffusion in the Late Neolithic and Early Copper Age on the island is the *domu de janas* (pl. *domus de janas*). This term is taken from one of the many words, according to the different local variations of Sardinian, used by the communities to indicate rock-hewn cavities that are clearly not the work of nature. It means “houses of the *janas*”, the latter term indicating small-sized feminine supernatural beings part of the traditional, syncretistic cosmology. This is just one of the several terms that in different regions of the island are used for the same concept. In scholarly practice, instead, the Latin term (sing. *domus*, used also as plural) is widespread.

Since the association with the Ozieri culture is well established, they are, besides pottery, the best indicator of Late Neolithic human occupation of the landscape. Opposed to a number of sites known from pottery finds that can nowadays be estimated over 300, there are roughly 3000 rock-carved tombs known on the whole island (Tanda, personal communication), although there is no comprehensive ‘catalog’ since the list compiled by Lilliu (1988a), who counted 165 total sites. Most of tombs, based on current knowledge, are to be considered associated with the societies that made Ozieri pottery. However, due to their long history of reuse after the first phase, those where intact Ozieri contexts were found are extremely rare, and not all those excavated have been published (S. Benedetto, Iglesias, sampled for human bone isotopic analyses, and tomb 2 at Serrugiu, Cuglieri: Contu 1997: 119; Lilliu 1988a: 91).
Table 4. Synthetic prospectus relative to the trends in site type, landscape archaeology, burial and ritual in prehistoric Sardinia ~4000-1900 BC.

<table>
<thead>
<tr>
<th>Phase</th>
<th>Landscape occupation</th>
<th>Typical living site</th>
<th>House building</th>
<th>Ceremonial sites</th>
<th>Burial type</th>
<th>Burial customs</th>
<th>Figurative art</th>
</tr>
</thead>
<tbody>
<tr>
<td>LN (Ozieri)</td>
<td>Alluvial lowlands, coastal lagoons</td>
<td>Open-air village</td>
<td>Wattle-&amp;-daub (perishable), sunken floor</td>
<td>(rare if any)</td>
<td>Rock-carved tombs (domus de janas)</td>
<td>Collective, dismembered remains</td>
<td>Bull heads, human figures and statuettes earlier type</td>
</tr>
<tr>
<td>4000-3300 BC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ECA (Post-Ozieri)</td>
<td>Continuity, + highlands (North)</td>
<td></td>
<td>Continuity (also stone foundations) + sunken floor</td>
<td>Possibly spaces near tombs, menhirs, cupmark-altars [unicum: flat-top pyramid, North]</td>
<td>(domus de janas), dolmens</td>
<td>Offerings/Meals</td>
<td>Diffusion bull head, human figures and on rock, statuettes later type (North), statue-stelae (center-West) sculpture &amp; painting</td>
</tr>
<tr>
<td>3300-2500 BC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LCA (Monte Claro)</td>
<td>Hills &amp; lowlands no coastal; hilltops</td>
<td>Open-air large village (cave?)</td>
<td>Wattle-&amp;-daub, + stone foundations</td>
<td>Wall-enclosed high places; menhir circle</td>
<td>Shaft-tombs (South), reused domus de janas; caves; added corridors elsewhere</td>
<td>Single burial, articulated (South); collective, with distinctions elsewhere</td>
<td>None [leaflet motif on pottery? Abstract bas-relief?]</td>
</tr>
<tr>
<td>2700-2300 BC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beaker</td>
<td>Occupation break, Mostly lowlands</td>
<td>Caves?</td>
<td>?</td>
<td>None</td>
<td>reused domus de janas, reused dolmens, caves, cists, pits</td>
<td>Collective, also with distinctions, occasionally single articulated individuals</td>
<td>Offerings/Meals</td>
</tr>
<tr>
<td>2500-2200 BC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EBA</td>
<td>Lowlands, + highlands</td>
<td>Caves? [Open-air farmstead?]</td>
<td>?</td>
<td>[wattle-&amp;-daub with stone foundations]</td>
<td>None</td>
<td>[maybe open burial pits?]</td>
<td>None</td>
</tr>
<tr>
<td>2200-1900 BC</td>
<td></td>
<td></td>
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<td></td>
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</tr>
</tbody>
</table>
The custom of carving burials in the rock was not new to the Late Neolithic: there are examples in the 5th millennium (Santoni 2000), but sporadic compared to the standardization and diffusion in Ozieri times, when the alternative types - mostly cave burials and increasingly common megalithic burials - are marginal. Domus de janas are carved in different rocks over the island, proving that the choice was not only dependent on the available geo-lithological substrate. If a trend can be recognized, it is instead visible in the distribution of megalithic burials (dolmens and chambered tombs), which are denser in the north and in the highlands. The only area where they are very scarcely documented is the northeastern tip of Sardinia (Gallura), close to Corsica, where apparently megalithic traditions were more rooted early on, apparently before Late Neolithic underground burial tradition begun.

Domus de janas are varied in their solutions as concerns plans and articulation in different rooms, a variation that shows also a spatial patterning: generally, plan complexity is mostly found in the Northwest, as is complexity in decoration and density of occurrence (Tanda 1995b). They are often found in clusters, at a few meters distance from one another, up to around 40 tombs, each containing several rooms (e.g. Anghelu Ruju, Alghero; Montessu, Villaperuccio: Contu 1997: 118-119).

Their plan (Figure 35) ranges from simple, single-cell tombs, as small as 1 by 1.5 m, with an immediate threshold between burial chamber and outside space, to more complex types of up to 20 rooms and stretching over areas as wide as 17 by 20 m, about 340 m² (Contu 1997: 128-129). More often there is a vestibular room, called anticella, which is a liminal space between the outside world of the living and the burial chamber. In the most complex types, the second room is as well transitional, large and spacious, and represents the center where all the openings of the real, smaller burial chambers are located, arranged radially. The shape of the rooms also varies, from circular or elliptical to rectangular, besides several irregularly-shaped examples (Santoni 1976; Tanda 2000).

Approximately 70 domus de janas, concentrated in the Northwest, show decorative elements that imitate open-air dwelling architecture, mostly in the more ‘social’ rooms, the anticella and the main chamber (Contu 1997: 111). Besides being relevant per se, this
Figure 35. Examples of Neolithic-Copper Age rock-carved tombs (domus de janas) from central-southern Sardinia: top left: Scaba ‘e Arriu; top right: San Benedetto, tomb II; bottom left: Santa Caterina di Pittinuri; bottom right: Cannas di Sotto, tomb 12 (only partially excavated). Skeletal remains of several individuals from these tombs were analyzed for stable isotopes (see chapters 6-8). Black ovals indicate the position of crania within the tombs. Images are elaborated by Luca Lai based on the original maps: respectively Usai 1998: 51, with permission from the Soprintendenza Archeologica per la Sardegna, formerly per le Provincie di Cagliari e Oristano; Atzeni 2001a: 27, with permission from the author; Cocco and Usai 1988: 19, with permission from Scorpione publishers; Santoni and Usai 1995: 72, with permission from S’Alvure publishers.

feature is important for the religious meanings and the social aspects it may reflect (Cámara Serrano and Spanedda 2002; Contu 1997: 111-113; Tanda 1984: 52-53), and for the understanding of the domestic structures that were built above ground with perishable materials and are not preserved. Roofs built with sloping planks over beams stretching the
length of the roof, pillars sustaining the ceiling, architraves and poles, and several other elements, including what is interpreted as furniture (Contu 1997: 113), allowed the reconstruction of nine types of hut plans, representing different combinations of semicircular and rectangular rooms with single or double sloped or conical roof (Depalmas, et al. 1998: 352-353; Tanda 1984: 54-55). The labor and organizational effort these magnificent tombs entail is substantial. This, coupled with the recurrent association of themes at several locations, has been interpreted as reflecting an authentic class of itinerant artists-artisans, working in teams and bringing their skills to different communities (Tanda 1984: 52), upon request by chiefs and leaders (Lilliu 1988a: 92-93). While, based on present knowledge, it seems that the institutionalized social differentiation implied in the word ‘chief’ is unlikely to have been in place, it is not unreasonable that artisans known for their skills were called for services from nearby communities.

As has been pointed out, the most complex outcomes of burial carving and decoration seem to have occurred at the latest phases of the Post-Ozieri tradition; most areas show a much smaller number of tombs, smaller number of rooms per tomb, and little or no decorative elements, whether they are architectural or cult-related (see the next section). These elements are also associated with oven-shaped, circular or oval plans for each room, which are also considered somewhat earlier. Besides the rectangular or trapezoidal plans documented in late Filigosa-Abealzu phases at Monte d’Accoddi, it is undoubtedly significant that the Monte Claro hut plan recorded at the village of Biriai corresponds perfectly with the combination of rectangular and semicircular shapes juxtaposed (Tanda 1984: 54-59). This may therefore be a general phenomenon, spanning the island at later times across the boundaries drawn by pottery styles. Geographically, more circular taste is found at tombs in the South, Southwest and in the western and southwestern flanks of the Gennargentu, the central mountain massif (Contu 1997: 127). This patterning appears highly significant, since rather than following altitude or valley watersheds, describes a radial divide around the Gennargentu that fits the subdivision in sectors associated to transhumance as described for the early 20th century (Le Lannou 1941: 174-180), with shepherds from the northern flanks moving seasonally mostly northwest, and from the southwestern flanks moving south.

The custom of burying the dead in rock-carved tombs lasted up to the Early Bronze Age (Bonnanaro A), but the tradition itself of carving them did not die at the end of the Post-
Ozieri material culture complex. An evolution, likely related to the influence of megalithic *allées* and chambered tombs, already took place within this tradition: at several locations in the Northwest there is evidence for more elongated ossuary-rooms, with tombs’ rooms preferentially arranged in length or on the two sides of the central room, rather than in a radial pattern. One type of elongated plan, apparently dating to the late Filigosa/Abalzu phase (Ferrarese Ceruti 1991: 88-89; Santoni 1976), is named ‘T-tomb’ for the presence of two cells on the sides of the central room in a T-shaped arrangement. Access is through a corridor, or *dromos*, which makes the entrance more monumental, in some cases with a large stairway, as at Anghelu Ruju near Alghero, and often with a semicircular *anticella*, the vestibular space typical of Ozieri tombs. These elements, together with the occasional presence of figurative petroglyphs, are considered indications of Early Copper Age occupation of the tomb (Lilli 1988a: 134).

The burial customs associated with Monte Claro pottery show remarkable geographic differentiation, as did most aspects of material culture. The only area with newly carved Monte Claro tombs is the southern lowlands around Cagliari (Figure 36). Everywhere else, grave goods and skeletal materials are found inside tombs of the Ozieri tradition or natural caves. The ones around Cagliari show characteristics that are relatively original in Sardinia,

![Figure 36. Example of plans of rock-carved tombs of Monte Claro period: left, Via Basilicata, Cagliari; right: Padru Jossu, possibly a pit rather than underground room. Skeletal remains from both burials have been analyzed for stable isotopes (see chapters 6-8). Images are elaborated by the author based on the original maps: respectively Arzeni 1967, p. 161, Fig. 3, with kind permission of the Istituto Italiano di Preistoria e Protostoria, and Ugas 1998: p. 261, Fig. 1, with kind permission of the Autonomous Province of Trento, Italy.](image-url)
consisting of a vertical shaft and horizontal oven-shaped rooms, often in groups, with one or a few articulated bodies (Atzeni 1985; Usai 1989b). The few close examples, which are rare, are around Oristano in the Middle Neolithic (Cuccuru s’Arriu, Bonu Ighinu phase: Santoni 2000), and sporadically across the island in the Ozieri tradition (Serra is Araus, Corongiu-Pimentel, Marinaru: Lilliu 1988a: 230; Cannas di Sotto: Santoni and Usai 1995). However, their plans are not as standardized, nor their distribution as clustered, as the examples near Cagliari. The single rooms with shaft access were sealed with small stone walls, and bodies were consistently laid still articulated, flexed on their left side (Atzeni 1967, 1985).

Elsewhere, both in domus de janas and natural caves, there is no evidence for rock-carving, but instead the intervention associated with Monte Claro pottery consists in the addition of slabs to create megalithic corridors before the entrance (Atzeni 2001b; Foschi Nieddu 2001; Pitzalis 1996: 206-218; Usai 1998), or the circumscription of a space, or cist, within a larger room (Ferrarese Ceruti and Fonzo 1995; Lilliu 1988a: 146-148).

I only mention here the phenomenon of the domus de janas with architectural façade. It is geographically confined to the Northwest, mostly the area around Sassari, and consists of the association of rock-carved tombs with stelae sculpted in the frontal side as to imitate the megalithic monuments that become common at the same time. With little stratigraphically reliable evidence, for long they have been considered as the outcome of Early Bronze Age modifications (Lilliu 1988a: 323-330), but as suggested previously (Ferrarese Ceruti 1981b: lxix-lxx) and today better documented (Melis 1998b, 2003b), they are a product of Middle Bronze Age communities, so they fall beyond the scope of this dissertation.

Regardless of this type of tomb, which would anyway be an exception, the general pattern is that the communities associated with Monte Claro, Bell Beaker and Bonnanaro A material culture buried their dead by utilizing tombs previously carved or built, or natural caves. Not much labor was invested across the island into building burials, while it is grave goods that do, occasionally, show a comparatively higher expenditure of resources. In most cases contexts are not found in primary conditions due to looting and reuse in historic times, but a tendency is recognizable to define the new burial space with rough stone separations on the pavement, or stone middens on which, or near which, certain individuals or some skeletal elements were laid (Ferrarese Ceruti 1974b; Moravetti, et al. 1998).
4.5.3.2. Dolmens, Chambered Tombs, Megalithic Circles, Cists and Pits

After early work by Lilliu (1966; 1988a: 214-228, 330-336), two comprehensive works on the dolmenic structures on Sardinia have been published (Cicilloni 1994; Moravetti 1998b). Dolmens have been documented in several types, from the simplest and most common, with three slabs defining the funerary space and one to cover, to the most elaborate long chambered tomb, referred to as an *allée couverte*. Besides complexity, types are differentiated based on plan (rectilinear vs. curvilinear). Slightly over 200 dolmens have been documented so far (Moravetti 1998b: 25), with a geographic distribution neatly cutting the island in two halves: the vast majority are found in the northern half, while no more than twelve are located in the southern half and only two of these in the deep Southwest, the rest are in the central highlands (Moravetti 1998b: 32). This geographic pattern, reflected also in the type of raw material utilized (Figure 37), definitely emphasizes highlands, and has been

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*Figure 37. Barchart of relative frequencies of lithic materials used for dolmen building in prehistoric Sardinia. Data after Moravetti (1997: 25) and Cicilloni (1994: 53-54). The percentages largely reflect the geology of the areas where dolmenic structures are located with higher frequency.*
commonly interpreted as reflecting a pastoral society (Cicilloni 1994: 77; Moravetti 1998b: 25). Moreover, the region with higher dolmen concentration extends beyond Sardinia into southern Corsica, showing similar formal traits without any interruption across the Bonifacio Straits: a preference for rectangular plan, an entrance carved in a slab, and their association with megalithic circles (Moravetti 1998b: 26, 39 figure 9).

Chronology is not documented for the large majority of megalithic burials, since only a few have been excavated, most of them have been reused, and their cultural materials are often out of context. Nevertheless, indications evaluated as relatively consistent come from those few, including Montiju Coronas (Ozieri), Motorra (Dorgali), Corte Noa (Laconi), and Montessu (Villaperuccio), pointing mostly to the post-Ozieri tradition complex (Sub-Ozieri and Filigosa: Atzeni 1989a, b; Cicilloni 1994: 73-74; Lilliu 1988a). The later Copper and Early Bronze Age, in the Monte Claro, Beaker and Bonnanaro A phases, which have previously been considered as the heyday of dolmen construction (Antona 2003; Lilliu 1988a: 214-219), appear to represent mostly the age of their reuse. Many dolmens have *cupules* and some incisions possibly including anthropomorphic figures (Cicilloni 1994: 69-70; D'Arragon 1998a, 1999b), which as discussed in other sections of this chapter seem to be also widespread during the early Post-Ozieri phase, both carved in *domus de janas* and impressed on pottery (Tanda 1984: 112). The earliest pottery style that has been found associated with megalithic monuments (Middle Neolithic, second half of the 5th millennium BC) has been recovered, probably not by chance, in Gallura, the northernmost tip of the island (see also Antona 2003; D'Arragon 1998b, 1999a). This may fit the reconstruction that this architectural class of burial monuments originated in the northwestern Mediterranean, where an extended megalithic area covers wide portions of France and Catalonia, and diffused in Sardinia from the North to the South.

As for more specific comparisons, Cicilloni (1994: 55-62) has examined thoroughly the occurrence of similarities across the central and western Mediterranean. He found partial matches for single sub-types, but no simple patterns. The simple rectilinear dolmens, the most common, seem to be rare in the French Midi lowlands, but more common in the highlands. In addition to the affinity with Corsica, mentioned above (de Lanfranchi 1992; Moravetti 1998b: 26), single elements found in Sardinia are in common with the French coast (entrance carved as a hole in the slab), with Puglia, in southern Italy (circular-polygonal plans, incision of unknown meaning near entrance), with the Pyrenean area including
Catalonia, southwestern France, the Basque Country (Guilaine 1992). Furthermore, dolmens in Sardinia show a prevalence for south-eastern orientations (Figure 38), parallel to suggested centers of diffusion in Catalonia and southern France (Cicilloni 1994: 74-75).

Since the association of ceramic styles with different types of dolmens does not follow chronological patterns, it seems that they reflect variation in complexity with no internal genetic connections (Cicilloni 1994: 75). Of course further data may change this view in the future. It seems that the Middle Bronze Age giants’ tombs derive from both *allées couvertes* and cists, by elongation of the chamber into a corridor, as shown by the modification of some tombs along these lines (Lilliu 1988a: 333-340). In sum, it seems that the origin of the megalithic phenomenon could have arisen from a common pool of construction options and shared ritual beliefs across discontinuous areas. Alternatively, it may have diffused more directly through communication, between the end of the Late Neolithic and the Early Copper Age, from the earliest examples on the Atlantic basin and the western Mediterranean coasts toward the southern Corsica-northern Sardinia area and the Balearics (Moravetti 1998b: 27), and followed specific developments in different areas.

*Figure 38. Radial chart showing prevalence of orientation in dolmenic tombs documented in Sardinia. Data from Cicilloni (1994: 71).*
A type of tomb recorded increasingly frequently is the *domu de janas* with megalithic (or dolmenic) corridor. It unites the underground and aboveground models in a hybrid type, where in front of the rock-carved entrance two or more standing slabs define a sort of corridor (Lilliu 1988a: 226). This type of *domu de janas* is more often simple, with one or two rooms. Although the data on this type of tomb are still scanty, based on the few that have been scientifically investigated (Cicilloni 1994: 65-66; Pitzalis 1996; Usai 1998) it seems that most likely they are to be attributed to the users of Monte Claro pottery. At Scaba ’e Arriu, particularly, a clear break is visible: later Monte Claro human remains were deposited after clearing the rock-carved room and after building a dolmenic corridor. The corridor cuts through the earlier anthropic layer containing human bones, pottery and animal offerings, dating to the previous Post-Ozieri phase (Usai 1998). This may indicate an ideological shift that can tentatively be applied to the whole category, although more data are needed for conclusive statements. Their geographic distribution is discontinuous, with clusters identified in Ogliastra (central-eastern Sardinia), near Perfugas (north) and near Abbasanta (center-west).

Megalithic circles, common in southern Corsica, are found in considerable numbers only in Gallura, the Northeast, with few examples in the rest of the island that had very different features besides just circular structures around tombs. While the higher frequency would make sense in the only area over the whole island with little underground tombs and an uninterrupted record of megalithic burials, starting from the Late Neolithic with Ozieri pottery (D'Arragon 1999a), a recent reexamination of the artifacts recovered at Li Muri (Arzachena), the most representative site of the category, has convincingly led to a placement in the Middle Neolithic (Antona 2003: 267). They are therefore not considered here.

The only ‘different’ circles are, consequently, those of Pranu Muttedu (Goni), which yielded fairly good relative dating. Considering the features of the ceramic assemblage (such as lack of *pyxides* coupled with abundant diagnostic Post-Ozieri pottery), they may be chronologically apart from the early examples in Gallura from several centuries up to possibly almost a millennium. The site of Pranu Muttedu seems therefore to gain even more uniqueness than it ever had before, as an independent, parallel development out of the common megalithic pool of ceremonial templates and building skills, fused with the local
underground tradition. Within a few hectares, this extraordinary site features several tombs showing a mix of the two traditions in both plans and techniques, such as a *domus de janas* carved in a boulder that was brought to the site and completed with a megalithic corridor. Other elements are stone circles, about 60 standing stones also arranged in long alignments, and the older, traditional, *domus de janas* carved in a nearby outcrop (Atzeni 1981; Atzeni and Cocco 1989).

Cists seem to appear in the Post-Ozieri Copper Age, they never become frequent, and continue to exist marginally up until the Early Bronze Age. Often found while being devastated by plowing, they seem to be more common in the southern lowlands and hills, and commonly they are not very refined. They may be connected to the sporadic presence of single burials from the Copper Age onward (see below for connected burial practices). They are usually made with large vertical slabs, without variations, or specific patterns apparent from the literature (Ferrarese Ceruti 1981a: lvi-lvii; 1981b: lxviii-lxx; Lilliu 1988a: 156-158).

### 4.6. Ideology and Symbols

#### 4.6.1. Figurative Art: Symbolic Decoration, Petroglyphs, Figurines

Most elaborate artistic expressions, excluding daily-life items such as pottery, are connected to the decoration of burials. Fewer cases are documented in caves and rockshelters. Here I focus on the types of artistic manifestations most frequently represented, whose presence or absence can therefore be considered to reflect widespread cultural traits and features, and I leave aside more sporadic kinds of artifacts.

The most represented symbol is that of the bovine head or horns, which is documented in over 70 *domus de janas*; next comes the human figure, which is found in tombs, caves, rockshelters (Basoli 1992; Dettori Campus 1989a), megaliths (Cicilloni 1994: 66-67), and portable objects (Lilliu 1999: 80-107). Diverse geometric figures such as discs (Contu 1997: 144), rectangular partitions (Tanda 1992a), and others, are occasionally found associated with them. The chronology of the most common of these motifs, and their association with other aspects of material culture has been reconstructed in its main aspects by Tanda (1984), based on research carried out on the necropolis of Sos Furrighesos (Anela), a work that became a milestone for the understanding of the diachronic development of
decorative funerary art in Sardinian prehistory. Techniques were the key element for a chronological seriation that could reveal lines of developments, and are therefore briefly summarized here (Table 5). This is also useful for comparison with other aspects of material culture, in order to suggest possible covariations. It seems that during the Late Neolithic Ozieri phase, mostly linear incision and sculpture were used, while the incision through percussion (Tanda 1984: 84-86) is typical of the Filigosa phase. Red painting seems likely to belong in the Sub-Ozieri, or Final Ozieri, phase (Tanda 1998: 125, 137), besides possible sporadic cases in earlier Ozieri contexts (Basoli 1992: 502-504). In fact, this technique is also known on pottery, and from the temple at Monte d’Accoddi on the plaster of its “Red Temple” (Tiné 1997; Tiné and Traverso 1992b). The incision of cupules has been assigned to the Sub-Ozieri phase, which fits their presence as impressed motifs on pottery, whereas their presence on menhirs is less useful to build independently a chronological reference (Tanda 1984: 112). Their carving may have lasted longer, as suggested by their presence at Filigosa, tomb I (Foschi Nieddu 1986) and several other rock-carved tombs (Contu 1997: 149-150).

**Table 5. Techniques, figurative art and relative cultural phases, as suggested by Tanda (1998). Although it may be a simplification, there seems to be a general trend from curvilinear to rectilinear and from simple to complex.**

<table>
<thead>
<tr>
<th>Technique + style*</th>
<th>General sequence</th>
<th>Features</th>
<th>Pottery style</th>
<th>Phase</th>
<th>Technique</th>
</tr>
</thead>
<tbody>
<tr>
<td>Curvilinear sculpture</td>
<td>1.a</td>
<td>Simple curvilinear (A I-II) &amp; rectilinear sculpture (A 1-2), red painting, linear incisions</td>
<td>Ozieri***</td>
<td>SFA**</td>
<td>Linear incisions, bas-relief, cupules, red painting</td>
</tr>
<tr>
<td>Curvilinear sculpture</td>
<td>1.b</td>
<td>Simple sculpture (A III-IV)</td>
<td>Ozieri***</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rectilinear sculpture</td>
<td>2.a</td>
<td>Transitional both curvilinear (B) and rectilinear (B)</td>
<td>Final Ozieri (Sub-Ozieri)***</td>
<td>II</td>
<td></td>
</tr>
<tr>
<td>martellina + statue-stelae</td>
<td>2.b</td>
<td>Complex both curvilinear (C) and rectilinear (C), horn-shaped incisions</td>
<td>Filigosa***</td>
<td>III</td>
<td>Section b, semiellipsoidal</td>
</tr>
<tr>
<td>martellina + statue-stelae</td>
<td>2.c</td>
<td>Anthropomorphic figures both sculpted and incised, statue-menhirs</td>
<td>Filigosa***</td>
<td>IV</td>
<td>Section c, hemispherical</td>
</tr>
<tr>
<td>martellina + statue-stelae</td>
<td>2.d</td>
<td>Anthropomorphic and anchor-shaped figures</td>
<td>Filigosa***</td>
<td>V</td>
<td>Section a, trapezoidal</td>
</tr>
</tbody>
</table>

* based on comparisons with other figurative examples

** Sequence as proposed for Sos Furrighesos (Anela).

*** Absolute dates are introduced in the section on pottery and discussed in chapter 8.
As concerns the iconography, bovine heads begin being represented in the Ozieri phase, becoming the most common motif in the following Post-Ozieri times. During the Filigosa phase, human figures were probably introduced, and they have been documented in over a hundred examples (Contu 1997: 139). So, they likely appeared somewhat later than the bovine heads, and appear remarkably abstract and linear. On the contrary, bovine protomes, which are by far the most common motif in funerary art, show an articulated evolution that has been outlined through rigorous methods based on technology, typology and the overlap of different motifs (Tanda 1984: 13-27).

They can be defined along two main lines of development: on one hand, a trend from curvilinear towards rectilinear figures is connected to a shift from naturalistic toward more abstract renditions. On the other hand, there seems to be a trend from lower to higher complexity in the association and repetition of the motifs (Tanda 1998: 137). These two lines of development were likely intertwined in various combinations, having one extreme in naturalistic, single representations of bovine heads, well outlined and in some cases even showing their ears, and another pole in multiple bovine horns in three or more layers, rendered as straight horizontal bands with a rectangle representing the head (Tanda 1998: 123). The association may also be seen in the general preference for round-shaped huts in settlements of the Ozieri and Sub-Ozieri phases (Atzeni 1962; Ugas, et al. 1989), versus a preference for rectangular rooms that can be observed at the very end of the Late Neolithic or beginning of the Copper Age, possibly in the earliest examples, at Monte d’Accoddi, Serra Linta (Sedilo), and later, in most Monte Claro housing structures (Castaldi 1999: 49-74; Tanda and Depalmas 1997; Usai 1997). Chronologically, this means that, generally speaking, simple and curvilinear is more likely to be earlier than rectilinear and complex. There are, however, examples of simple rectilinear or complex curvilinear figures.

From a geographic perspective, the variation in funerary decoration seems to show meaningful patterns. In fact, such artistic expression is for the most part limited to the northwestern sector of the island, with few exceptions outside of this area. Whichever meanings were attached to it, they may not have held elsewhere, or their medium must have been different. Furthermore, an area in northern-central Sardinia has been identified, where most multiple horned motifs but scarce curvilinear motifs are located (Contu 1966). In the west, the distribution of tombs with painted decoration appears in geographic clusters (Tanda 1992b: 88), and in Ogliastra a peculiar version of the bovine horns has been documented,
with tips downward instead of upward as in the rest of the island (Pitzalis 1996). These cases highlight that decorative complexity reflects spatial variation besides temporal variation, where common motifs have been elaborated according to local preferences and needs. A model that recalls core-periphery relations has been suggested in the identification of three main zones, “distinct but interconnected”: the Alghero area, which may have been the main center, the Sassari area, as lively in its artistic innovation, and the interior, where motifs would be received and elaborated (Tanda 1984: 115-116).

Local archaeologists, following Lilliu’s (1988a: 254-259; 2002: 63-175) influential understanding and a long interpretive tradition, identify the bull as the divine partner of the Mother Goddess represented in figurines. Its message, however, was likely to involve social display, and it appears also likely that as other elements reproduced in tombs, sculpted bovine heads themselves mimic real bull heads or their reproductions as decorative elements of houses. Elsewhere, they have been tentatively connected to their importance in feasting events that were instrumental for creating and maintaining social relations (Robb 2004), whether such relations were of equality and reciprocity or of dependence. Otherwise, they may be symbols connected to the creation of power by means of ritually inducing situations of debt (Cámara Serrano and Spanedda 2002: 377-380).

Incised human figures (for the last updated synthesis see D’Arragon 1999b) are present in a few burial contexts in large numbers (e.g. Sas Concas, Oniferi; Moseddu, Cheremule: Contu 1997: 374-377), while at most of the sites where they are represented they appear in small numbers. In certain incised human figures, some have recognized sexual attributes and it is noted that, whenever recognizable, the vast majority would be males (Basoli 1992). This is inversely proportional to the pattern recorded in portable figurines, and directly proportional to that recorded for the statue-menhirs. Human figures assume shapes that make them resemble other beings, such as birds, spiders, and others, likely expression of shamanistic beliefs. The symbolic importance of cattle in this framework is illustrated by the exceptional example of a figure merging a human body and bovine head (Melis 1998a). A typical posture for incised human figures is with lifted arms, and certain ensembles seem to represent authentic scenes of collective action (Tanda 1984: 120-122). Concentric circles and spirals engraved in tombs, boulders and dolmenic slabs, found at several locations (Fadda 1998, and personal communication 2007; Lilliu 2002: 196-201; Saward and Saward 2005; Tanda 1992a) contribute, with the rest of human and geometric figures, to the evidence that
Sardinia participated in a common symbolic code extended over most of western Europe. A particularly strong similarity has been pinpointed with the western Mediterranean Iberian examples (Tanda 1992a: 490-491).

Human figures are apparently incised in the same part of the tomb, which was used for performance of rituals and offerings, not in the ossuary rooms, the true burial chambers where the remains of the deceased were permanently deposited. While Contu (1997: 373-374) attributes these representations to the Bell Beaker culture, based on his reading of the occurrence of similar types in continental Europe, this operational element seems to support Tanda’s attribution to the Copper Age of Ozieri tradition. In fact, the trend in the later Copper Age and Early Bronze is instead, as discussed above, toward the elimination of such an intermediate, transitional space between the living and the dead, possibly due to new ideas related to the strengthening of the megalithic phenomenon (Pitzalis 1996: 191-193). The Bell Beaker groups seem to have considered rock-carved rooms as more generally funerary, not unlike natural caves. On the other hand, we also have fewer cases of petroglyphs and rock paintings not related with burials, but their rarity makes their discussion less important here; they do add a component to our reconstruction of gender roles, in that there are some sporadic representations of clearly sexed male individuals (Luzzanas: Basoli 1992; D’Arragon 1999b).

Figurines of the so-called ‘mother goddess’ are among the most known categories of artifacts produced in prehistoric Sardinia, because of their frequency and the fine crafting of many specimens. While I do not delve into any of the many details that accurate stylistic analyses have pointed out (Antona 1980, 1998; Atzeni 1975), as they are not relevant to the point and the scale of this dissertation, in 1999 a comprehensive catalog has been published, which provides the most up-to-date overall picture of the phenomenon and a useful reservoir of raw data (Lilliu 1999). Hereafter, I mostly follow the descriptive statistics drawn by Vella Gregory (2005: 18-35), based on Lilliu’s data, which count 131 figurines including the Middle Neolithic (ca. 4700-4000 BC).

The complete typology includes 10 groups, although all but three (Figure 39) are represented by fewer than five specimens, and one has clearly been attributed to the Middle Neolithic. The most important are consequently the two geometric types, named ‘unperforated plaque’ and ‘perforated plaque’ figurines. The first, also referred to as ‘cruciform’, is extremely simple in its lines: a vertical stick with the head on the upper end,
no differentiation of legs, and a rectangle representing the trunk and arms (Antona 1980). Nose and breasts are the only other elements that are represented almost always, while the eyes appear often. Only a few examples, all from the western lowlands, have male attributes and no breasts (Lilliu 1999: 32-54). The ‘perforated plaque’ figurines are very similar to the former type, but show the profile of the arms detached from the body by two empty spaces; eyes are found more rarely, figures tend to be more standardized than before, and there are no male figures (Lilliu 1999: 55-70). Even many of the Middle Neolithic obese figures, traditionally assumed to represent female entities, do not have clear sexual attributes, turning out to be rather undifferentiated (Vella Gregory 2005: 48), so that a trend appears clear towards a progressively sharper differentiation in gender attributes during the Ozieri and Post-Ozieri trajectory.

Figurines of the first type are more evenly distributed over the island, while the second type is more concentrated in northwestern Sardinia. The trend in the use of raw
materials and context of recovery is also significant: of the unperforated type, about two-thirds are made of clay, one-third of marble, and few of other stones, and the majority were found in open-air settlements. The perforated type figurines are almost all made of calcite and marble, and normally found in burials (Vella Gregory 2005: 34, graph 7; 51, graph 10). Calcite frequency is not surprising, since sources are common in the northwest, where most figurines have been recovered. Marble is present in the central-northern highlands, near Orune (Lilliu 1999: 62). Chronologically, there is a general agreement that most figurines of the first type are to be considered Ozieri, and the second type ‘Filigosa’ and ‘Abealzu’ (Antona 1998). While Lilliu (1999: 68) is persuaded that the unperforated figurines stretch the whole duration of the Ozieri ceramic culture, evidence is not fully convincing against the possibility that their production and use may have begun in the later ceramic period, in transition towards or even within the so-called Sub-Ozieri. The trend toward a geometric rendition of figures should be parallel to analogous trends in tomb decoration (as defined by Tanda 1984, see above).

The traditional view of these figurines is that of a representation of a ‘Mother-Goddess’, connected with an important role of women in a social structure explicitly or implicitly assimilated to matriarchal systems. Different interpretations have been suggested for such a phenomenon, which took different aspects in different times and places. These interpretations emphasize the role of figurines as agents in reproducing gender identities, and the representation of specific individuals (Bailey 1994; 2005a: 66-87). Câmara Serrano and Spanedda (2002: 381-382) have suggested that they would mirror gender relations definitely unfavorable to women, underlining how in the Middle Neolithic cases, male individuals were laid in the tomb with a female figurine in their hand. This, they suggest, possibly reflected the appropriation of women’s labor related to the polarization of gender roles following the introduction of plowing. It must be noted, however, that the diffusion of the plow in Sardinia in these times is not supported by current evidence.

4.6.2. Menhirs, Statue-menhirs, Statue-stelae

Upright stones, or menhirs, another aspect of western European megalithism, are as common as dolmens, especially in highland Sardinia. While the majority are elongated boulders set upright but left in their natural shape or minimally modified, there has been in
the last several decades increasing evidence of types representing human figures, many of
which with a complex array of symbolic attributes (Atzeni 1994, 2004).

The few comprehensive discussions give us a general idea of the phenomenon: at
least 332 menhirs were counted (Lilliu 1988a: 96; 2002: 189), found in higher concentrations
in the central-northern highlands, but extending more to the south if compared to the
distribution of dolmenic burials. One concentration in the center-south, that of Pranu Muttedu
(Goni), is a necropolis that alone contains some 60 standing stones, representing a unique
rather than typical case (Atzeni and Cocco 1989). Intense survey work in several areas on the
island in the last twenty years has increased considerably these numbers, particularly in the
east and southeast, which had not been investigated as much previously, possibly because of
their distance from the headquarters of the two Soprintendenze. In Ogliastra (east-central
Sardinia), a high concentration of menhirs, often located close to burials, is accompanied by a
high frequency of rock-carved tombs with dolmenic corridor (Pitzalis 1996: 197-204), and of
so-called ‘altar stones’ consisting in slabs and boulders with cupules (Frau 1996; Lilliu 1999:
203-207; Pitzalis 1996: 199-200; Sanges 1997). In the coastal Sarrabus (Southeast), several
menhirs, also arranged in alignments and circles, have been documented by non-academic
amateurs (Ledda 1985: 179-245). They are similar to other menhir groupings, more inland,
which are better known to the scientific literature (Pranu Muttedu at Goni, Is Cirquittus near
Laconi), although not fully published (Atzeni 1996c: 4-6; Atzeni and Cocco 1989).

Sardinian menhirs, or standing stones, show diverse dimensions, from slightly over half a
meter to over 5 m, and their prevalent orientation, corresponding to the flat side, seems to be
towards the east (Lilliu 1988a: 98). They tend to occur alone or in dense groups, less often in
twos or threes, and the raw materials utilized reflect the geology of the geographic
distribution, highlighting some discrepancies with the dolmenic percentages (Lilliu 1988a:
96-97) (Figure 40): while granite is the most common, due to the granitic matrix of much of
the northeastern quarter of the island including Ogliastra, basalt is not, since menhirs are less
frequent in the central-northwestern highlands. Sandstone is instead overrepresented by its
widespread use at the unique site of Pranu Muttedu, mentioned above.

Typologically, several different groups of menhirs have been defined (Atzeni 1982,
1996c), based on the degree of detail in the expression of human-like figures. Most menhirs
are rough standing stones hardly shaped at all, and they are found, even if not very
frequently, in open-air settlements, near occupied caves, associated to burials, in a few cases even within rock-carved tombs, or as part of megalithic structures. More refined specimens are shaped into oval profiles and accurately smoothed by sculpting (proto-anthropomorphic).

Those that are defined as anthropomorphic show an approximate rendition of the human head with two concavities for the eyes and a ridge for the nose (Atzeni 1996c: 4-10). The most elaborate and rich in symbolic attributes are the so-called statue-menhirs. These have standardized ways of rendering the human face on the top and have at least one additional symbol in the center of the flat frontal side, which allows us to distinguish clearly gendered figures. Besides a few examples of uniquely sculpted stelae, they are a highly standardized type repeated in over a hundred examples, which has been found within a circumscribed area stretching the belt of hills and low mountains that surround the central highlands on their western and southwestern side. The highest concentrations seem to be documented near Laconi, but this may be because of the early research following the first occasional finds (Atzeni 2004). Tens of analogous statue-menhirs have been found in the last fifteen years near Isili (Saba 1993, 2000), and several more across the land belonging to nine different municipalities, often reused in the construction of tombs and nuraghi in the Early and Middle Bronze Ages (Atzeni 1992: 50; Moravetti 1984; Perra 1994).

Besides the undistinguished face, feminine menhirs, in small frequency compared to armed masculine menhirs, are indicated by two simplified breasts. Masculine figures always
show a knife/dagger or objects of unknown meaning, horizontally placed as if held on a belt around the waist. Only some figures, most of which are located near Laconi, show the so-called capovolto, scholarly jargon from the Italian word for ‘upside down’, since it has been interpreted, based on comparisons with petroglyphs incised in burial contexts, as a human-symbolic figure diving or flying down into the underworld (Atzeni 1996c: 10-15; 1998: 71; Lilliu 1988a: 274). In reality, comparison with stelae from Corsica and the northwestern Mediterranean would indicate more likely the origin of the motif in the representation of a dagger held with both hands. Several combinations and variations of presence-absence of capovolto, substitution thereof, or modification of the weapon, provide distinctive elements across groups: in some groups, a club-shaped object is found; near Senis and Laconi, the knife is double-bladed, near Nurallao single-bladed; at other locations there is a tendency for miniature examples, or the knife is replaced with a leaf-shaped object (Atzeni 1996c: 16, figure 2), or with another showing two round ends instead of blades (Saba 2000: 147-152). In a few cases, there is a representation of a frame that compares with the ‘false door’ motif found in rock-carved tombs of Post-Ozieri tradition (Atzeni 1998: 67).

As for chronology, and the association of menhirs with other expressions of material culture, the problem of having no data on the vast majority of them has been recognized early on (Lilliu 1988a: 100). Nevertheless, the authors of the two main syntheses believe that most of the plain ones were erected during the Ozieri ‘culture’, continuing in the Copper Age. This is considered to be the case at Pranu Muttedu, where along with Ozieri pottery there was also later Post-Ozieri ceramics. However, no stringent stratigraphic associations with menhirs have been published or demonstrated. Atzeni (1996c: 3) also relates menhirs at Villa Sant’Antonio with the nearby domus de janas, but this is only based on spatial closeness. The same argument holds for the attribution to the Copper Age of final Post-Ozieri tradition of the menhirs near Laconi, since the allées couvertes of Corte Noa and Masone Perdu yielding such kind of materials were spatially close, in what may have been a cultural landscape of ritual significance (Atzeni 1989b). The presence of cupules on several menhirs has been recognized early, and since the late 1980s, when Lilliu (1988a: 98-99) counted 13 cases, the number has greatly increased (Atzeni 1996c: 6-7; Frau 1996: 255-258). These may be used to limit the chronology to the Copper Age; of course these rock excisions could have been added at some point to already existent standing stones, but they provide an approximate chronology at least of the continuity of occupation. What is definitely a Copper Age mark in
the statue-menhirs are the symbols themselves, particularly the *capovolto*, which are documented in tombs and have been assigned by relative chronology to a full Filigosa phase (Tanda 1998).

The symbolism of central Sardinia’s statue-menhirs finds parallels in several areas, and particularly in Lunigiana (Lilliu 1988a: 273; Saba 2000: 156). The knife represented in many of them has been recovered in northern Italy in contexts of the Remedello culture. During the Copper Age there seems to be a trend toward regionalization in the manifestations of material culture. Patches of distribution of statue-menhirs and other unique phenomena are recorded within circumscribed ‘districts’ (Robb 2001a: 190), such as the cited features found in Ogliastra (Frau 1996; Pitzalis 1996). I interpret this pattern as reflecting autonomous elaborations of a common symbolism, with the caveat that our assessment may be biased by the sharing and transmitting of much cultural messages through perishable materials such as wood and textiles. A few important facts to be highlighted are the prevalence of male representations, which has been related to a shift toward more patrilinear and patriarchal ideology, and the identification of males with weapons, which may reflect an important role of warfare (Lilliu 1988a: 273). Knives would be the symbol of a new ideology of power and wealth epitomized by metal items, intertwined with an emphasis on the cult of the ancestors (Saba 2000: 150). This symbolism may have been related to warfare, or to sacrificial functions, but the link changing gender roles seems reasonable. On the other hand, continuity in collective burial customs should not be overlooked, and also the continued centrality of breasts in the rendition of women, which seems to indicate a long-lasting symbolic emphasis on nourishment as a gender attribute.

4.7. Burial Practices

In the period between approximately 4000 and 1900 BC, the most consistent element of burial practices is represented by its being collective. Only the period characterized by Monte Claro pottery shows a substantial anomaly in this regard, more clearly in the South, while elsewhere there is more a realignment with the long tradition of communal burial, with some distinctions.

Single burials have been documented in the Middle Neolithic (Cuccuru s’Arriu), but only at a specific location, which may well represent a local development (Santoni 2000).
while there is very little evidence for the Ozieri and Sub-Ozieri culture, involving one case of burial within the hut floor (Tanda 1995a: 38). Within the context of the Ozieri culture, the evidence concerning burial practices and treatment of the bodies is also scarce. This is due to either the uninterrupted utilization of the same tombs that lasted into later times up to the Copper Age within the same material culture tradition (Post-Ozieri, from what is labeled in the literature as Sub-Ozieri through Filigosa and Abealzu: see above), or the reutilization of the same burial spaces by later cultures after clearing from previous bones and items. In several cases, both phenomena are observed, with the continuous use within the Ozieri tradition and subsequent use by users of Monte Claro, Bell Beaker and Bonnanaro pottery. This can clearly be inferred from the presence of residual sherds from all these phases, either found in small portions of preserved deposits still in situ in the corners and sides of burial chambers (due to inaccurate cleaning), or by their presence outside, in front of the tomb, where they had been presumably disposed of to set up the interior for reuse. These conditions are shared by the large majority of the domus de janas. Finally, we ought to consider the many cases where there has been reuse in later times, from the Middle Bronze Age to contemporary period, either for burial or often for other purposes, as temporary shelter or to keep livestock.

One of the rare rock-carved tombs that was found intact and preserved a ‘classic’ Ozieri material culture context, and also the only one of them partially published, is San Benedetto (Iglesias). While this was the first interpretation of the ceramic style (Maxia and Atzeni 1964), the assemblage has later been assigned to ‘between the end of the Neolithic and the beginning of the Copper Age’ (Atzeni 2001a: 25). The radiocarbon dating on bone has yielded a date that seems more compatible with the first placement in the middle of the Late Neolithic, or even towards the beginning (Lab # Beta-72233: 4920 ± 70 BP, 3941-3532 cal BC, 2σ). Unfortunately, the focus on cultural materials in the very brief published reports does not give any details about burial practices. It appears that there were no articulated skeletons. Some kind of skull curation must have been practiced, since crania were prominent. They were stored in the three sealed rooms accessible from the central one, which in turn communicates with the outside. While this central room has been interpreted as a space for ritual rather than permanent burial, at San Benedetto crania were arranged in it with no clear difference from those in the smaller rooms. I suggest that this may reflect a somewhat later period, due to the tendency toward the disappearance of the intermediate
spaces between the outside world and permanent burial space in the Copper Age (see above). A carefully designed strategy of AMS dates on remains from different rooms may help shed light on these aspects in the future.

The ritual involving collective burial, according to current evidence, continued into the Copper Age, parallel to the pattern of gradual change within the same tradition that has been recorded in material culture and settlement patterns. Even if the fully published intact burial contexts of Post-Ozieri Copper Age tradition are few, a similar pattern of disarticulated skeletal materials, often described as ‘randomly scattered’ has been documented at most locations, e.g. Cannas di Sotto, tomb 12 (Santoni and Usai 1995) and Filigosa, tomb I (Foschi Nieddu 1986).

Other elements of ideology that may have affected ritual at burial sites, if not necessarily burial rituals, are found in the spatial arrangement of the tomb and in its change over time and space. The Early Copper Age rock-carved tombs often show the loss of the anticella, the vestibular space dedicated to offerings and presumably rituals: at the best-known site of Filigosa, tomb I, the largest room that gives access to the smaller ossuaries has concentric incisions on the pavement, possibly symbolizing a hearth, but most skeletal remains and most pottery offerings/grave goods were also found in it, similarly to San Benedetto (Foschi Nieddu 1986: 19). As Pitzalis (1996: 208-209) notes, a change in funerary practices underlies the abolition of the liminal space for ritual between the world of the living and that of the dead, introducing the innovation of a non-transitional, non-mediated separation. One of the few windows into the rituals performed at Post-Ozieri Copper Age graves is offered by the context uncovered at Santa Caterina di Pittinuri: it seems that the role of the transitional room was gradually eliminated or replaced by the corridor: abundant small cups were recovered, accompanied by pig mandibles, in both the corridor and the anticella, showing similar use of the room. In the corridor, tripods were found still lying on ashes; of the two layers identified in the anticella, the lower, besides traces of fire, tripods, and swine mandibles, yielded fragments of deer antler placed in the center, on a cupule-hearth carved in the floor (Cocco and Usai 1988: 14-15). In light of this evidence, I suggest that at San Benedetto the presence of human bones in the central room might date to the last phase of use, when ritual offerings were possibly performed outside and consequently the rock-carved space was permanently reserved for select, ‘processed’ and skeletonized human remains.

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While there may be some preliminary evidence for ritual breakage of pottery (Foschi Nieddu and Paschina 2004), something that could appear as a ritual termination is possibly found at Santa Caterina di Pittinuri: a layer of clay and stones was recorded, lying over the anthropic soil containing bones and artifacts as to seal on purpose the remains of the dead (Cocco and Usai 1988: 13). At San Benedetto a layer of culturally sterile soil, less than half a meter thick, was also recorded, and interpreted as naturally leaked sedimentation (Maxia and Atzeni 1964: 124), but in light of Santa Caterina’s evidence this may have been intentional, when for some reason the burial function came to be considered over.

As discussed above, the emphasis on the corridor, whether it is carved in the bedrock or constructed with megalithic techniques, is presumably parallel to the decline of the vestibular room in rock-carved tombs, and to be dated to the Post-Ozieri and Monte Claro Copper Age, along with the height of the dolmenic monuments. It is again unfortunate that we do not have any data concerning burial practices and body treatment in any dolmen; in some cases human remains are mentioned, but no details are given. Generally, since a large portion of dolmens are built with granite, the acidity in most cases has hindered bone preservation, so that the bias in documentation may turn out to be systematic, regardless of the poor publishing of the sites.

Cists, as mentioned above, are described but not documented in their details; those attributed to the Copper Age, such as that of Serra Cannigas near Villagreca (Nuraminis) contained certainly a collective burial (Atzeni 1985). Some finds instead, as at Mind’e Gureu, Nerbonis (Gesturi), and Pranu Muttedu, tomb III (Goni) seem to suggest the possibility of single burials, but the contexts are not known or not published in sufficient detail (Atzeni and Cocco 1989; Fonzo and Usai 1997; Lilliu 1988a: 156). They would be significant exceptions within a strong collective tradition, reflecting the same dynamics in action in the social and ideological domains that we see in the Monte Claro, Bell Beaker and Bonnanaro A phases, with well documented single or articulated burials (Lilliu 1988a: 340).

In summary, the only data we have do not allow us to infer details of body treatment and/or manipulation (Contu 1997: 120). Most of the evidence for the remaining phases has not revealed much of the procedures followed between death and the reduction to skeletonized remains, nor are there studies addressing the possible selective storage and curation of specific skeletal elements, as has been ascertained for other areas in Europe and described, non systematically, at some Sardinian sites. Most data concern the constant
presence of ceramics and lithics as grave goods and/or later offerings. In the Copper Age Filigosa phase, to these traditional items, metal jewels were added, mostly silver but also copper (see above, Usai 2005b).

Apparently, burial customs changed radically in the South, in coincidence with the Monte Claro ceramic style. Besides the new tomb types discussed above, the permanent deposition of articulated bodies in the grave was introduced and widely practiced. The series of burials in the southern lowlands around Cagliari is a homogeneous group, where the shaft tombs contained one or a few bodies in flexed position per each room, laid on their left side usually facing the entrance and with no regard to orientation, accompanied by several pots and various objects as grave goods (Atzeni 1967; Lilliu 1988a: 155, 167-168; Lilliu and Ferrarese Ceruti 1959). Even when the tomb type is different, such as lithic cists, or pits in village context, individuals buried in the same area are similarly articulated, laid singularly or in small groups of two or three (Tanda 1995a: 47; Ugas 1982a). Two cases are particularly significant: the cist at San Gemiliano (Sestu) contained two adults with a juvenile about 8-9 years old who was buried with a necklace (Atzeni 1958: 99-104), and tomb 2 at Simbirizzi (Quartu S. Elena), a child burial (Usai 1984, 1989b). The age of the youths indicates that they were already recognized as holding the right to be buried as an adult; alternatively, if their presence in the grave was due to the family’s social condition, it may be indicative of ascribed status. Simbirizzi’s child was buried with ceramic grave goods fully comparable to those found in the adults’ tombs.

Except from the southern lowlands, though, the large majority of Monte Claro burials are typically in natural or artificial caves, the domus de janas of Ozieri tradition (Lilliu 1988a: 154). As discussed above, there is some evidence that several older tombs were modified through the addition of a megalithic corridor. Even without any change to the outside of the tomb, it has also been recorded in several instances the creation, with stone rows, of well-defined spaces within larger burial chambers. Observed not just in domus, but also in caves (Ferrarese Ceruti and Fonzo 1995; Lilliu 1988a: 146-147), this may have served the purpose of establishing boundaries for a single burial or for a certain group of people, or of remains, entitled to special respect or treatment. Something similar may be seen behind the custom, documented at Scaba ’e Arriu, of depositing, inside large vessels, some crania and a few other skeletal elements (Usai 1998).
Pottery is definitely the main type of grave good preserved. During the Monte Claro phase, metal is occasionally present but rare, and lithic tools have already significantly declined. The inhumations of the kind just described typically contain from one up to eight vessels per individual, placed in the middle of the burial room or around the head of the deceased (Lilliu 1988a: 166-167; Ugas 1993b; Usai 1989b). Considering the whole island, a vast number of reused tombs all over Sardinia yielded Monte Claro pottery, but because of later reuse we do not know whether funerary practices remained unchanged or had already yielded to the old custom of collective burial, which apparently the Bell Beaker groups in most recorded cases observed too.

Single burial seems to have been present, but even rarer, in association with Bell Beaker pottery, which is found in distinct contexts but partially contemporary with Monte Claro, depending on the geographic location: one case has been reported (Santa Vittoria di Nuraxinieddu) where the skeleton would have been in supine, extended position (Ferrarese Ceruti 1981a: lvi-lvii; Usai 2001a). Other cases of cist burials were collective, with no detailed data on skeletal elements and their spatial arrangement.

The reuse of rock-carved tombs, very common in northwestern Sardinia, shows the definition of a circumscribed space for the remains, similar to what was described for Monte Claro, with a circle of stones or authentic cists (Atzeni 1996b; Ferrarese Ceruti 1981a: lvii; Usai 2001b). Sometimes this was repeated at different stages, so that something similar to middens of small stones formed between layers of remains, a ritual that is documented also in the following Early Bronze Age at Iscalitas, su Crucifissu Mannu, t.16, and other sites (Ferrarese Ceruti 1974b: 200-204; Manunza 1998). Since single burials in cists and reuse of megalithic monuments are the most typical widespread features of Bell Beaker burial customs in mainland Europe, assuming such external practices and symbolisms are to be seen reflected in the recorded cists, it is then clear, on the other hand, that the local tradition of collective burial and manipulation of remains maintained its overall prevalence in the long run. This is well established at several locations where disarticulated and manipulated remains of tens, or hundreds of individuals were documented, only a minority of which were partially or fully articulated (Atzeni 2001b; Ugas 1982b; Usai 2001b). At sa Serra Masì, it has been suggested that the presence of a cist in a context of collective burial may have served to mark the difference of an important burial (Usai 2001b: 82). This of course does not imply any institutionalized rank, since there is no other kind of evidence for ascribed
social inequality from any Bell Beaker burial in Sardinia, but may be a clue to incipient, or short-term cross-generational inherited status, as ethnographically documented in the classic examples of Big Man societies (Sahlins 1963).

Beaker pottery users also seem to keep the skull curation customs documented in Ozieri and Monte Claro times, in this case expressed as niches, or spots, where skulls were concentrated and accumulated (Atzeni 2001b; Ugas 1982b). This pattern, recently recorded also in central Italy at Fosso Conicchio, has been connected with the elaboration of rituals beyond those strictly connected with the burying of the dead, with a feature, interpreted as an altar, that is remarkably similar to one at Padru Jossu (Fugazzola Delpino and Pellegrini 1999).

Burial practices in the Early Bronze Age Bonnanaro A phase are very much along a continuum within the Bell Beaker tradition: there is similarly a small number of single burials with articulated bodies across the island in reused domus de janas and natural caves, but the collective ritual definitely outnumbers these few occurrences (Ferrarese Ceruti 1981b: lxix-lxx). Cists, pits (Cuccuru Nuraxi: Atzeni 1958: 101-110; s’Arrieddu: Ferrarese Ceruti 1981b: lxix; Iscalitas: Manunza 1998), and caves, where a large portion of the known cultural materials have been recovered (Lilliu 1988a: 321), complete a picture of relatively eclectic burial customs, which suggests the absence of customs and ideologies that could be identified as normative as was apparently the case for the preceding centuries. On the other hand, the continuity between the two phases is underlined by spatial continuity: in several tombs that were cleared from previous remains and items by Beaker users, the depositions were accumulated in layers, with no evidence for removal of the old ones. There is also evidence for sterile layers laid in order to seal the remains at the end of a cycle of use, or possibly just to even out the ground for an easier use of the space. Trends in the use of personal ornaments (discussed above) are as well substantially shared across the two phases.

An interesting phenomenon, relevant to gain insights in the dynamics of social relations, is the presence of articulated skeletons within contexts of generalized disarticulated, scattered remains: besides Padru Jossu, this was documented at Bingia ’e Monti, where only three individuals, out of an MNI (Minimum Number of Individuals) of over 150, were laid flexed, on their left side, according to the tradition already found in the 5th millennium BC, in both the Bell Beaker and the Bonnanaro A layers (Atzeni 2001b: 6-7). At Iscalitas, several individuals, out of an MNI of about 80, were found articulated; most, but
not all of them seem to have been in the top layer, and one infant was uniquely laid on top of a bed of cobbles (Manunza 1998: 77).

Several observations can be made from this evidence: while the traditional functionalist explanation would explain the articulated skeletons as the last ones to be deposited, clearly this is not the case for all of them. An alternative explanation, which has been proposed for analogous evidence in central Italy (Dolfini 2004), is that certain individuals did have a special role, and therefore treatment, within the community. While this does not mean ascribed status, the presence of juveniles and especially the child may reveal a trend, or structural episode, toward that outcome, a trend never fulfilled but reoccurring over and over. Such a model fits well that of unstable power relations in Big Man societies, where if skills are equal, someone can have a better chance of becoming a leader if his father was one. Later, this trend will be reversed, and from the Middle Bronze even personal adornment will disappear, reflecting a strictly egalitarian ideology or disguising increasing inequality within it.

Very few documented cases of partial cremation can be found in the literature, and they are never unquestionable: among the possible cases is the Copper Age tomb 1 at Filigosa, where human bones were described as showing burning, in some cases to the marrow, and deep cutmarks (Foschi Nieddu 1986: 19), but the site had been devastated by looters, and no osteological report authored by a bioarchaeologist ever appeared. Similar argument holds for Serra Cannigas (Atzeni 1985), where due to the devastation that compromised all possible taphonomic clues, we cannot rule out the possibility that burning happened in later times. A thick layer of burnt bones recovered in the cave of Baieddu de sa Sedderenciu, near Tanì, with Monte Claro, Bonnanaro A and later Bronze Age pottery, was long believed to date to the Copper Age despite no clear stratigraphy having been recorded (Ferrarese Ceruti and Fonzo 1995). In fact, an AMS date placed some of them in a much later time (Sanna, et al. 1999), and regardless of the chronology, the unreliable context does not guarantee that burning did not occur much later than the deposition, for possibly unrelated reasons.
4.8. Concluding Remarks

All the elements analyzed in this chapter do show, I believe, how complex a comprehensive and synthetic interpretation of so many different types of data necessarily is. The complexity of cultural changes mirrored in the material culture are important in order to understand how they related to changes in subsistence and climate, which are the target of the stable isotopic analyses at the core of this study. Here I mostly point out main features that could be observed, and their possible meaning, so that they can be later integrated holistically with the paleoeconomic information.

For the Middle Neolithic, Sardinia has some common points with general trends in mainland Europe, such as single burials, but no ditched enclosures were documented. The Ozieri period as is known today seems to represent a strong normative point, with a similar type of collective burials, presence of open-air sites, and homogeneous material culture. For the reconstruction of the corresponding social organization, burial ritual is crucial. The collective ossuaries, with men, women and children buried together, point to an egalitarian ideology, with use of resources and probably communal land holding. Identifiers found as grave goods reflect gender and possibly age, with no exotics as prestige items, in a kind of social organization that is based on kinship (Thomas 1987). Pottery evidence reinforces this, with prevalence of middle-sized vessels for common consumption. Ritual is centered in the cult of the common ancestors, whose individual identity is erased by disarticulation of the remains. In the Early Copper Age, there are signs of change: first, the emphasis on decorative display in rock-carved tombs in northwestern Sardinia; the bovine representations have been related to the increased importance of the plow and/or herding as symbols of new ways to acquire wealth and social status, possibly through feasting and inducing the guests into material and social debt (Cámara Serrano and Spanedda 2002). Display of prestige items such as metal ornaments may have been an alternative or complementary strategy to the same effect. Change in gender roles, with an increase in male dominance (Hayden 1998; Robb 1999), and the birth of warrior ethics, appear also involved in this process at some locations, as arguable in the phenomenon of the armed and gendered statue-menhirs (Atzeni 1982, 2004; Perra 1994; Saba 2000).

The spread of megalithic monuments particularly in the Copper Age, parallel to mainland Europe, and more specific to Sardinia the omission of the vestibular room for
rituals in domus de janas, support a picture of conflicting value systems and mechanisms to maintain or attain power. Spiritual and economic individualism would be opposed to the normative and traditional role of religious intermediaries spatially exemplified in the anticella (Sherratt 1991; Thomas 1987: 420-422). If we consider the distribution in highlands and the almost universally propounded association with pastoral areas, they could represent a strategy to break the traditional system by using new burial structures to legitimize a family’s new power and social standing derived from individual wealth. The adoption of megalithic monuments may on the other hand represent a reaction to the attempt to erode the age-based old system, by reaffirming the values of the community against a more generalized concept of prestige where the display of material wealth is opposed to specific, non-convertible skills or qualities (Robb 1999: 113-115). In Sardinia, the reaction might chronologically overlap with some Monte Claro aspects, and its material, secondary agents would be the open-air ceremonial centers and the revival of menhir erection in a different context (Castaldi 1999: 14-29), a fairly sober personal adornment and decreased use of metal, in comparison with both some Post-Ozieri burials (Serra Cannigas: Atzeni 1985; Usai 2005b: 736) and the mounting Bell Beaker fashion with its taste for rich pendants, beads, decorated pottery, copper items and likely elaborate woollen clothing (Ferrarese Ceruti 1981a: Ivii-Ixiv).

The new norm of single burial in the southern lowland Monte Claro tombs, on the other hand, seems to indicate just the opposite trend, a break with the collective-oriented past and toward individualism, in line with cist burials, which probably became common slightly later. While the deposition of offerings may be read linearly as reflecting the status of the deceased and increased individualism and inequality, such simplistic explanations have been criticized both on empirical-theoretical grounds (Brück 2004), and drawing from ethnographic examples (Carr 1995). In fact, they overlook the role of personal identity, as formed by the relationships that the dead as actors had interwoven with other social actors, which can be independent or not included in status and gender.

It is with this premise and caveat that the trends outlined in this chapter can be provisionally accepted as working hypotheses to guide future research, and so their possible meanings in terms of social change. For this project, they function both as framework and as an independent qualitative dataset to be compared with, and examined for correlations with, paleoenvironmental, paleoeconomic and paleodietary data.
Chapter 5. Previous Data on Diet and Economy in Sardinia

5.1. Introduction

The aim of this chapter is to review critically the published evidence for diet and economy in prehistoric Sardinia, so as to evaluate it in order to recognize possible trends, pinpoint the gaps in our knowledge, the questions raised, and the limitations. This will allow me to integrate these data with cultural and climatic data, and particularly to provide at least a qualitative framework for the stable isotopic values to improve our ability to trace diet. This, in connection with the cultural and climatic contexts highlighted in chapters 3 and 4, provides a fuller understanding of more complex dynamics, as announced in the introduction to this dissertation. The importance of such synthesis of previous data is in the fact that they have not been analyzed critically: this contribution is therefore the foundation for both a strong interpretation of the dietary isotopic values, and an accurate integration with broader climatic and cultural patterns of change.

Sardinia’s climate and environment are presently Mediterranean, a term which indicates conditions involving winter rainfall and summer drought (the western side receiving more meteoric waters because of Atlantic influxes); temperatures are cool in the winter and hot in the summer, according to latitude and elevation (for general reference, see Pracchi and Terrosu Asole 1971), with moderate overall differences among different parts of the island. Between 4000 and 1900 BC, though, some variations and century-scale phases make climate more articulated (chapter 3). The first half of the 4th millennium seems to have been warmer and rainier, with more widespread deciduous forests, while later on, Mediterranean conditions were established, on a north-south gradient, by sharper seasonality of precipitation, increasingly long summer droughts, and somewhat cooler temperatures. These factors, intertwined with human modifications that affected species competition, also brought
about typical Mediterranean vegetation, with prevalence of evergreen species and shrubs better adapted to arid conditions and frequent fires.

Sardinian biogeography was inferred up to the 1990s mostly by analogy with Corsica, since faunal studies were still very few, while today more data are being published for Sardinia as well (e.g. Wilkens 2004). The history of fauna in Corsica after the last ice age has been outlined mainly by Vigne in several analytical and synthetic studies (Vigne 1984, 1988, 1991, 1992, 1995). The two most important processes informing this history and Sardinia’s as well, whose mutual relationships are still to be understood in detail, are extinction of the aboriginal species on one hand, and introduction of foreign species on the other – a long process of displacement.

In the pre-Neolithic period, the only mammals on both islands are *Prolagus sardus*, *Rhagamys orthodon*, *Tyrhenicola henseli*, and *Episoriculus* species, all relatively small sized, carnivores and rodents. In Sardinia *Megaloceros cazioti*, a small deer, is also documented, but it disappeared before the Neolithic. *Rhagamys orthodon* is documented in two Sardinian contexts only, dating to the Late Neolithic (Sanges and Alcover 1980) and to a generic Neolithic, and there is no evidence thereafter, while *Episoriculus* has been found only in one Early Neolithic context (Wilkens 2004: 182): these two species probably were becoming increasingly rare through the Neolithic. *Tyrhenicola henseli* was present throughout the period considered, since it has been documented in Bronze-Iron Age contexts (Wilkens and Delussu 2002). The most common hunted mammal, however, was by and large *Prolagus sardus*, which has been identified in contexts up to the Iron Age in Sardinia and the Roman period in Corsica (Wilkens and Delussu 2002), and makes up the large majority of wild specimens at most Neolithic sites, at a time when deer and wild boar were probably not yet very common.

It is unclear what the role of humans was in the extinction of larger mammals in general within the insular ecosystems, and specifically in Sardinia as concerns *Megaloceros*, the only medium-sized wild animal that survived into Post-glacial times (Hofmeijer and Sondaar 1992; Sondaar, et al. 1986; Vigne 1996). Humans are more likely to have had a role in the extinction of the smaller species, which disappear progressively after agriculture and animal husbandry affected the landscape more deeply, and possibly also under hunting pressure (Vigne 1988, 1992), since deer was probably not very common due to its late
introduction, and wild sheep and pig had not drifted completely into moufflon and boar to create substantial autonomous populations.

The complementary side of replacement, introduction and spread, is quite well ascertained (Dobson 1998). The pattern in Corsica is a first phase with the introduction of sheep, goat and pig, and a second slightly later, concerning cattle and dog, within the Early Neolithic, 6th-early 5th millennium BC. By the Middle Neolithic (5th millennium), *Erinaceus europaeus* (hedgehog), *Apodemus sylvaticus* (long-tailed field mouse) and *Glis glis* (dormouse) are documented (Delussu 2000; Vigne 1992). Already in the Early Neolithic it has been possible to distinguish *Ovis musimon*, the moufflon, a feral sheep that drifted and speciated from the domesticated stock, and *Sus scrofa meridionalis*, the wild boar, which speciated from domesticated pig (Sanges 1987; Wilkens 2004). Wild cat is believed possibly to have drifted from domesticated cat in the same way (Vigne 1992). Various rodents made their appearance later in the Bronze Age. Deer may have been introduced already in the Early Neolithic (Corbeddu Cave: Sanges 1987), certainly it was present in the Late Neolithic and Copper Age (Fonzo, personal communication; Wilkens 2004; Wilkens and Delussu 2002).

Other species of rodents and small carnivores, such as rats, weasels (*Mustela nivalis boccamela*), martens (*Martes martes*), and the donkey, were introduced by the Iron Age, but in any case they are not relevant in the period under investigation. According to Wilkens (2004: 186-188), the first reliable identification of horse would be in the Iron Age. In reality, considering that in the Italian peninsula it was introduced during the Bell Beaker period in the mid-3rd millennium BC (Corridi and Sarti 1990), a few cases may be reevaluated. One specimen of Equidae was recovered at Filiestru: certainly intrusive in the final Early Neolithic layer where it was found, but possibly belonging to Copper or Bronze Age layers documented above (Levine 1983: 125). Another was recovered at Su Crucifissu Mannu, tomb 16, in an Early Bronze Age context (Cassoli 1974), and two more reported in 19th-century explorations at the later Bronze Age sites of Nuraghe Don Michele (Ploaghe) and Nuraghe Domu ’e s’Orcu (Sarroch) (Lo Schiavo 1981: 266). It seems possible therefore that the horse was introduced between the end of the Copper Age and the Early Bronze Age also in Sardinia, remaining a rare novelty, with no structural impact on the economy, for over a thousand years.

After this general overview of faunal diversity available on the island, I discuss all the proxy data available in an integrated perspective, divided, for ease of discussion, into
groups: 1) biotic remains; 2) osteology and paleopathology; 3) settlement patterns; and 4) features, artifacts, figurative arts. Some of these sources are qualitative (figurative art), or indicative of processes hard to pinpoint accurately. Others are semi-quantitative but their relevance varies depending on the representativeness and contextual information, besides all the biases due to sample preservation. Finally, for some specific points different kinds of analogical processes can be used, to widen our horizons as regards the possibilities that the studied human groups had in similar ecological contexts, although rarely can these be translated into real testimonies (ethnographic, ecological analogy, site catchment analysis). Many other methods have never been applied to prehistoric Sardinian contexts.

5.2. Biotic Remains

5.2.1. Botanical Remains

Very few studies report on botanical remains (Table 6), and only one is a contribution going beyond the simple list of species. In the Middle Neolithic, at the burial cave site of Grotta Rifugio, alongside species more or less adapted to Mediterranean climate and widely present today (Quercus, Pistacia, Juniperus, Phyllirea, Arbutus, Acer), the recovered wood charcoal also indicated mountain pine forests (Pinus nigra), which are not found today (Castelletti 1980). This may reflect both cooler conditions, which would counter what is known about the climatic optimum in the 5th millennium BC, or more likely the remains of original glacial mountain forests before fires favored the spread of oaks. As discussed above (chapter 3), pines do not recover as easily from burning.

More information comes from a report on macrobotanical remains associated with cultural materials dating to the Late Neolithic-Early Copper Age (Sadori and Tanda 1989): the site is a rock-carved tomb at Molia (Illorai), and the charcoal was mostly attributed to evergreen oak (Quercus ilex). Assuming that a fire to cook or perform ritual activities reflects the availability of timber nearby, a trend could be reconstructed towards the spread of evergreen oak through drier climatic conditions and the extensive use of fire for deforestation. Such macrobotanical remains provide information on the environment and not only on economy and subsistence. More recently, a few botanical remains were analyzed
Table 6. Botanical remains at Sardinian sites dating to the Early Neolithic (EN) through the Middle Bronze Age (MBA). Data from Bakels (2002) with integrations from Castelletti (1980) and Celant (1998).

<table>
<thead>
<tr>
<th>Species</th>
<th>Period</th>
<th>Site</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Filiestru</td>
</tr>
<tr>
<td>Hordeum vulgare</td>
<td>EN</td>
<td>X</td>
</tr>
<tr>
<td>Triticum aestivum/durum</td>
<td>MN</td>
<td>X</td>
</tr>
<tr>
<td>Triticum dicoccum</td>
<td>MN</td>
<td>X</td>
</tr>
<tr>
<td>Triticum monococcum</td>
<td>LN</td>
<td>X</td>
</tr>
<tr>
<td>Lens culinaris</td>
<td>LN</td>
<td>X</td>
</tr>
<tr>
<td>Pisum sativum</td>
<td>LN</td>
<td>X</td>
</tr>
<tr>
<td>Pisum sp.</td>
<td>LN</td>
<td>X</td>
</tr>
<tr>
<td>Vicia faba</td>
<td>LN</td>
<td>X</td>
</tr>
<tr>
<td>Fabaceae</td>
<td>LN</td>
<td>X</td>
</tr>
<tr>
<td>Olea europaea oleaster</td>
<td>LCA</td>
<td>X</td>
</tr>
<tr>
<td>Olea europaea</td>
<td>MBA</td>
<td>X</td>
</tr>
<tr>
<td>Quercus sp.</td>
<td>MBA</td>
<td>X</td>
</tr>
<tr>
<td>Quercus ilex</td>
<td>MBA</td>
<td>X</td>
</tr>
<tr>
<td>Pistacia</td>
<td>MBA</td>
<td>X</td>
</tr>
<tr>
<td>Juniperus</td>
<td>MBA</td>
<td>X</td>
</tr>
<tr>
<td>Phyllirea</td>
<td>MBA</td>
<td>X</td>
</tr>
<tr>
<td>Arbutus</td>
<td>MBA</td>
<td>X</td>
</tr>
<tr>
<td>Acer</td>
<td>MBA</td>
<td>X</td>
</tr>
</tbody>
</table>

The three groups distinguished by gray shading represent, from top down: cereal grains, legumes, and trees from a rock-carved tomb reused in Bell Beaker times (Celant 1998), and the identified species were evergreen oak and wild olive tree (*Olea oleaster*).

The rest of the evidence is discussed in a synthetic study by Bakels (2002). Due to the inconsistency in recovery methods and reporting results, data are not quantitative but are presence vs. absence lists. The whole Neolithic ‘package’ was likely introduced in the Early Neolithic, although only wheat and peas have actually been identified. In any case, barley, lentil and fava bean are documented in the Middle Neolithic, so they were clearly available for planting after 4000 BC. After the Early Neolithic, einkorn is not documented until one single grain in the Iron Age, so possibly it was discontinued as a staple, and other varieties of wheat were preferred. From a survey of data from the rest of the Western Mediterranean, there is a shift from naked barley to hulled barley around the Early Bronze Age; this may have involved Sardinia, since all specimens from Duos Nuraghes identified to the variety level are indeed hulled barley (Bakels 2002: 7). Interestingly, the Copper-Early Bronze Age is the time of the European-wide diffusion of drinking containers, such as cups, mugs, and particularly the bell-shaped beakers (Sherratt 1987, 1991), and hulled barley is the variety
considered best for brewing beer in opposition to the naked variety which is preferred as food.

Most relevant is the absence of any evidence for fruit trees before the Middle Bronze Age, when the first olive stone is documented (uncertain whether wild or cultivated olive: Bakels 2002: 6). Evidence from three sites in Mediterranean Spain and France has shown a consistent pattern compatible with olive tree timber cutting during the Neolithic and management for fruit exploitation beginning in the Copper Age and increasingly in the Early Bronze Age (Terral 2000). It is therefore reasonable to hypothesize that this was the case also in Sardinia. Unfortunately, since we have no botanical data whatsoever for Sardinia in the whole period after the Late Neolithic and before the Middle Bronze Age, approximately 3000-1600 BC, these issues will remain unresolved until new analyses are carried out.

5.2.2. Faunal Remains

Faunal remains have been studied more, but still insufficiently for us to get a full grasp of the variation within the 4000-1900 BC period and between this period and previous and subsequent times (Figure 41). Wilkens and Delussu have provided in recent years almost comprehensive syntheses of the current knowledge of Holocene fauna in Sardinia (Delussu 2000; Wilkens 2004; Wilkens and Delussu 2002), pinpointing how the lack of consistency in methods and mostly the silence regarding such methods, makes results not systematically comparable. Issues such as whether fragments were counted as found or also refitted, and whether the calculation of MNI (minimum number of individuals) was done by adding counts from subunits or by pooling, topics which should be discussed and explicitly mentioned (e.g. O’Connor 2000: 54-81), are largely missing.

After over two decades, Levine’s work on the assemblage from trench D at Filiestru Cave is still the most thorough and detailed study on a long stratified sequence, which spans the Early Neolithic to the Bronze Age and later (Levine 1983). The sequence at Filiestru is also the only one encompassing all the phases of interest for this study, and the study of the faunal remains is the only one where statistics is employed to gain insights into taphonomic processes and biases of representation. These aspects make it important to examine these data including earlier times and not only the layers overlapping with the timespan of interest.
Figure 41. Map showing sites dating ca. 4000 to 1900 BC mentioned in the text where faunal and/or botanical remains have been analyzed and at least some results published. Map by the author, based on cartographic material from S.A.R. Sardegna consortium, with kind permission.
Based on ethnoarchaeological analogy, the proportions of skeletal elements appeared to reflect natural processes. The only human effect detected was the selection of forelimbs more than hindlimbs, so if animals were killed at the site, the most meat-rich parts may have been taken away. The population distribution is tentatively interpreted as reflecting natural death rather than a consistent killing strategy. Despite the high frequency of *Prolagus* specimens, there is no indication of human consumption, and due to its being a burrower, it is possible that these rodents were simply having their dens in the cave, or that predators such as foxes brought them inside as prey (Levine 1983: 123-124).

In Sardinia, evidence of *Prolagus* roasting has emerged at Punta del Quadro (Wilkens 2004: 185), as already documented in Corsica (Vigne 1981), while in Sardinia at the cave of Is Aruttas a pattern of consistent removal of cranial vaults is taken as an indication of brain consumption (Germanà 1995: 64). Unfortunately this site, where Final Neolithic pottery and several remains were recovered (radiocarbon date placed them in the 15th-12th century BC), did not yield any stratigraphy due to looting. Furthermore, there is no specific analysis aimed at evaluating whether similar patterns would result from predators crushing the bones in a similar way. Since for many contexts (e.g. Filiestru) the shadow of possible intrusion remains, the real importance of *Prolagus* consumption is not easily quantifiable. Finally, very few marine shells testify to the scarce input of seafood in the diet at Filiestru (Levine 1983: 125).

Looking at actual economic proxies and specifically at proportions of domesticated animals, and keeping in mind the bias implied in each of the parameters available (Vigne 1992), if the number of identified specimens (hereafter NISP) (Figure 42) is considered ovicaprines are the most represented at all layers. Considering instead the minimum number of individuals (hereafter MNI) (Figure 43), they are still the most frequent throughout the Neolithic, but in the Late Copper-Early Bronze Age layer pigs become more important. Cattle increase in the Middle Neolithic, and remain proportionally constant up to the Late Copper-Early Bronze Age layer, while pigs decrease throughout the Neolithic, and after reaching the lowest point in the Late Neolithic-Copper Age become much more frequent in the Final Copper-Early Bronze Age and later. Additionally, if meat-yield estimates were considered, cattle would turn out much more important.
Figure 42. Relative proportions of remains of domesticates recovered at Filiestru Cave (data after Levine 1983). Number of identified specimens (NISP);

Figure 43. Relative proportions of remains of domesticates recovered at Filiestru Cave (data after Levine 1983). Minimum number of individuals (MNI)
The life history of the cave, however, was not consistent all along the sequence. The charts below illustrate the density of bones and artifacts (Figure 44), and of different species (Figure 45), calculated as number of specimens divided by volume of soil (Trump 1983: table 12). It seems that the cave was mostly used for keeping animals in the initial Early Neolithic, and used for increasingly intense human activities from the later Early Neolithic to the Middle Neolithic (layers 5, 6). Trump suggested that the main dwelling site of the small community shifted out of the cave already in the Middle Neolithic, to be closer to fertile land and chert sources, while animals were still being penned inside. I suggest that this may have been later, in the centuries around 4000 BC, as suggested by the drop in artifact frequency, by the ritual activity documented in another nearby cave (Trump 1989), and by the disappearance of wheat, reported after the Middle Neolithic. At some time during the Copper Age, while human occupation continues at a similar pace, animals were probably not present at the cave in as large numbers or for as much time of the year. Likely it had become an occasional shelter for hunters, as the increase in arrowheads supports (Trump 1983: 87-95).

We can go further integrating the information we have on general patterns of establishment of Neolithic economies and on botanical remains. A new Early Neolithic economies.

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*Figure 44. Stone tools and potsherds divided by volume of soil as an indicator of the intensity of human activity and/or time, and bone fragments divided by volume of soil as an indicator of animal presence/consumption in the cave. Data after Trump (1983) and Levine (1983).*
community would have relied mostly on sheep herding; in the following phase, between Early and Middle Neolithic, the introduction of new cultivars such as legumes (Bakels 2002) may have reduced the need for meat and milk and given more importance to farming. This picture fits the increase in cattle, and the peak in human activity revealed by artifact density. At some point in the Late Neolithic-Early Copper Age, either the community moved its central dwelling to somewhere else, or a more mobile pattern of subsistence led to regular but only seasonal presence in the cave. This would be supported by a slight increase of ovicapprines but not cattle and pig. Cattle, especially in the milking period, may have been kept near the village, which would correspond to historically-recorded practices (Ferrante and Mattone 2004; Le Lannou 1941: 117), or possibly they may have become less profitable because of less abundance of pasture due to reduced precipitation, and therefore kept in smaller numbers. Pigs may have been kept for periods of time in the oak forest as historically documented, and this would correspond to the spread of forest due to climate change and fires.

The analysis of the age structure, particularly for ovicapprines, is evaluated based on ethnographic models as reflecting a natural population pattern, where animals are not
regularly killed as an economic strategy, but just occasionally, or even butchered after their natural death. Such pattern would lead to the inference that shepherds temporarily occupied the site, with no regular butchering taking place. However, this is considered between tentative and speculative because the number of individuals is too small when subdivided in phases and groups, and all phases spanning over 4000 years were therefore added up (Levine 1983: 122-123). In fact, Webster (1996: 60) argues for an emphasis on butchering young animals, which would imply husbandry for meat rather than for secondary products.

Even if important, it must be underlined that Filiestru is nonetheless a very small sample that cannot be considered necessarily representative of different areas of Sardinia, and especially the study area investigated through isotopic analyses. Unfortunately, the remaining faunal assemblages have much shorter time spans, often questionable stratigraphies, and as has been already pointed out, the methods of analysis are not comparable because they are not explicitly explained (Wilkens 2004). In other cases they are ‘preliminary’ notes that instead of anticipating full reports, ended up replacing them. Such short reports can only be taken as gross approximations of what a standard archaeozoological report should be like, and consequently provide only blurred impressions of the real post-depositional and post-recovery patterns. Two Middle Neolithic cave contexts list species of small mammals that have been considered suspiciously early, and may be due to burrowing and disturbance from later layers (Wilkens 2004: 184).

Excluding the reports with no quantitative information but only lists of documented species and genera (Agosti, et al. 1980; Sanges 1987; Sanges and Alcover 1980) and looking at all assemblages from the Neolithic to the Early Bronze Age (Boschian, et al. 2002; Cassoli 1974; Levine 1983; Sorrentino 1982; Wilkens 2004), there is a great variation in the relative frequencies of domesticated vs. wild mammals. Most of these wild mammals are small-sized species, mainly Prolagus, complemented at some sites by moderate occurrences of fox, other rodents and insectivores, and at some sites by relatively few remains of larger-sized wild mammals, amphibians, reptiles, birds, and fish (Figure 46).

All sites where Prolagus is found in large quantities are natural caves, except one which is a rock-carved tomb (su Crucifissu Mannu, tomb 16: Cassoli 1974). This emphasizes the point that, despite some consumption as food, Prolagus is likely to have been intrusive at many sites, as well as the few remains of birds, frogs, snakes, turtles, foxes and other
mammals that would have found comfortable shelters in sites permanently or temporarily abandoned by humans or would have been brought into such dens as food by small carnivores. Examining separately faunal assemblages in tombs (Figure 47), two can be assimilated to caves, the other one, Padru Jossu (Sorrentino 1982), may have had a different post-depositional history and/or utilization pattern, since only offerings of domesticated animals are represented.

It is possible to appreciate the presence of biases depending on the site type itself and on its susceptibility to intrusion of small mammals after or during human utilization by looking at the proportion of domesticated and wild species in the three open-air settlement assemblages (Figure 48). These three contexts, despite their distinct chronological and cultural diversity, all show percentages of domesticated animals over 90%. Assuming that daily food refuse should reflect overall economy and diet better than assemblages that come from ritual, marginal and/or disturbed deposits, this reflects an economy fully reliant on food

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Figure 46. Barchart with relative proportions of faunal remains at all Sardinian sites dating from the Early Neolithic through the pre-Nuragic Middle Bronze Age (see text for multiple sources). Since published data on Padru Jossu are preliminary and relative to groups of skeletal elements in association with no definite NISP, it is not strictly comparable with the rest, but only provides a rough quantitative approximation.
Figure 47. Barchart with relative proportions of faunal remains at Sardinian burial sites at least partially included in the Late Neolithic-Early Bronze Age timespan (see text for sources). Absolute number of specimens is on top of each column. Since published data on Padru Jossu are preliminary and relative to groups of skeletal elements in association with no definite NISP, it is not strictly comparable with Via Besta and su Crucifissu Mannu. It only provides a quantitative approximation.

Figure 48. Barchart with relative proportions of faunal remains at Sardinian open-air settlements dating from the Late Neolithic through the pre-Nuragic Middle Bronze Age (see text for sources). Absolute number of specimens is on top of each column.
production (of course this concerns primarily protein needs and possibly lipids, but botanical remains did not yield any evidence for significant wild food sources either).

Aquatic resources are very different in their preservation potential. Fish, rich in soft tissue, is usually underrepresented in a given assemblage because of the physical and mechanical features of its skeleton, which is made up of small and fragile bones. Furthermore, since screening was not standard practice in most excavations until recently, much of what did not deteriorate for taphonomic factors was not retrieved. On the other hand, molluscs have a very low yield of edible tissue, but their shell is usually remarkably well preserved. They are often highlighted by archaeologists for their use as ornaments. Both marine and land molluscs are documented at virtually every dwelling site and many burials, in varying proportions. Rowland (1987) drew a list of sites where marine shells were reported in previous literature, but no attempts to update it have since been made. This testifies of movements of goods between the coast and the interior, but no nutritionally significant presence of shellfish has ever been documented. Besides unique finds such as whale bones or lobster shell fragments in suspicious contexts (Ferrarese Ceruti and Fonzo 1995; Germanà 1995: 64), fish bones were found in small but significant numbers in the Early Neolithic layers at Filiestru (genus undetermined), at the coastal site of Punta del Quadro, where there is no chronological distinction within the Neolithic, and at the Copper Age open-air site of Monte d’Accoddi (Levine 1983: 125; Wilkens 2004). As discussed in chapter 3, sea-level rise must have obliterated or eroded the majority of Early Neolithic coastal sites. However, it has not been ascertained whether a temporary marine regression during the 3rd and part of the 2nd millennium (as has been well documented in the Turkish Aegean: Kayan 1997) may have caused also most Copper Age coastal sites to be submerged in later times.

Mollusks and fish could have assumed locally, or at specific ceremonial sites, social importance as delicacies for feasting events: Contu (2000: 55) describes the presence of shells in large quantities, even in small middens near outdoor hearths, all around the large temple-platform, and the presence of remains of fish and sea urchin. Among the rare dwelling sites spanning the Late Neolithic-Copper Age transition, the situation described at Cuccuru s’Arriu is extremely important, even though quantitative data are not yet available: in Late Neolithic hut floors, shell remains are prevalent, while in the Early Copper Age, bones of
vertebrate domesticates are more frequent (Santoni 1989). At Su Coddu and Terramaini, there seems to have been a shift from more cattle to dominant ovicaprids (Melis 2003a: 738; Usai 1987). A similar status of occasional delicacies may be cited for wild birds; the use of eggs, recognized in the composition of the red paint used in tombs (Rampazzi, et al. 2002), can also be hypothesized.

From the current evidence, the overall nutritional economy on Sardinia between 4000 and 1900 BC was thus mostly terrestrial, and fully dependent on food production. Faunal assemblages are therefore most useful to understand shifts and changes within this framework. Relative proportions among domesticates are of utmost importance to define differences in managing the different livestocks and their importance in relation to plant foods. Besides the still outstanding case of Filiiestru, a general look at the composition of all available assemblages covering the Neolithic up to the Middle Bronze Age shows that ovicaprids dominate most assemblages (Figure 49), with percentages lower than 60% in only one case (Su Coloru, Middle Neolithic). Unfortunately only NISP are available, and

![Figure 49. Barcharts showing relative proportions of domesticates (NISP): at various sites in Sardinia from the Early Neolithic to the Middle Bronze Age (all sources in text); absolute number of specimens is on top of each column. Since published data on Padru Jossu (in brackets) are preliminary and relative to groups of skeletal elements in association with no definite NISP, they are not strictly comparable with the rest. They only provide a quantitative approximation.](image-url)

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from Filiestru it appears that this tends to underrepresent the importance of cattle, and particularly of pig, compared to the MNI (see above). On the other hand, diagenetic and taphonomic processes probably tend to underrepresent ovicaprids since their skeletal elements are much smaller. So, even if it is presently impossible to assess how representative of depositional patterns these proportions really are, we may reasonably consider them as good working approximations for gross comparative purposes, without entering the specifics of meat yields (Vigne 1992).

Our sample must be considered while taking into account the presence of geographic variation which certainly affected the economic choices within the constraints of the communities’ system of values. The few multi-layered sequences are for this reason key testimonies: at both su Coloru and Filiestru (Levine 1983; Wilkens 2004) there is an increase in cattle from the Early to the Middle Neolithic (Figure 50). Cattle is dominant at both phases at su Coloru, which speaks of a peculiar local economic aspect. At Filiestru, the increase in *Sus scrofa* in the latest phases, when the site had become an occasional shelter or hunting camp, may be due to wild pig, since the report does not mention any differentiation. The lowest proportion of pig and highest of ovicaprids in the Late Neolithic/Early Copper Age

![Barchart with relative proportions of faunal remains at Sardinian cave sites dating from the Neolithic through the Middle Bronze Age (see text for sources). Absolute number of specimens is on top of each column.](image-url)

*Figure 50. Barchart with relative proportions of faunal remains at Sardinian cave sites dating from the Neolithic through the Middle Bronze Age (see text for sources). Absolute number of specimens is on top of each column.*
may support the model that pastoralism may have gained importance, possibly in coincidence with the beginning of seasonal movements entailing several months away from the village. Proportions of domesticates in burial contexts (Figure 51) are more likely to reflect ritual preferences more than economic facts. Whereas the four assemblages considered are generally parallel to the cave sites, the absence of cattle and dominance of ovicaprines from the Bell Beaker layer at Padru Jossu (Sorrentino 1982) are notable. This, compared with the following Early Bronze Age where cattle is present, has been interpreted as reflecting an increase in the importance of agriculture between the two phases (Ugas 1982b), although the final report is still awaiting publication (Fonzo, personal communication). Two important assemblages from burials have been analyzed but the data are unfortunately not yet published: Scaba ’e Arriu and Santa Caterina di Pittinuri, both dating to the Copper Age (~3200-2500 BC). Particularly interesting is the latter, which contains an unparalleled prevalence of pig mandibles (Fonzo, personal communication): needless to say, this rather than nutritional importance reflects a fundamentally ritual preference, as confirmed by stable isotopy (see chapter 8).

Figure 51. Bar chart with relative proportions of domesticates (NISP) at Sardinian burial sites at least partially including the Late Neolithic-Early Bronze Age timespan (see text for sources). Absolute number of specimens is on top of each column. Since published data on Padru Jossu (in brackets) are preliminary and relative to groups of skeletal elements in association with no definite NISP, it is not strictly comparable with Via Besta and su Crucifissu Mannu. It only provides a quantitative approximation.
Considering the fauna from the few published open-air sites (Figure 52), ovicaprids are dominant, above 60% in the two sites from the 4th and 3rd millennium BC, and as well from the 2nd millennium BC site of Bruncu Madugui (Fonzo 1987). However, cattle seem to be consistently present in higher proportions than many cave sites: above 25% of NISP at Late Neolithic Contraguda (Alhaique, et al. 2004: 36; Boschian, et al. 2002: 262-263) and Middle Bronze Age Madonna del Rimedio (Santoni and Wilkens 1996). Whereas at Contraguda and Monte d’Accoddi cattle is more common than pig, at the later site pig comes second after sheep/goat.

Not enough data are available in order to assess whether this is a temporal trend reversing at some point during the Copper or Early Bronze Age, or rather a geographic pattern, with northern sites being more amenable for cattle raising due to moister conditions and consequently better pasture. This is also a pattern documented historically. Comparing Sardinian assemblages with those in peninsular Italy (Figure 53) underlines the strong role of sheep in the island’s economy and historical ecology. Ovicaprids at comparable latitudes in

![Figure 52. Barchart with relative proportions of domesticates (NISP) at Sardinian open-air settlements dating to the Late Neolithic and Copper Age, with two Middle Bronze Age sites for comparison (see text for sources). Absolute number of specimens is on top of each column.](image-url)
Central and Southern Italy are more common in the Early and Middle Neolithic (between 45-85%: Wilkens 1992; Wilkens and Delussu 2002), but much less than in Sardinia, and they further decrease in the Final Neolithic and Copper Age, when cattle and pig show NISP percentages in some cases higher than 50% (cattle at S. Maria in Selva, pig at Atiggio, layer 4: Wilkens 1992).

In the Italian mainland there seems to be some increasing emphasis on cattle towards the Final Neolithic and Copper Age, and anyway generally fewer remains of ovicaprines, a situation maintained with wide variation through the Bronze Age. Sardinia instead seems to show possible an increase only in the Middle Neolithic, and subsequently not earlier than the Middle Bronze Age. Conversely, sheep/goat would appear to have been even more important in the Copper Age, when pig may also have gained importance locally and possibly in the later centuries. In Sicily (Figure 54), lesser importance of ovicaprines is documented in the Late Neolithic, with a gradual increase in the importance of pig through the Copper Age, particularly as shown at the multi-layered site of Grotta Chiusazza (Leighton 1999: 60, 90).
Sardinia finds instead better parallels in the arid area of Southeastern Spain (Figure 55), where a consistently high proportions of ovicaprines is recorded (Chapman 1990: 116-118).

An important point lies also in the lack of evidence for older bovines, which is found instead at some contemporary sites in Italy (Wilkens 2003). This contradicts the hypothesis of use for plowing and transport (Wilkens 2004: 185), while ovicaprines seem to have been killed at all ages, so they appear to have been exploited for both meat and milk, and probably wool, since we know that generally this fabric appeared in Western Europe between Copper Age and Early Bronze Age, over the course of the 3rd millennium BC (Sherratt 1997a: 180-181, 203-205, 233-234). On the other hand, ovicaprines were tended for milk already in the Early Neolithic (Vigne 1998). As concerns pigs, it has been argued that in Sardinia as in Corsica, they were mostly kept loosely in the forest, since the morphometry is similar to wild boar: in case of animals strictly controlled near the dwellings, the two subspecies maintain rather distinct characteristics (Albarella, et al. 2006; Wilkens 2003).

Figure 54. Barcharts showing relative proportions of domesticates (NISP) at various sites in Sicily, from the Early Neolithic to the Early Bronze Age (data after Leighton 1999). Absolute number of specimens is on top of each column.
In conclusion, the evidence of biotic remains, also summarized visually in tabular format (Table 7), suggests:

1. at least from the Middle Neolithic, all main Neolithic cultivars were present in Sardinia. It is unfortunate that we do not have any data for Copper and Early Bronze Age sites, because hulled barley and olive are documented in the Middle Bronze but there is no way to pinpoint when they were first used as foods;
2. seafood had an overall negligible nutritional importance; coastal sites integrated their agro-pastoral economies with occasional gathering of molluscs, which may have further decreased during and after the Copper Age;
3. hunting of *Prolagus* and other mammals was practiced but is hard to quantify throughout the examined period, due to possible intrusion at cave sites in later times and to the scarcity of its remains at open-air villages;
4. ovicaprines were generally prevalent at most times and locations;
5. cattle raising seems to have increased only in the Middle Neolithic, at least in northern Sardinia, while at Filiestru, our longest documented sequence, an increase in ovicaprines
in the Late Neolithic may have coincided with the beginning of some kind of seasonal movement of the flocks;

6. after the Early Neolithic, ovicaprids probably represented the most important domesticate again in the Copper Age (Monte d’Accoddi, Filaiestru 4), with possible local and/or later emphasis on swine (Filaiestru 3, 2, Santa Caterina di Pittinuri?) through the Middle Bronze Age;

7. age at death of sheep/goat indicates differentiated uses: they were likely exploited for milk already in the Early Neolithic, while we do not have specific data concerning wool. Elsewhere in Western Europe wool sheep appeared in the Copper Age (Sherratt 1997a: 203-205), and this was likely the case for Sardinia. This is supported by the high frequency of loom weights. Since old cattle are scarce, there is no evidence for their widespread use for traction. Plow and carts may have been routinely used in the Bronze Age or later.

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**Table 7. Synthetic prospectus of possible trends in agriculture and animal husbandry in prehistoric Sardinia ~4000-1900 BC, as identifiable from biotic remains and phenomena documented elsewhere in the Western Mediterranean**

<table>
<thead>
<tr>
<th>Phase</th>
<th>Tree crops</th>
<th>Seafood</th>
<th>Wild fauna</th>
<th>Domestic animals</th>
</tr>
</thead>
<tbody>
<tr>
<td>LN (Ozieri)</td>
<td>Probably just figs, wild</td>
<td>Occasional mollusk</td>
<td>Scarce, occasionally</td>
<td>Less cattle from MN, ovicaprine</td>
</tr>
<tr>
<td>4000-3200 BC</td>
<td>berries and nuts</td>
<td>gathering</td>
<td>Prolagus</td>
<td>dominant</td>
</tr>
<tr>
<td>ECA (Post-Ozieri)</td>
<td><em>Probable increase in</em> acorn?</td>
<td></td>
<td>Beginning red deer</td>
<td>More ovicaprine</td>
</tr>
<tr>
<td>3200-2500 BC</td>
<td></td>
<td></td>
<td></td>
<td><em>Start wool sheep?</em></td>
</tr>
<tr>
<td>LCA (Monte Claro)</td>
<td><em>Possible start olive</em> cultivation?</td>
<td>Quantitatively</td>
<td>?</td>
<td>Possibly more pig</td>
</tr>
<tr>
<td>2700-2300 BC</td>
<td></td>
<td>negligible, progressive</td>
<td></td>
<td>(locally)?</td>
</tr>
<tr>
<td>Beaker</td>
<td></td>
<td>decrease?</td>
<td></td>
<td>More ovicaprine</td>
</tr>
<tr>
<td>2400-2200 BC</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EBA</td>
<td>Possibly hulled barley</td>
<td></td>
<td>Quantitatively negligible?</td>
<td>Possibly more pig</td>
</tr>
<tr>
<td>2200-1900 BC</td>
<td>diffusion?</td>
<td></td>
<td>?</td>
<td>(locally)?</td>
</tr>
</tbody>
</table>

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5.3. Osteology and Paleopathology

The study of skeletal remains from Sardinian prehistoric sites started early in the 20th century, following the methods and theoretical assumptions of the times. Since the 1960s the general approach has not changed radically, and the few scholars who analyzed the collections made available through excavation have tended to focus their attention on cranial measurements aimed at identifying genetic groups classified into “types”, with scarce interest for any statistically significant documentation of pathological conditions detectable from the bones.

Therefore, to this day, the few studies dealing specifically with paleopathology of prehistoric Sardinian populations are only brief reports on overall trends recognized without systematic nor quantitative approaches (Germanà 1992a, 1999). A number of researchers from the 1950s and 1960s (Maxia 1964; Maxia and Atzeni 1964; Maxia and Fenu 1962, 1963; Maxia, et al. 1973), and more recently the research group at the University of Cagliari (Cosseddu, et al. 1983; 1994a; 1994b; Floris and Sanna 1999), and Germanà in Sassari (Germanà 1992b, 1995) produced analytical and synthetic studies mainly focusing on anthropometrics (Figure 56). Additionally, many collections were recovered in contexts that had been looted or not excavated scientifically, and therefore attributed to cultural/chronological phases based on loosely associated material culture. Several attributions have been corrected by direct radiocarbon dating of bone, starting in the early 1990s and continuing up to now, so that much of the (mostly metric) data regarding Neolithic and Copper Age had to be assigned to the later Bronze and Iron Ages (Cosseddu, et al. 1994b; Sanna, et al. 1999). The outcome is that whereas until 15 years ago we did not have any comprehensive or at least coherent corpus of data on pathologies but some data on morphometrics that could be tentatively organized in a sequence (Germanà 1995), now even much of the latter are not useful for the period of interest here, which is 4th-beginning 2nd millennium BC.

There are only scanty data from Middle Neolithic skeletal materials to be compared to later times. The group of Grotta Rifugio (Oliena), composed of 11 individuals and associated with Bonuighinu cultural markers, has been evaluated based on dental health as having a balanced nutrition, possibly based on processed food and fats (Germanà 1995: 45).
Figure 56. Map showing the location of sites mentioned in the text, for which some kind of quantitative osteological information has been published. Map by the author, based on cartographic material from S.A.R. Sardegna consortium, with kind permission.
Fat is actually one of the factors that can favor the occurrence of arthrosis (bone formations in the bone surfaces of joints), which is documented at the site with remarkable frequency, at all levels of the spine. Caries are rare, but serious, while occlusal wear is more common. Sexual dimorphism was strong, average stature being 162 cm for males and 150.4 cm for females. Two individuals showed bone formation in the radii related to the intense and specialized use of the arms (Germanà 1981). Three individuals from the Middle Neolithic burials at Cuccuru s’Arriu (Cabras) had statures of 148, 162, and 163 cm and were slightly more robust than the group from Grotta Rifugio; they had no caries, but some occlusal wear was reported (Germanà 1992b).

Concerning the Late Neolithic, out of the three relatively large skeletal collections still considered pertinent in the early 1990s (San Benedetto-Iglesias, Is Aruttas-Cabras, and Lu Maccioni-Alghero), the last has been radiocarbon-dated to the 12th-9th century BC (Cosseddu, et al. 1994b), the second to the 15th-12th BC (this study). Consequently, the only large population is currently San Benedetto (Maxia and Atzeni 1964), that counts 35 individuals, radiocarbon dated to the first half of the 4th millennium. To this, only three individuals from the cave sa ’Uccà de su Tintirriolu near Mara (Germanà 1995: 64-65), can be added. Average stature of the group from San Benedetto is 160.5 cm for men, 151 cm for women. Caries occurrence not higher than 2% is reported. This, from large comparative databases to be taken with caution (Larsen 1997: 187-189), would place this population at a level slightly higher than foragers. Such low levels are likely to indicate that the consumption of processed cereal products or starchy, sticky foods was not very intense. Partial, unpublished data from a systematic study of dental pathologies might indicate, though, higher occurrence (R. Floris, personal communication). Possibly the proportions in the original report referred to number of individuals with caries rather than to number of teeth out of the total. Low consumption of processed foods seems also supported by the remarkable development of mandible ridge in all individuals, indicating heavy masticatory stress. While in the case of occurrence in a few individuals this could be due to specialized activities, such a widespread trait is to be connected to consumption of hard or resistant foods, as would be expected in a carnivorous diet. Furthermore, the demography of the group includes a large
percent of elderly (38.9%), which besides the additional possible exclusion of children from the burial, could indicate that life expectancy was relatively good.

The only collection that has been partially studied dating to the Copper Age, Post-Ozieri tradition is from Santa Caterina di Pittinuri (Cuglieri), a rock-carved tomb that yielded important evidence for ritual and offerings (Cocco and Usai 1988). The MNI calculated on bone elements is 65, although from loose teeth the represented individuals are over 200. This highlights the long utilization of the tomb, confirmed by the two radiocarbon dates, which have non-overlapping ranges and span over a thousand years (see below, chapter 6). This is particularly important because, since no earlier diagnostic potsherds were recovered, the dates can safely be referred to the Post-Ozieri phases, rather than being potentially related to bone remains handled but kept in the tomb from Late Neolithic times. No data are available on the bone elements beyond sex and age counts, while the analysis of several thousand teeth revealed very unhealthy conditions, with caries levels at about 18%. Data on Monte Claro populations are extremely scanty: in a sample of less than ten individuals from Serra Crables (tomb 2), Padru Jossu and La Crucca, it is remarkable only that four surgical interventions are documented, at least two following trauma (Germanà 1999). Caries, occlusal wear and pre-mortem tooth loss are also documented in the same period (Germanà 1995). Cranial and postcranial measurements were performed on skeletal remains recovered in the early 20th century at Anghelu Ruju (Alghero), a necropolis pertaining to the Late Neolithic through the Early Bronze Age period: unfortunately, all remains have been lost, and no contextual data were produced (Germanà 1984).

Among the dozen individuals studied of probable (su Crucifissu Mannu, tomb 15) or stratigraphically documented Bell Beaker period date, besides some dental problems within the norm, it is important to underline the occurrence of cribra orbitalia in five cases, which can be connected to several causes, including genetic anemia, parasitic or infectious diseases, or malnutrition (Germanà 1987, 1999). The Early Bronze Age is the best documented, since it usually represents the last phase of utilization of the tombs carved since Late Neolithic times; over 190 individuals have been studied. Unfortunately, they were recovered at different sites, with the common focus on craniometrics, so that useful data are less than this number would suggest. The three large collections come from s’Isterridolzu (Ossì), Pedralba (Sardara), and Iscalitas (Soleminis, included in the isotopic study section of this dissertation), with the addition of about 20 individuals from several tombs recovered at su Crucifissu
Mannu (Alghero) and other smaller groups (Buffa, et al. 2000; Businco 1934; Germanà 1995: 117-136). The most striking element is the frequency of *cribra*, an anomaly of the bone surface that appears pitted by small or larger cavities. Including both orbital and cranial, it is found in the groups from northern Sardinia in 20-35% of the individuals. The presence of at least four cases of cranial surgery in the form of trepanation is also documented. In the group of su Crucifissu Mannu and in the more substantial sample of Iscalitas, occlusal wear was very frequent and often severe; at Iscalitas this was found even in deciduous juvenile teeth (Usai, et al. 2005: 188-190).

An overview on stature based on extant data (Germanà 1998), particularly after excluding the newly radiocarbon dated specimens that turned out to be later (Cosseddu, et al. 1994b; Sanna, et al. 1999; this study, for Is Aruttas), would be quantitatively insignificant, because only few individuals per each phase could be measured. Middle Neolithic males are on average 162.2 cm tall, women 150.4 cm (based respectively on 13 and 6 long bones). In the Late Neolithic group of San Benedetto, males’ average is 160.5 and females’ 151.0 cm (Maxia and Atzeni 1964). All data for the following Copper Age phases are based on five or less long bones, and they are not therefore relevant even for single groups, while stature of the Early Bronze Age Iscalitas population is 169 cm (average on 8 males) and 154 cm (one female) (Usai, et al. 2005). In addition to this scarcity of data, we must consider the problem of applying equations for calculating stature to long bones already sexed based on dimensions. This procedure is likely to skew the numbers toward an overestimation of sexual dimorphism.

Most available data are synthesized in Table 8. This table is to be considered an impressionistic, preliminary attempt to outline trends useful to understand possible meaningful patterns, with no pretense of being accurate due to poor documentation. As far as dental health is concerned, based on San Benedetto (Late Neolithic), Santa Caterina di Pittinuri (Early Copper Age), Pedralba, su Crucifissu Mannu and s’Isterridolzu (Early Bronze Age), there were worse pathological conditions, particularly caries, from the first to the second site, and a sharp decrease, possibly indicating better health, in the Early Bronze Age groups (Coppa unpublished). Germanà (1999: 29) reports the highest frequency of caries during the Monte Claro phase (northern groups), and confirms its scarcer occurrence both before and after (besides collections considered by Germanà, see also Cuccuru Nuraxi and Iscalitas, where caries occurs in ca. 3%: Atzeni 1958: 103-104; Usai, et al. 2005). Most data
Table 8. Synthetic overview of tentatively identifiable trends in pathologies and other indirect indicators of stress or dietary patterns.

<table>
<thead>
<tr>
<th>Period</th>
<th>Caries</th>
<th>Occlusal wear</th>
<th>Cribra &amp; hyperostosis</th>
<th>Stature dimorphism</th>
<th>Trauma &amp; trepanation</th>
<th>Cranial shape</th>
</tr>
</thead>
<tbody>
<tr>
<td>MN-LN 4700-3200 BC</td>
<td>Low</td>
<td>Higher</td>
<td>Low</td>
<td>Moderate?</td>
<td>?</td>
<td></td>
</tr>
<tr>
<td>ECA 3200-2500 BC</td>
<td>High</td>
<td>Lower</td>
<td>Low?</td>
<td>Higher?</td>
<td>Low?</td>
<td>Longer?</td>
</tr>
<tr>
<td>LCA 2700-2300 BC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>High (north)</td>
</tr>
<tr>
<td>EBA 2200-1900 BC</td>
<td>Low</td>
<td>High</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

refer to number of teeth rather than individuals, although in older studies this is not clear. As mentioned above, caries may derive from high reliance on foods rich in carbohydrates and therefore is generally proportional to reliance on farming. Otherwise, it may also depend upon processing techniques, and even among populations of foragers frequent caries have occasionally been detected (Larsen 1997: 68-71; Meiklejohn, et al. 1992). An impressionistic evaluation of the trend in occlusal wear from previous observations may confirm the pattern, documented worldwide in societies that made use of pottery and therefore presumably cooked their plant foods (Molleson and Jones 1991; Molleson, et al. 1993), of an occurrence inversely proportional to caries; this is clearly the case at Iscalitas, possibly also at San Benedetto and Padru Jossu. Contu (1997: 426-427) also mentions severe tooth wear in EBA remains. In fact, it appears to be more common and serious during the Neolithic than later; which might point out to a more intense consumption of non-processed foods. The only study that addressed dental wear quantitatively (Buffa, et al. 2000; Usai, et al. 2005) found that at Iscalitas wear was angled, a pattern typically associated with agriculturalists who process their grains as opposed to flat, which is typical of foragers (Smith 1984). Lack of explicit attention to the covariation of dental health and age should be a warning, since older populations should accumulate more pathologies with time, so that dying young could result in a false impression of good health (Wood, et al. 1992). On the other hand, it does not seem that Early Bronze Age populations have a higher age at death.
than Copper Age populations, possibly lower, which if confirmed could make such a pathology even more significant.

Porotic hyperostosis and *cribri*, sporadically present during the previous phases, seem to become more common in the Beaker phase of Padru Jossu, and to increase sharply in the Early Bronze Age and later (Germanà 1999: 27; Germanà and Ascenzi 1980; see also Moravetti, et al. 1998). Among the limitations of this marker is the presence of several potential causes for the same symptoms, since infections, parasites (hookworms etc.), and genetic anemia leave similar traces on the bone. In fact, while anemia was commonly considered the main cause, increasing evidence widened the spectrum of potential etiologies, some of which can be distinguished through microscopy (Wapler, et al. 2004), which would be a fundamental subject for future research, for the remaining factors the relative incidence depends on environment: in tropical latitudes, parasites are very common, while in areas like parts of Africa and the Mediterranean, genetic anemia such as thalassemia and G6PD deficiency are genetic traits selected for as they provide resistance to the endemic malaria (Larsen 1997: 29-40; Siniscalco, et al. 1961). In Sardinia, the malarial environment is well documented historically since Roman times, when political adversaries of the empire would be sent to the island with the hope they would die of disease; malaria is believed to have been a major factor hindering economic development until after World War II (Brown 1986; Le Lannou 1941: 72-81; Webster 1996: 43). Besides lack of iron, vitamin deficiency has also been shown to be associated with *cribri*, particularly scurvy, a chronic illness due to insufficient intake of vitamin C (Melikian and Waldron 2003; Ortner, et al. 1999; Salis, et al. 2005), but vitamin B-12 deficiency also causes anemia.

While arthrosis has been reported only from the Middle Neolithic site of Grotta Rifugio, there is some mention of trauma and especially cranial trepanation starting in the Monte Claro groups of northern Sardinia and in the Early Bronze Age, in seemingly relevant proportions especially for the small Monte Claro sample (Germanà 1999: 31-32); one case is documented also at the Early Copper Age site of Scaba 'e Arriu (Fonzo, personal communication). No clear distribution of pathologies according to sex seems to be discernible, although at Serra Crables all cases of tooth loss and anomalous dentition are documented for females, and at Padru Jossu it seems that *cribri* were more frequent in females (Germanà 1980a, 1987). This, coupled with the uneven occurrence of trauma, may
fit the pattern of changing gender roles with an increase in male dominance that material culture overshadows, and/or reflect a different division of labor.

Decreased sexual dimorphism itself, which can be one of the consequences of reliance on agriculture with the change in lifestyle it involves, can be assessed only based on stature (Figure 57) calculated on a small number of remains (Foschi Nieddu 1986: 19; Germanà 1981, 1998; Maxia and Atzeni 1964; Maxia and Fenu 1962): expressed as M-F/F, it decreases from Middle Neolithic individuals from Grotta Rifulg to those from San Benedetto, it is higher in the small Monte Claro sample of Serra Crabiles, lower in the Late Copper-Early Bronze Age groups of Iloi and Anghelu Ruju, and much lower in the few specimens from Concali Corongiu Acca II. For the Sardinian Neolithic, average stature as found in the literature is higher than the average in Neolithic mainland Italy, but the groups are not comparable, since calculations are based on different systems: Germanà (1995: 220) utilized the Manouvrier method, despite more recent ones, yielding lower statures, being shown to be more accurate for Neolithic populations (as in Robb 1994b: 199).

Figure 57. Barchart showing sexual dimorphism in stature in Sardinian human remains dating from the Middle Neolithic (distinguished by the blue color for being earlier than the studied period) to the Early Bronze Age (data sources in text). Absolute number of elements/individuals the index refers to are on top of each column, males on right and females on left of each pair. See text for explanation of the index.
Cranial shape has mostly, even recently, been used as a proxy for ‘racial’ origin and classification. It is clear since the mid-20th century that a major role besides genetics affecting cranial shape is played by stress-related muscle stimulation. Nevertheless, the trait most highlighted in the literature is the index of cranial elongation as an indicator of “racial” origin. Additionally, this continuous variable is artificially transformed into a discrete one (dolicomorphous vs. brachymorphous). Rather than origin, it can reflect dietary adaptations related to mastication: in several instances foraging has been found associated with more robust and elongated crania, whereas after the onset of farming and especially of pottery technology, consumption of softer foods is associated with reduction of this robusticity, and with faces that are smaller and less protruding (Larsen 1995: 196-197 and references therein; 1997: 226-232). Such an interpretive key has not been suggested to explain variation in Sardinian cranial shapes. As found in the cited literature on Sardinian skeletal remains, from the Bell Beaker phase there would be an increase in newcomers with long heads (Figure 58).

While genetics may account for some variation, a revision of the large mass of cranial measurements, a product of a long-lasting preferential interest, would probably reveal much more.
about the lifestyles of prehistoric communities of Sardinia, more than it did the quest for
evidence of migration. Shorter crania may be connected to heavier consumption of processed
foods. Beyond the limitations mentioned for specific indicators, an important point to
consider is also that in general, since most recent paleopathological data come from
Germanà’s work, the approximate description may depend heavily on his particular research
interests and strengths.

5.4. Material Culture Evidence

5.4.1. Figurative Representations

Much of this section for obvious reasons draws from information already presented in
chapter 4 on material culture, and it serves the purpose of focusing on the functional and
practical inferences that can be drawn from material culture.

The representation of animals or plants likely to have been food sources may be
important to understand at least the emic perspective of the community or group that
determined their production. This is to say that such figurative testimony can hardly ever
reflect the bare nutritional importance of what is reproduced, but it is the complex result of
the social settings and relations behind it. In a way similar to faunal remains, to be considered
as eco-artifacts due to their different contexts, we can consider so-called ‘artistic’
representations. They are, however, extremely rare in prehistoric Sardinia, at least until the
Final Bronze-Early Iron Age transition around the 10th-9th century BC. As covered in chapter
4, concerning pottery, decoration is in some phases barely present: most of the later Post-
Ozieri tradition and Early Bronze Age Bonnanaro A. In others, it involves impressions, lines
and grooves with little indulgence to figurative motifs (Monte Claro, Bell Beaker).

Following a Middle Neolithic trend, it is mainly in the Ozieri phase and its later
tradition that human and animal figures are present on pottery, in funerary art, in rock art,
statuettes, or incised on loom weights. While human figures have been mentioned in chapter
4 as cultural elements, here I focus on animal figures, which, in Sardinian prehistory, are
mostly bovine figures. Plastic representations of bovine heads are found on Middle Neolithic
vessels of Bonu Ighinu style, and on handles of ceramic and stone vessels (Lilliu 1999: 108-
Apart from these sporadic examples, the context where bovine protomes or their abstract surrogates are most common is the burial one, clustering in the *domus de janas* of northwestern Sardinia. The number of occurrences is probably now closer to a hundred, not including multiple representations within the same tomb.

The bovine head is clearly recognizable in naturalistic examples, attributed to the Ozieri ceramic phase, while in later developments it becomes more abstract, and it may itself be an imitation of dwelling architecture and decoration that is expressed in many other details (Cámara Serrano and Spanedda 2002: 376-379). The ears, evidently not as meaningful, disappear, while the horns are simplified into linear motifs or merge with the geometric motif of the spiral, so that often it is not possible, nor possibly meaningful, to distinguish them (Tanda 1984, 1998). The geographic distribution, corresponding to the overall distribution of funerary art beyond the simple carving of tombs, covers the northwest corner of the island, with significant extensions toward the central highlands and the coastal west, apparently following a distribution that in some areas is roughly complementary to the areas of densest megalithic burials. Possible outliers may be seen in the more abstract motifs decorating tombs in the Southwest (Montessu and others), around Pimentel (Usai 1989a), and in the East, where they seem to occur in a specific version (Ogliastra: Pitzalis 1996).

The importance of bovine representation has been connected to a new mythology and ritual connected to the rise of pastoral practices (Usai 1992: 382-383), and to the productive potential involved in the ox-drawn plow in the exploitation of marginal land with further opportunity to increase wealth inequality. This would have given a powerful symbolic role to the animal that was responsible for wealth production, and as documented in several East African societies, may also have been important to acquire wives (Cámara Serrano and Spanedda 2002: 379-380). Comparatively few cases have been interpreted by some scholars as representing ovine protomes (e.g. the so-called Domus dell’Ariete, the Tomb of the Ram: Lo Schiavo 1982, and a few others), but some disagree on the identification, and their style is so simple and geometric that it may be impossible to agree on a single match; in any case, they would be a slim minority compared to the widespread and intense phenomenon of bovine heads spanning the whole duration of the northwestern Ozieri tradition.

It must be underlined that not only does the frequency of bovine representations not match our current knowledge of its economic importance as a direct food source that we have from faunal analyses, but in fact it may possibly be a symptom of the opposite trend. In
southern Italy, bovine representations have been found to increase precisely when their dietary relevance – as shown from faunal remains – declines in favor of ovicaprines (Cassano 1993: 229), and a similar trend is documented in Saharan Africa. In Sardinia, after the first cases dating to the Middle Neolithic, the highest frequency dates to the Final Neolithic-Early Copper Age, and the scarce faunal data currently available may well be compatible with a trend similar to the Italian peninsula.

While there are some decorative motifs defined or described in terms of ‘leaflets’ and ‘branches’, mostly in the Monte Claro phase, to my knowledge there is no undisputable representation of anything identifiable with plants or plant foods in Sardinian prehistory before the bronze figurines in the later Bronze and Iron Ages. On the other hand, indirect evidence of the production and processing of possibly both vegetal and animal textile fabrics, has been identified in the representation of clothing items and decorative textiles on pottery and tombs (Lilliu 1999: 92-102; Tanda 1988, 1995a).

5.4.2. Lithic Implements for Food Production, Processing, Consumption

Simple flaked tools, mostly made of obsidian, have been common on the island since the Early Neolithic. However, the microlithic retouched flakes typical of these early times are not as common in the Late Neolithic Ozieri phase. Usually these instruments have been interpreted as elements for sickles and other composite tools, but this would not explain their drop in the Late Neolithic, since regardless of the prevalence that pastoralism may acquire, farming should have remained one of the pillars of subsistence. The prevalence of obsidian from the SB Monte Arci subsources could account for the small size of tools in the 6th and 5th millennia BC, since this kind of obsidian is mostly found as cobbles of small dimensions; the exploitation of SC and particularly SA subsources allowed an easier, more standardized, production of longer blades (Cappai, et al. 2004: 229; Lugliè 2000a: 23-25), which could have replaced the small elements for the same practical applications, while possibly increasing the range of uses. The increase in arrowpoints through the Neolithic (Lugliè 2000a; Lugliè and Sebis 2004), if they are functionally, beside symbolically, connected with hunting, would make sense in an island where the first Neolithic settlers only had small mammals to hunt. The multiplication of introduced deer, and of wild boar and moufflon after
their drift and speciation from sheep and pig (see above), must have gradually increased the pool and relevance of potential game, while the social significance of hunting was probably enhanced by its association with maleness in the context of increasingly defined gender roles.

To my knowledge, no specifically functional or economic meaning has been suggested for the peak in foliate points in the final phases of the Post-Ozieri assemblages (phases C and D: Melis 2000d: 67-68). Considering some evidence for an increasingly difficult acquisition of obsidian (Cappai, et al. 2004) and apparently also chert (Melis 2000d: 67), a higher relative proportion of very specialized and standardized tools may make sense as the best realization of their potential, for materials that were starting to become rarer, and consequently less utilitarian and more symbolic. In other words, raw materials whose appreciation had become very high were not used for a wide variety of daily tasks as much as before, but reserved for the manufacture of valued status symbols. Therefore, I believe that no linear correlation with economic facts lies behind these trends. In fact, in the following phases, Monte Claro, Bell Beaker and Bonnanaro A, formal tools found in burials represent the majority of the flaked lithic industry.

Conversely, a specific type of large, flaked adze, mostly made of volcanic rock, that has been convincingly shown to date to the Sub-Ozieri and particularly to the Monte Claro phase (which in the southern and western lowlands directly follows Sub-Ozieri: Lilliu 1988a: 163-164; Lugliè 1988, 1992, 1999), due to its less formalized aspect and its recovery in open-air settlements, may mark either a new activity or a different way of performing the same task: in order to understand such function, microwear analyses, which has been undertaken up to now only on obsidian assemblages (Hurcombe 1993; Hurcombe and Phillips 1998; Setzer 2004), would be extremely useful.

As discussed in chapter 4, there is not much systematic, quantitative information regarding grinding implements, and no broad investigations on their variation over time in terms of type, size, frequency, and context. While being represented at all phases included in this dissertation, and often recovered through surface collection at sites with long occupation periods, an impressionistic reading of the literature seems to pinpoint that at some Copper Age sites their frequency was remarkably high. This involves both sites of the Post-Ozieri tradition such as Su Coddu, Monte d’Accoddi, sa Corona (Lilliu 1988a: 127, 141; Melis 2000d: 69), and Monte Claro; in this last phase, they also appear to be on average larger than before. Despite the wide variation, overall shape seems to change from more oval with a flat
grinding surface in the Neolithic, to more elongated with a concave top in the Copper Age (Atzeni 1981: xlii; Contu 1997: 344-345; Lilliu 1988a: 164). At Biriai (Oliena), thousands of grinding implements have been found, either exhausted, broken and reused in walls, or still in use at the time the site was abandoned. The main observation resulting from the small sample of 85 specimens studied is that despite the large site (about 300 houses), grinding stones are rarely larger than 50 by 40 cm, and most of them can only be used with one hand (Neuville 1999). No large-scale food processing was evidently carried out, and apparently the grinding of cereal and other foodstuffs was performed at a household level. This seems to suggest that daily food processing activities were not organized by a managing power and probably were not even done communally in larger kin groups as in the Bronze-Iron Age Nuragic villages.

Concerning the Beaker and Bonnanaro A phases, since they are represented mostly by funerary contexts, it is no surprise that food-processing implements are not known in the literature. In fact, two fragmentary grindstones were retrieved at Costa Tana, one of the few known dwelling sites (Santoni 1996). Interestingly, from the isolated hut excavated at su Stangioni (Portoscuso) several pestles are reported, but no millstones (Usai 1994: 242). Such small implements fit the reconstruction of the site and of the material culture as that of a temporary or seasonal campsite for mobile herders.

Generally, what was ground in the millstones is almost certainly for the most part cereal grains, as most of the evidence shows in Mediterranean prehistory as a whole. Lewthwaite (1982), however, notes the large amounts of acorns recovered in southern France at Copper Age walled settlements, to which the northern Sardinia Monte Claro sites have commonly been compared. The increase in evergreen oak in the pollen diagrams across the Western Mediterranean (see chapter 3), already evident in the early 1980s and even better ascertained today, may therefore have been deliberately favored as an advantageous, unintentional byproduct of clearing through fire. Besides human consumption, this would also fit the possible increase in swine tending that has been observed at many locations also in the Italian peninsula in the Copper Age.

What may have been the function of the so-called “testa di mazza” (Italian for “club-heads”) remains unclear. If their use was indeed as weights for digging hoes, their intensification through the Copper Age and later (Contu 1997: 205, 344-345; Lilliu 1988a: 122, 140; Santoni 1996; Usai 1994), especially from the Monte Claro phase, may be connected to an intensification in farming practices. If at least some of them were used as
weapons or ceremonial objects, their frequency may be also connected with the increase in trauma and organized ritual activity that the impressionistic overviews of osteological and artifactual data reveal. No synthesis about the frequency of hardstone axes is available in the literature. While the miniature ones could hardly have had a practical function, the larger specimens may have served to clear vegetation and various domestic tasks, and were present in the whole western Mediterranean area. Their apparent decrease in the Copper Age (Melis 2000d: 70) could be part of the same shift in the system of values that is reflected by the emphasis on maleness and herding as opposed to farming.

The remains of a *sui generis* lithic-earth implement has been identified in structures on the island of Lipari, which were made of stones, some of which are somewhat aligned around the feature. They are inside and on top of pits with traces of combustion (Bernabò Brea and Cavalier 1960: 10-13), and have been interpreted as earth ovens, or pits for the slow cooking of large quantities of meat, possibly whole animals, at special feasting events (Robb 2007: 148-151), in a way that was still practiced until a few decades ago. In Sardinia, to my knowledge there are no structures that have been interpreted this way, and it would certainly be useful to review the reports on some of the hundreds of excavated *fondi di capanna* looking for similar atypical characteristics.

5.4.3. Ceramic Implements for Food Processing, Storage, and Consumption

Ceramic ware shapes and sizes have been used in archaeology to infer function since the birth of processualism and mostly up to the 1980s. The recognition that especially in less complex societies implements are often multitask rather than specialized warns against any kind of simplistic conclusion. Vessel shapes and dimensions have been characterized through ethnographically documented associations with specific uses, which did enable the identification of some general predictors to be utilized in interpreting function in archaeological artifacts. Parameters such as the openness of the vessel (ratio between rim circumference and vessel surface), the rim diameter, and the volume, have been shown to be to a certain extent related to function (Sinopoli 1991: 80-98; Smith 1988). This type of inference is much more productive when applied as part of a direct historical approach, since where some degree of continuity can be reasonably demonstrated, analogy becomes more reliable since it is supported by the duration of structural cultural phenomena, rather than
being based on generic convergence in human behavior. While vessels for processing, washing and cooking tend to be more similar and often multitask, serving vessels may be more commonly recognized for being finer and more decorated. Individual consumption, dry and liquid storage and/or transport are usually more distinct, and have been statistically predicted with more success (Smith 1985). However, there is clearly a wide range of possibilities that need to be taken into account; large vessels, for instance, can be used for storage but also in feasting contexts, so that they are not necessarily a linear measure of wealth and surplus. They can also be borrowed for specific occasions, so that status cannot be easily detected through their presence (Nelson 1985).

In Sardinia, the tripod is one of the most common and distinctive types of the Late Neolithic Ozieri period, it lasts in different versions and decorations until the Early Bronze Age. As mentioned in chapter 4, its frequency decreases in the Early Copper Age, Filigosa phase (Melis’s phase C), but is still present in Monte Claro contexts, especially in the South. Its revival during the Bell Beaker and Early Bronze Age Bonnanaro A phases (Atzeni 1995, 1996a; Contu 1997: 180, 313-314, 342, 362-363, 429-431) may be due to different functions. Trump (1990: 41-42) relates tripods to heating porridge made of cereal and milk. This practice would have been replaced, after the Early Bronze Age, by bread baking on low pans and platters on one hand, and milk processing in tall, large vessels with an internal ledge on the other, marking the shift towards more specialized processing of resources. This interpretation would fit the higher frequency of millstones at Monte Claro sites, indicating that possibly grains were then increasingly ground into flour while milk was separately processed, instead of eaten together with less processing. The increase in *cupules* or *cupmarks*, small concavities created in the rock or on menhirs, seems also significantly parallel to the decrease in tripods: even though *cupules* seem to be documented in Sardinia particularly at burial sites, their frequent presence on ‘altar slabs’ in the center-East of the island, and their suggested association with cereal grains in Corsica (Frau 1996; Lilliu 2002: 206-207, footnote 96 and references therein) could be an indication of specific preparation habits.

It is important to note that Trump considers all tripods from the Neolithic through the Early Bronze Age as fulfilling a similar function, which was replaced by baking on the low pans that become widespread at that time. However, taking into account the discontinuity between Copper Age and Bell Beaker tripods, their different shape and contexts, it seems that
rather than cooking vessels, the latter were mostly components of ceramic sets related to specific drinking practices, likely connected to the consumption of alcoholic beverages (Sherratt 1987, 1995). The Bell Beaker and Early Bronze Age tripods are mainly found in burials along with the remains, as grave goods or offerings, whereas tripods in the Ozieri tradition seem to be more common in dwelling sites or related to cooking and consumption in the anticelle, the liminal rooms of the rock-carved tombs (Santa Caterina di Pittinuri: Cocco and Usai 1988). Common shapes in funerary contexts are instead the so-called vasi a cestello and pissidi (Pranu Muttedu: Atzeni 1981; San Benedetto: Maxia and Atzeni 1964), also found in open-air settlements, which are peculiar types apparently linked to personal consumption, possibly including narcotic substances.

Some vessel shapes with internal rims, typical of the Monte Claro phase, have traditionally been attributed to milk processing, and labeled as milk-boilers (Contu 1997: 339; Lilliu 1988a: 172). Their more intense distribution in the central belt and in the Sardinian Southwest (Lilliu 1988a: 171-174; Usai and Santoni 1998), areas with strong contemporary pastoral tradition if compared with the plains of the South and Northwest, may provide some indirect support, although residue studies are showing in recent years how such inferences may turn out erroneous (Craig, et al. 2003).

From the Copper Age Sardinia certainly partakes of the general change in ceramic repertoires that characterizes most of Western Europe: the diffusion of containers for liquids (bottles, jugs) and the increase of vessels for individual consumption (chapter 4). This is again likely to be related to social and symbolic behaviors rather than mere subsistence practices. Chronologically, such changes, which in continental Europe have been interpreted as reflecting alcohol consumption (Sherratt 1987) take off in Sardinia in the advanced Post-Ozieri (Filigosa, phase C: Melis 2000d), continuing in the Beaker phase and in the Early Bronze Age. A conspicuous increase in brewed alcohols may have affected the cultivation of grains, as suggested by macrobotanical evidence (Bakels 2002: 7).

Keeping in mind the caveats discussed briefly above, we can also consider the functional meaning we can draw from vessel size. While Ozieri and Post-Ozieri ceramic pots typically are less than 500 cm$^3$ in volume, it is in the Copper Age, including the Post-Ozieri assemblages but particularly the Monte Claro phase that the largest vessels are documented. Some of the tall ziri (jars) and situlae were so large as to be used within tombs, broken, as a burial bed (Lilliu 1988a: 148, figure 42). Vessels around 90 cm tall and 40 cm wide (Contu
1997: 338), in some cases with an internal volume over 3000 and nearly 4000 cm$^3$, found mainly in the southern lowlands, seem compatible with human groups that produce and/or concentrate surplus beyond the needs of a household. However, it is uncertain whether this was wealth in the form of surplus foodstuffs, or instead surplus collected occasionally for social gatherings. In the hut ps at Monte d’Accoddi, large jars were recovered (Melis 2000d: 55), to my knowledge the largest ever found in the long Post-Ozieri tradition: significantly, this building was near the well-known temple-platform that represents a unique ceremonial site in Sardinian prehistory. It is important that several Monte Claro sites, at least in the center-north of the island, also include ceremonial areas clearly identifiable and distinct from the dwellings, a fact that may fit the interpretation of large jars (which are not as large as in the south) as feasting utensils rather than storage implements, which is documented elsewhere (e.g., Mills 1999; Nelson 1985). Similarly large storage vessels are not documented among the known Beaker assemblages and from the standard Bonnanaro A repertoires, which are almost all funerary or cave sites. Typical volumes do not exceed 500 cm$^3$ (tripods), although a type of large jar over 1600 cm$^3$ in volume was actually found at the only Early Bronze Age dwelling site that has been systematically excavated (Usai 1994). These large jars continue through the different phases of the Bronze Age, as the typical biconic jars with inward ledge (a tesa interna) and other large containers (Campus and Leonelli 2000: 602-612).

Important, non-alimentary secondary vegetal and animal products are also textiles and basketry: impressions of mats on vessels, formed when the clay was still soft, are reported in sherds from several locations dating to the Neolithic and Copper Age (see also: from Via Basilicata, in Atzeni 1967; those listed in Lugliè 1988; and from Cuccuru s’Arriu, in Santoni 1989), whereas proper textiles are more rare (Vittoria di Nuraxinieddu: Tanda 1995a: 40, possibly linen). Due to the sharp seasonality of Mediterranean climate with moist and dry conditions alternating every year that favor decay of organic materials, no remains of textiles were preserved. Among non-vascular ceramic items, loom weights and spindle-whorls represent, if not a dietary practice, an economic one which is important for the integrated reconstruction of prehistoric systems of production and consumption. Besides the few impressions on clay, and figurative art (see above), they are therefore the main indirect testimony for weaving. Spindle whorls are present throughout the period but there are no specific studies on them. Loomweights are common in the Late Neolithic, and especially in...
the Copper Age. The latter are the only ones that have been systematically studied, and this has allowed the documentation of their variation, sophistication, and in some cases remarkable dimensions and weight, which all point to a flourishing activity (Melis 1993). Their recovery in groups in domestic contexts has profound implications. Even though similar objects made of wood and perishable materials could have existed, so biasing our judgment, we can relate this florescence to the use of wool, possibly in coincidence with the diffusion of woolly sheep. This increase in loom weight presence is documented elsewhere, and the increase in the symbolic importance of decorated textiles suggested for the 3rd millennium has been also connected to the Bell Beaker decorative motifs. Among the types found in Sardinia, the kidney-shaped ones are frequent in Late Neolithic Ozieri contexts, while at least three types are documented in several Copper Age contexts. Some loom weight types find comparisons in mainland Italy, whereas at least one, with several fine holes in rows, seems peculiar to Sardinia (Melis 1993: 150-152), pointing to some kind of local technological specialization.

5.5. Landscape Use and Occupation

5.5.1. Broad Patterns

Landscape archaeology in Sardinia is still moving its first steps. Very few projects have been undertaken that had, as one of the primary goals, that of systematically investigating the change in the occupation and use of landscapes across time within a given area. Many projects aimed at cataloging all the archaeological sites in a town’s territory, which produced a large mass of data that do not have common methodological standards, thus preventing full comparability. Moreover, since the rationale for many such projects was more or less explicitly cultural resource promotion for touristic purposes, monumental architecture became the focus, while settlements, ceramic and lithic scatters, and less evident signs of human presence were likely overlooked. In the last fifteen years, the only two large-scale systematic projects that stand out for their thoroughness and scholarly organization are the Rio Mannu Survey Project (van de Velde 2001; van Dommelen 1998), focusing on Iron
Age and Roman sites, and the Progetto Iloi (Tanda 1996a, b), which will be mentioned below.

This premise makes it clear that much of the evidence we have for settlement and landscape use patterns is likely not to be homogeneous, accurate and systematic, but rather “impressionistic”. The advancement of research shows over the course of the years how many such impressions and patterns may be changed. In this section I examine broad patterns as they have been identified in the literature, and then sample a few areas that have been investigated and reported on relatively well.

The first synthesizer who attempted to outline the spatial patterning of human presence on Sardinian land is Lilliu (1988a). His general description is still valid today, although later research has added to his dataset, enriching and correcting it. The Late Neolithic characterized by Ozieri pottery marks the moment of densest occupation of the island before the Middle to Final Bronze Age. The total number of sites was 165 in the mid-1980s (Lilliu 1988a: 69-70). Considering as a site one where Ozieri pottery was found, the count may now be over 250, but I am not aware of a later update that aims at being comprehensive. If we also attribute to this period all rock-carved tombs found on the island, which are over 2500, the count is much higher, despite the fact that many of the tombs are in groups within the same site.

It has been observed that the highest density of sites is found in the plains around the main Gulfs, Cagliari and Oristano, and in the Sassari-Alghero area. In Lilliu’s statistics, which are still a fairly good rough indicator of patterns, 43% of all sites were within 10 km of the present-day coastline. What is important, though, is also that signs of human presence are found for the first time in all regions of the island, and also in the central mountains, with pottery found at altitudes over 800 m asl and obsidian up to 1400 m. The typical location for open-air living sites is on low elevations in or near alluvial plains. It must be underlined that these data merged together Ozieri sites and others that are now considered Copper Age Post-Ozieri sites, two phases that show remarkable continuity at many locations. Keeping this in mind, site size is also to be considered the sum of areas occupied in Late Neolithic times, in Early Copper Age times, and in both. Villages seem to be on average large in the Campidano plains, where they have been investigated: between 2 and 4 hectares (Lilliu 1988a: 83-86). In one case of extensive investigation some hut floors were found to show possible evidence for
specialized craft manufacture, with large quantities of pottery and obsidian, respectively (Puisteris, Mogoro; Lilliu 1988a: 86).

As concerns the *domus de janas*, the rock-carved tombs typically associated with Late Neolithic pottery even if later reused, they are particularly frequent in the Sardinian Northwest, near Sassari, Alghero and in an area that extends to the South near Cuglieri and Asuni, and into the central highlands in the regions of Goceano and Barbagia. Other denser clusters are found in the Southwest (Sulcis) and in the East (Ogliastra). Densities are particularly remarkable in the highlands, where the typology is simple and often involves a single room: in the Barbagia Ollolai approximately one tomb every 5 square km. Within this region, the territory of Fonni, which includes the highest elevations on the island, has a density close to one tomb every two square km (Fadda 1989a; Lilliu 1988a: 90). All these, however, are for the largest part not excavated, so that we cannot be certain of how many belong to the Late Neolithic and how many were first carved in the Post-Ozieri Copper Age. Since cupules, which have been shown to be most common in the Copper Age, are often the only decoration, even if they may have been added to pre-existing tombs, it seems that many *domus de janas* were carved in the 3rd millennium. As already mentioned in chapter 4, tombs reach remarkable complexity in plan and decoration mostly in the Northwest corner of Sardinia during the Copper Age; in the hundreds of tombs in the highlands, both bovine representations and portable human figurines are extremely rare (Fadda 1989a).

Since Lilliu merged Ozieri and Sub-Ozieri ceramic style into one aspect, and the latter is only found in the South, and also considering that the late Post-Ozieri sites are known mostly from burials, the demographic trend between Late Neolithic and Copper Age seemed to be a sharp decline. Only 24 sites were then known, versus 165 from the former phase (Lilliu 1988a: 133). In reality, considering the Sub-Ozieri as a distinct phase within a continuum, and the much shorter duration of the late Post-Ozieri phases (Melis 2000d), this trend is not as evident anymore. A systematic study of geographic patterning of Copper Age sites within the Post-Ozieri tradition shows a progressive shift of the location choice at higher average elevation (Figure 59). Also, the ratio between dwelling sites over burials decreases through Melis’ pottery-based phases A-E: open-air settlements are dominant in the Sub-Ozieri (A) phase, they are in equilibrium in the B phase, and become rare in the C and D phases, which are documented mainly by tombs. From a geographic perspective, most phase A sites are
Figure 59. Barchart illustrating the trends in the elevation of archaeological sites in different cultural phases within the Post-Ozieri tradition (data from Melis 2000x). The proportion of lowland sites declines, and inversely the proportion of highland sites increases.

southern, most C-D are northern, so rather than only chronological phases the effect may be enhanced by geographic variation, but no statistical tests for covariation have been attempted (Melis 2000d: 93-94).

The change in average elevation is correlated to a parallel shift from lowland areas with good agricultural potential to hills and highlands, today for the largest part covered by scrubs; this may reflect either a different economic strategy where herding and/or farming in marginal lands became more important than in the past due to climate change, or that non-economic factors were favoring the selection of areas for the intensification of economic activities that were less practiced in the past. It is important that closeness to ore deposits has not been found to be a relevant factor in site location. Site location has also been analyzed as concerns hydrology: average distance from coasts and coastal lagoons increases over time, whereas distance from springs decreases (Figure 60). Again, the statistical significance of these findings has not been tested for covariation: parameters such as altitude, distance from coasts and from lagoons, and closeness to springs (Melis 2000d: 93-108) are likely to be positively correlated, so these crucial descriptive data may reach their full explanatory potential in the future with multivariate statistical methods.
Figure 60. Barchart illustrating the trends in the distance of archaeological sites from freshwater springs in different cultural phases within the Post-Ozieri tradition (data from Melis 2000e). There is a decrease in the proportion of sites further than 2 km from freshwater springs, and an increase particularly evident in the proportion of sites within 400 to 1000 m from springs, a comfortable walking distance. However, the problem of correlation with altitude has not been addressed.

Site catchment analysis, despite the many underlying assumptions that have generated increasing doubts on its usefulness after the 1960s and 1970s (Bailey 2005b; Depalmas 1996: 34) has in Sardinia a somewhat late florescence, and has been often applied to Sardinian prehistoric sites (Foddai 2001; Melis 2000d: 111-119; Melis and Vacca 2000; Onesti 2001; 2002: 12-19). Its contribution has generally been that of confirming the shifts in site selection outlined above. Interestingly, this approach has been limited to single-site analyses, whereas a consideration of the several geological and pedological parameters in a matrix including large numbers of sites could give deeper insights into overall, broader patterns of variation.

The Monte Claro ‘culture’, which as discussed in chapter 4 has been commonly considered brought to the island by outsiders due to the sharp distinctiveness in material culture features, is present all over Sardinia, and the number of recorded sites, 90 in the mid-1980s (Lilliu 1988a: 143), could probably be today over 150. Their distribution is particularly
dense in the Sardinian Southwest, in the southern lowlands, and in the hills, located between the southern plains, Monte Arci and the central highlands (particularly the regions named Marmilla and Trexenta). In the former, the typical site-type is the cave burial, whereas in the Campidano, Marmilla and Trexenta, Monte Claro pottery is rather found in open-air villages (Dessì 1989; Lilliu 1985). In the northern half of the island, Monte Claro settlements are built at higher elevations, with stone foundations for houses, and in some cases massive megalithic walls were constructed around part of the village. As compared to the Ozieri and Sub-Ozieri settlement pattern, where over 40% of sites were located within 10 km from the coast, there is a clear shift inward, with less than 20% being documented within the same belt; on the other hand, 91% of sites (lowlands and Marmilla) are on areas historically cultivated for cereal (Depalmas 1989; Lilliu 1988a: 143-149), leaving unsubstantiated the hypothesis that an increased economic emphasis on animal husbandry could be at the root of this cultural change.

Research in the last decades has shown that some of the sharp contrasts documented in the prevalence of a certain site type in any given region may be due to lack of research. In the island’s southwest, large villages, comparable to those in the north, have been identified, with similar megalithic architecture and rectangular hut plans (Canino 1998; Usai 1997; Usai and Santoni 1998).

No clear data on site size are available for Monte Claro villages: in the most investigated area, settlements were often inhabited in the preceding phases, and not always a quantitative assessment of areas occupied in each phase can be found in the reports. At the site of San Gemiliano (Sestu), often cited in the literature as an example, only eight huts yielded Monte Claro pottery, in contrast to several tens from earlier phases. This and other settlements have an area ranging from about one to a few hectares, and in the north distinct areas, interpreted as ceremonial or defensive, are defined by megalithic walls or standing stones (Lilliu 1988a: 149-153).

The problem of the nature of the Monte Claro aspects and its relationship with previous phases is a crucial issue for the understanding of the dynamics underlying the observed changes. This is in turn fundamental for a holistic interpretation that may overcome the common place of migration and replacement often perpetuated acritically in the literature. Lilliu (1988a: 148) calculated that about one-third of Monte Claro sites, most located in the southern and western plains (Atzeni 1981), had been occupied also during the Ozieri/Post-
Ozieri phase. In the western plains, there is a clear occupation break at some sites, whereas others have a Monte Claro phase strongly represented. Some continuity in ceramic style has been recognized at Conca Illonis by Locci (1988), who suggested that rather than cultural factors, environmental change possibly related to the nearby Cabras lagoon may have led to the progressive abandonment of different sites at different times. Other elements of similarity have been identified in the apse-houses, documented in villages of both Monte Claro and Post-Ozieri tradition, as well as in the plan of rock-carved tombs of the latter phase (Pitzalis 1996; Tanda and Depalmas 1997).

Rather than migration of newcomers into the island, therefore, patterns of occupation in the landscape are as much compatible with a change in site location preferences by the same groups, which coincided with a change in pottery style. If sites on the lowest coastal areas were progressively abandoned and higher density is recorded on higher plains (Middle Campidano) and low hills (Marmilla, Trexenta), this may coincide with a lowered water table due to increasing aridity (see chapter 2). In economic terms, this may be interpreted both as an increase in emphasis on animal husbandry, or rather as a necessary means to have agricultural land with more viable rates of precipitation and maintain, rather than change, previous subsistence practices. A similar argument holds in general for the shift towards higher elevations in the whole Ozieri/Post-Ozieri sequence.

The Bell Beaker phase, chronologically overlapping with Monte Claro and evolving into the following Bonnanaro A, is known mostly from tombs, while just a few sherds have been found in Monte Claro open-air sites (Ferrarese Ceruti 1981a). The overall number of sites is the lowest of all phases in the 4th and 3rd millennia (36 in the mid-1980s: Lilliu 1988a: 185). However, its geographic distribution is quite different: a stronger presence is recorded in northwestern Sardinia (one-third of all sites), where the earliest style is also represented, and in the southwest, where the later style seems more frequent and shows a more gradual drift towards and into the later Early Bronze Age Bonnanaro A pottery (Atzeni 1996a; Ferrarese Ceruti 1989; Lilliu 1988a: 185). While Monte Claro pottery is also well represented in these areas, the sharpest contrast is in the hills of Marmilla and Trexenta mentioned above, where very few finds are recorded in contrast with the high density of Monte Claro sites. The Bell Beaker style is the first clearly intrusive element in a long indigenous autonomous ceramic tradition, and it coincides with the increase in the use of metal. Considering that the southwestern and northwestern regions of the island are rich in metal ore, such distribution
may reflect the main interests that such groups had on the island. Rather than being related to primary, food-production choices, closeness to raw materials better explains such patterns.

In the Early Bronze Age, a similar distribution pattern is recorded for the Bonnanaro A ceramic phase, which evolves directly from the Bell Beaker. The densest occupation is still in the Northwest and Southwest (Lilliu 1988a: 320), but the whole island is better covered, including the highlands, where Beaker finds are comparatively rarer (Fadda 1989b; Ferrarese Ceruti 1978). The emphasis on caves, for the most part believed to represent burials, could also involve a return to cave dwelling, which would be compatible with the lesser investment on house structures typical of seasonally mobile groups; this, along with coarse pottery, and the only investigated open-air site being a roughly-constructed single household structure, are all elements that have been recognized as reflecting mobile animal husbandry (Abdi 2003: 405-407).

5.5.2. Case Studies

A closer look at a few sample areas can better illustrate some of the problems highlighted above on a smaller, more localized scale. This will provide real cases and show the complexity of drawing inferences from non-systematic or non-comparable data.

An area including several towns in central-western Sardinia (Borore, Dualchi-Noragugume, Aidomaggiore, Sedilo), approximately 120 square km in size, has been investigated, providing relevant data for the 4000-1900 BC period (Depalmas 2001; Tanda 1996a), as part of a larger project, the Progetto Iloi, which is one of the few accurate, systematic and comprehensive archaeological projects ongoing in the last decades. On the central altiplano, both rock-carved tombs, mostly curvilinear and simple, and megalithic tombs are found (Moravetti 1985: 6-7). In the contrary, near the creeks connecting it with the lower fluvial valley and with the higher terraces there is a clear prevalence of megalithic tombs. This may be a confirmation of the association between megalithism and pastoralism, very common in the literature: megaliths would represent symbols of land-use rights in passes important for seasonal mobility of the flocks, whereas the rock-carved tombs would represent more sedentary, farming communities. The largest settlement in the area, Serra Linta (Sedilo), dates to a late phase of the Late Neolithic Ozieri (Tanda and Depalmas 1997) or possibly to the transition to the Early Copper Age, although dating is based on lithics, no
pottery is published from the site. It is located in the alluvial valley of the main river, the Tirso; its location has been interpreted in terms of economic strategies emphasizing farming land (Depalmas 1996). Megalithic walled hilltops, not yet excavated, are attributed to the Copper Age, between the final Post-Ozieri and Monte Claro. Only three of them, at about 10-15 km from each other, seem to reflect needs of defense and visual control (Depalmas 2001: 102-104). The only two allées couvertes (see chapter 4), that the author seems to place in the Early Bronze Age, are found on the main river’s bottom valley, not far from the largest rock-carved necropolis in the area and from the open-air site of Serra Linta. This seems more compatible with the Early Copper Age chronology for dolmenic monuments as suggested by Cicilloni (1994), since it would fit the Neolithic-Early Copper Age cultural and spatial continuity already discussed. These, and the small dolmens (see also Depalmas 2001), are interpreted as reflecting a phase of intensification in the exploitation of productive lands, which seems an important point if attributed to the Copper Age.

The Bonu Ighinu valley, where many early discoveries crucial for Sardinian prehistory were made, has been researched thoroughly in the 1970s and 1980s through survey and excavation: the caves of sa ’Ucca de su Tintirriolu and Filiestru yielded some of the earliest stratigraphic sequences (Loria and Trump 1978; Trump 1983). At the beginning of the history of the human landscape, Filiestru, the largest cave in the valley, is the only inhabited site, housing an estimate of 20-30 people. Population seems to have increased in the Middle Neolithic, after which the site identified at Monte Noe became the main settlement, whereas the caves became occasional shelters or cult sites. A smaller open-air site has also been documented. The community’s burial ground has been recognized in the rock-carved necropolis of Bitti, completing the picture of the human landscape in the Late Neolithic (Trump 1990: 49-50). Among the problems with the data is that the open-air sites were attributed to the Late Neolithic only based on lithic scatters, since no sherds were found. Moreover, the next phase mentioned is the Middle Bronze Age (after 1900 BC). The 1300-year hiatus may have occurred but seems unlikely; assuming that the Post-Ozieri Copper Age is included in what is identified as Late Neolithic Ozieri thins the gap to possibly 500-600 years. Some admittedly atypical features documented at the Nuraghe Noeddos village (both pottery and architecture, for which see Webster 1994), could be attributed to the Monte Claro period, which in the 1970s and early 1980s was not as thoroughly known yet.
The territory of Bonarcado, on the foothills of Monte Ferru, to the north of the Western plains around the Cabras Lagoon, seems to have weak evidence for occupation even in the Late Neolithic; no rock-carved tombs are found, nor dolmens or menhirs. Three open-air sites are attributed to the transition Late Neolithic-Early Copper Age, and five megalithic walls to the later Copper Age (Manca 2002: 26-35). The following phase documented is marked by corridor nuraghi, a building type that is currently dated to the Middle Bronze Age. The geographic position on the border of the Western plains where Neolithic communities prospered, and the first traces of human presence dating to the Early Copper Age, support the reconstruction of a shift in residential preferences towards higher elevation, and a sharp decline in human impact on the landscape in the Early Bronze Age.

The territory of Gesturi, in Marmilla, was systematically investigated in the early 1980s (Lilliu 1985). The area includes part of the flat basalt altiplano known as sa Jara, with scarce evidence of human occupation before the Middle-Late Bronze Age, and a fertile hilly area to the southeast, with several streams running through it, where all Neolithic and Copper Age sites are found. The first human presence documented dates to the Late Neolithic-Early Copper Age, consisting of four rock-carved tombs and a few megalithic monuments, with the addition of the burial at Mind’e Gureu (Fonzo and Usai 1997), part of the sample for isotopic analyses. Two allées couvertes are the only pre-Middle Bronze Age structures on the altiplano. If pertaining to Copper Age groups, they would reflect the trend for expansion into higher elevations considered as a general feature of this phase. Only one site yielded Ozieri pottery, while Monte Claro sherds were recovered at 14 locations, witnessing to the first intense presence on this landscape currently characterized by cereal cultivation and pasture. The Monte Claro sites are on hills, separated by streams that deeply incise the landscape, and a few km apart from each other. After that, no evidence of Bell Beaker and Bonnanaro A finds is mentioned, so that if not a hiatus at least a contraction in density of settlement seems to be likely up to the transition Early-to-Middle Bronze Age, when the large structure of Bruncu Madugui was built (Lilliu 1985: 298), marking the beginning of a new phase of expansion and control of the landscape. Again, the first occupation is documented in the Late Neolithic-Early Copper Age, followed by intensification in the later Copper Age Monte Claro, and by subsequent contraction. Economically, this seems once more to indicate an interest for agricultural land that increases during the Monte Claro period.
Somewhat similar to the landscape history near Bonarcardo is that of the territory of San Sperate, about 25 km², which instead is located in the southern lowlands. In fact, no signs of human presence dating prior to the Early Copper Age have been identified (Ugas 1993b: 205). Neolithic sites are known farther north, east and west; the extremely low elevation, nowhere higher than 70 m asl, may have obliterated through erosion and flooding possible older settlements: no prehistoric materials were identified at elevations lower than 40 m. The only six sites attributed to the 4th and 3rd millennia, mostly located in the northeastern and eastern area where the altitude is over 40-50 m, pertain to the Sub-Ozieri and Monte Claro ceramic aspects. Again, a hiatus characterizes the area up until the end of the Early Bronze Age. Importantly, of the three Monte Claro sites (Ugas 1993b: 98-101), one continues a prior Sub-Ozieri site, and two are located near the few available freshwater springs (Piscinortu), where currently lies the only forested portion of San Sperate’s territory. Some similarities are found in the territory of Decimoputzu, more to the west; main discrepancy is the presence of several sites dating to the Late Neolithic Ozieri, some larger than others, on low hills in the midst of flat lowlands (a typical geomorphologic feature known in Sardinian as ‘cuccuru’). Two out of five are still occupied in the Early Copper Age, while two new sites in the western hills confirm the discussed trend upward (Ugas 1990: 21-23). Here, Monte Claro pottery is only found on already existing sites, which strengthens the impression of continuity from the initial Copper Age developments of the Ozieri tradition, in contrast to models arguing for intrusion and cultural break. Continuity remains a constant even through the Copper-Bronze Age transition: Bell Beaker pottery was found at one site, and Bonnanaro A pottery at the same three sites where human groups had been living for roughly a thousand years. The spatial continuity of Monte Claro-period presence is confirmed, although burials change location (Ugas 1990: 21-23).

In the contiguous territories of Iglesias and Villamassargia (southwestern Sardinia), over a vast area of more than 100 km², surface collections and non-systematic archaeological surveys provide some data to investigate spatial patterns. The area has at its center a long plain, roughly 10 km wide and oriented E-W, which connects the larger lowlands stretching from Cagliari to Oristano with the coast and plains of the southwest. It is bordered by hills and mountains, which in the northern section open up in valleys and creeks. The whole area is very rich in natural caves. The human presence in the landscape is well rooted into the Early Neolithic and Middle Neolithic phases. The Middle to Late Neolithic transition
definitely follows the general pattern already identified, with the occupation of highland areas that were possibly previously unexploited. Interestingly, the Late Neolithic Ozieri pottery is present at 14 locations all in the Iglesias area, and no mention of Ozieri-tradition Copper Age sites is made (Alba 2001a; Canino 1998). Since the Ozieri label could include later development of the same style, such pattern may be parallel to what has been observed elsewhere, with a shift to higher elevations in the Copper Age (the area near Iglesias is higher than the plains). However, it may just reflect the impact of construction works near the town; moreover, geomorphological processes still to be considered may also have contributed to systematic bias. The Monte Claro phase seems to have represented in this region the highest population density, if we accept site number as a proxy: open-air villages and particularly burial caves add up to some 30 sites, over twice as those of the previous phase.

Parallel to the general counts discussed above for the whole island, Bell Beaker pottery is found at only four sites, and its presence becomes more intense in the Early Bronze Age Bonnanaro A (16 sites, all burials). Interestingly, the highlands north of Iglesias are not occupied before nor after the Ozieri phase (Alba 2001b; Canino 1998). This increase in site density in the caves just bordering the central plains with no penetration in the uplands seems to indicate preference for locations close to farming land rather than an increased focus on herding as has been claimed for the Monte Claro pottery users.

Concluding this sample of local-scale landscape occupation patterns is the territory of Villaperuccio, covering an area of about 25 km². Human presence based on open-air sites seems relatively thin: there are only one Late Neolithic-Early Copper Age settlement in the bottom valley, and one later Copper Age Monte Claro on a steep slope (Melis 2000a). The concentration of menhirs at su Terrazzu probably pertains to the Late Neolithic-Early Copper Age (the cupules recorded at another site may indicate a later phase), as does the large necropolis of Montessu, among the largest on the whole island, located uphill from the village to which it has been attributed. Another cluster of rock-carved tombs to the southwest must indicate an additional human group, and both necropolises show reuse through all phases of the Copper and Early Bronze Age (Filigosa, Monte Claro, Bell Beaker, Bonnanaro A) (Melis 2000b, c). Here there seems to be a shift from the plain to the hillslopes at the Early-to-Late Copper Age Monte Claro transition. In reality, as the author notes, another nearby Monte Claro site is at a lower elevation: this indicates specific histories for
individuals sites, and possibly different cultural and/or economic choices in different contexts, so warning against excessive generalizations.

5.5.3. Summary of General Trends

This synthetic overview of general patterns and localized case studies can be summarized in a few important points:

1. the intensification of human presence in the highlands apparently began already in the Late Neolithic Ozieri, and continued in the Early Copper Age;
2. several lowland sites show continuity between the Late Neolithic and Early Copper Age, with a subsequent occupation break; others show continuity into, or contraction from, the Monte Claro phase; still others appear to be occupied for the first time in the Early Copper Age;
3. there is an overall shift to higher elevations in the Early Copper Age, which may reflect increased importance of animal husbandry and seasonal mobility and/or a strategy to maintain viable agricultural outputs in changing environmental conditions;
4. in the Monte Claro phase, along with continuity at some lowland sites, there is an intense presence in the hilly areas of the South between plains and highlands, with high potential for cereal cultivation: this may indicate substantial reliance on cultivating grains;
5. an increase in hilltop walled settlements – which may indicate defensive and/or ceremonial purpose - is documented in the northern half of Sardinia during the Copper Age;
6. wide areas experience an occupational break or at least a demographic decline after the Monte Claro culture, particularly in the south;
7. Bell Beaker presence, much sparser than the earlier Monte Claro, seems more intense in the northwest and southwest, possibly due to the rich ore deposits found in those areas in a period of increasing use of metal items;
8. in the Early Bronze Age, human presence in the landscape follows Bell Beaker patterns with continuity, while becoming more intense and widespread.
In conclusion, regarding specific variation within a mixed agro-pastoral system, there seems to be a decrease in settlement in alluvial lowlands from the Late Neolithic to the Copper Age, which means a detachment from the typical pattern of Neolithic riverbed farming and from the nearby aquatic resources. The trend to higher elevations could be interpreted as increased reliance on animal husbandry with occupation of marginal land, and this in turn could be due to new needs and exigencies of fundamentally cultural character, rather than related to changing environmental constraints. Alternatively, in the case of increased aridity striking the lowlands, it could be a strategy to maintain viable agricultural outputs where rains make it possible, or to facilitate the survival of the herds suffering from water scarcity. Cattle are particularly dependent on the availability of large quantities of water, more than swine, which have a metabolism similar to that of humans, and much more than ovicaprines, which are moderately drought-tolerant, being able to survive for weeks without water more than the leaf water from plants (Adebayo 1991: 14; O’Connor and Kiker 2004; Schmidt-Nielsen and Schmidt-Nielsen 1952).

Research on soils and land use potential in the area surveyed within the Progetto Iloi shows that besides the colluvial fans in their borders (Melis 1996a: 30), the plains can be exploited more productively through animal husbandry than through farming. Interestingly, the best geomorphologic-pedologic unit for farming is instead the altiplano, while some land optimal for herding is found everywhere (Melis 1996b). On the altiplano, small depressions favored the accumulation of deep soils that can keep moisture longer than well drained bottom valleys (Melis 1996a: 29).

Consequently, taken as such, the best evidence for a more mobile lifestyle in the Early Copper Age of northern Sardinia and in the Early Bronze Age remains the higher relative ratio of burials over open-air sites, which should reflect less populated and less sedentary communities, rather than the average elevation of sites. During the Monte Claro phase, lifeways were definitely sedentary, with stone-based dwellings, megalithic walls in the north, and preference for land good for growing cereal in the south. Defensive concerns may also have played a role in hilltop sites, and possibly closeness of metal ores was also a relevant factor in determining human landscapes in the Bell Beaker and Early Bronze Age phases.

One indirect way in which aridity could have induced the intensification of animal herding, although not necessarily an increased reliance on them for nutritional purposes,
could have been the accumulation of stock as an insurance against drought. There is some ethnographic evidence that at the household level, herd accumulation is beneficial for the conservation of the herd when droughts occur unpredictably (McPeak 2005). This on the one hand was likely the case for cattle, which are more susceptible to climate vagaries due to their high water needs. The social and symbolic importance of cattle cross-culturally is well known (Abbink 2003; see among others Crandall 1998; Robb 2007: 142-144 discusses its role in peninsular Italian Neolithic), and their preservation, or the attempt to increase one’s herd for heightened social competition, fully independent from changes in the outer environment, are also plausible rationales for a progressive occupation of highlands, which can be seen since the Late Neolithic. An integrated perspective should finally consider the option that such probably gradual, long-term cultural changes may have interacted with similarly long-term environmental change or with century-scale climatic change, as shown for the 3rd millennium BC.

5.6. History and Ethnohistory

The direct historical approach has been successfully applied to the understanding of societies where there was clearly some degree of continuity. For societies sans documents, whose knowledge is fully based on material remains, and already extinguished (in their material features) thousands of years before any writing was used, some have expressed the opinion that much of their meaning systems will be forever out of reach (Fowler and Hardesty 2001: 84-85; Hawkes 1954), although it has been pointed out (Robb 1998: 330-331; Sherratt 1999) that the dichotomy between technology and symbols is a fallacy, an abstraction of modern minds trying to categorize past lives and their material remains. Whatever the case, if taken in a generic sense (Ucko 1969), analogy can at least help widen our perspective of potential behaviors behind material culture patterns.

Ethnohistoric comparisons have been made on specific practices. For instance at Scaffa Piana, in Corsica, the remains of wild olives associated with unusual features have been interpreted as evidence of oil-making on the basis of present-day practices (de Lanfranchi and Thi Mai 1998). Rather than persistence of the same practices since prehistory, it is of course possible that in similar ecological and environmental conditions simple and efficient techniques were forgotten and reinvented several times over the course of six
thousand years. Similar hypotheses have been made on the use of both wild olive and lentisk berries (*Pistacia lentiscus*) to obtain oil (Lilliu 1988a: 146; 2002: 207), a practice documented in Sardinia until a few decades ago, but with no archaeological correlate. The direct or indirect nutritional use of oak acorns has been suggested with stronger arguments. The main diffusion of evergreen oak in the Western Mediterranean dates precisely to the 4th and especially 3rd millennium. Acorns have been recovered in Corsica, at later archaeological sites in Sardinia (Contu 1997: 468) and in large quantities in Copper Age walled settlements in southern France that show resemblance to the Monte Claro sites in northern Sardinia (Lewthwaite 1982). While the use of acorns to feed pigs is widespread in the Mediterranean, their utilization for bread-making, though rare, was common over wide areas of Sardinia still in the 1700s, and is still known today (Usai 1969).

The hypothesis that middle to long-distance seasonal mobility with the flocks (transhumance) was practiced in prehistory is as well based on ethnographically-documented practices. While in a few cases it has been reasonably traced archaeologically, through faunal analyses (Courty, et al. 1992) and biochemistry (Balasse, et al. 2002; Bentley and Knipper 2005), for most of the prehistoric Mediterranean it is mostly assumed due to its persistence in later history and to its alleged ‘perfect fit’ to particular climatic conditions characterized by sharp seasonal variation. According to Lewthwaite (1981), short-distance mobility with the purpose of fertilizing the fields after harvest would be more likely and convenient than long-distance transhumance following the best pastures.

Since transhumance and pastoralism are generally difficult to detect archaeologically as compared to settled lifestyles, several studies involve an ethnoarchaeology approach to investigate patterns of material culture in modern Mediterranean groups that can be related to such economic practices. Some carried out in Sardinia focused on intra-site spatial patterns and economic phenomena. Unfortunately, rather than providing clear analogues with the archaeological evidence, these studies showed instead that no easy comparisons can be made, and that all modern pastoral systems are structurally embedded into a market economy matrix, turning out to be influenced by global dynamics (Mientjes 2003, 2004). Adaptation is embedded in cultural systems that are sometimes arbitrary to ethnocentric eyes, and conditioned by specific historic events that may be impossible to detect archaeologically. An illuminating example is found in Ogliastra, on the mountainous east coast of Sardinia: transhumance to more southerly lowlands, apparently embedded in the ecology of the region,
may instead have started in the Middle Ages, when the disappearance of several towns caused the allotment of the deserted land for the common use to certain communities in the 15th century AD (Cannas 1997). In fact, there are other strictly pastoral towns that do not move their flocks from their territory and cope with seasonal variation with small-scale displacements, with territories that sometimes stretch in elongated shapes between mountains and lowlands (Lai 1998; Le Lannou 1941: 177, 205).

5.7. Summary and Conclusions

This critical review of the evidence for paleoeconomy makes it clear that from the Neolithic through the Early Bronze Age food acquisition was grounded on the same pool of elements. It was consistently based on terrestrial ecosystems and specifically on food production in the form of agriculture and animal husbandry involving wheat, barley, lentils, peas, fava beans, cattle, sheep, goat and pig. While fishing and gathering of molluscs was not common especially after the Early Copper Age, the role of hunting, even though nutritionally marginal, may have remained constant or increased, since the decrease in *Prolagus* paralleled the increase in red deer and presumably boar. This means that the main economic, nutritional differences across this period are to be understood in terms of relative importance of agricultural versus animal products.

Regarding the use of secondary animal products, Sherratt’s (1983) early influential model placed it in the mid-4th millennium for western Europe as a consistent suite of innovations - somewhat similarly to the Neolithic ‘package’. As elsewhere in Europe, a more articulated picture is emerging for each one of the elements (Sherratt 1997b): while sheep, goat and cattle were probably already kept for milk throughout the Neolithic (Craig, et al. 2005), there is no clear evidence for the generalized use of bovines for traction until later in the Bronze Age. The plow may have been used from the Copper Age, possibly by a minority in each community, but cultivation by hoe appears to have been prevalent. No evidence is available for the presence of bulk transportation means (carts), while the increase and elaboration of loom weights does suggest the flourishing of weaving, which is possibly related to the beginning of wool production.

The importance of cattle seems to have decreased from the Middle to Late Neolithic, possibly for its being less suited to endure summer droughts than sheep and goats are. This
seems to correlate with bovine heads becoming a powerful symbol in the course of the Late Neolithic and Copper Age, possibly exemplifying strength and wealth, and associated with funerary decoration. Ovicaprines are dominant at all times, with a possible peak in the Copper Age, when pig also becomes important, possibly in connection with the exploitation for acorns of the spreading of evergreen oak forests. While it is unquestionable that agriculture was fundamental in the Late Neolithic, the change in location preferences and site type in the Copper Age may reflect an increase in the importance of mobile animal husbandry, but also the need for land less susceptible to crop failure if there was a highly seasonal and more unpredictable rainfall, as could have been the case in the lowlands. The agricultural focus seems particularly clear for the Monte Claro sites. Agricultural intensification is indicated by the apparent increase in grinding implements in the Copper Age. Stable isotopic analysis seems particularly appropriate to gain independent and quantitative insights regarding these problems.

Besides the staples, cereal and legumes, for which we do not have any data regarding their importance relative to one another, we can hypothesize, based on general trends in the Western Mediterranean, the beginning of production and consumption of fruits. Among these are acorns, which were spreading during the 4th and 3rd millennia BC due to progressive aridity and likely forest fires; still today, mashed acorns are mixed with clay and made into bread in Ogliastra, eastern Sardinia. Hulled barley may have replaced naked barley during the Late Copper and Early Bronze Age as more suitable for brewing alcoholic beverages, a practice indicated by multiple kinds of evidence. Besides other crops such as figs, dates, and berries, management or even cultivation of olive trees, in the wild or domesticated variety, was likely introduced or intensified during the 3rd millennium, if not as a staple, as a valued complement to the diet.

It remains uncertain, and represents a crucial point in the biocultural history of the island, whether some symptoms of anemia, increasing substantially in the Late Copper-Early Bronze Age (Germanà 1999), are to be considered evidence for malnutrition or rather the establishment of deficiencies adaptive to malaria. The latter hypothesis would likely account for the progressive abandonment of sites on coasts and on the shores of the large lagoons on the lowlands during the Copper Age, in contrast with the occupation of well-drained, good farming land on fertile hills. Tracing malaria seems to be a fundamental research direction for the understanding of Mediterranean prehistory and to explain genetic adaptations that still
exist today (Webster 1996: 43). The peak in frequency of dental health problems does not match the peak in hyperostosis and *cribra* in the Early Bronze Age. I argue that this is best explained if nutrition was not the cause for this phenomenon, which makes parasites and genetic anemias the most likely candidates.

The non-systematic, rarely quantitative and very small amount of data on all the proxies for prehistoric economy and practices examined in this chapter make the availability of quantitative data very important. Among the several other avenues that still need attention, the method used here to provide information on climate and diet is that of stable isotopic analyses. This is what the operative section of this study is about, and this is the subject of the next chapters.
6.1. Introduction

Isotopic analyses of human skeletal remains have become in the last decade very common as tools to investigate dietary variation, at least in Britain, the US, and South Africa. The use of this method has expanded, both in the number of researchers involved and in the degree of specialization. In fact, investigating principles and particular archaeological contexts is becoming increasingly difficult due to the complexity of the interactions between dietary signature on one hand, and environmental, physiological, and cultural factors on the other. This means that a combination of all these factors is to be accounted for in interpreting isotopic measurements. Human physiological mechanisms at least are applicable to all humans. Environmental conditions, ecological systems, historical trajectories, and cultural preferences differ remarkably across time and space, representing sources of variation to be investigated in each different context.

Consequently, while the natural mechanisms of selection of certain isotopes by living organisms are being investigated through experimental, controlled study of humans and animals, archaeologists apply this knowledge to specific questions in order to understand practices that are embedded in biological and cultural contexts. Due the complexity of interaction among these factors, I believed it was necessary to analyze all other sources of information while focusing on stable isotopic analyses to provide new, more quantitative data to reconstruct economy and climate in Sardinian prehistory. This holistic perspective involves the acquisition of all possible coordinates to triangulate diet and to better understand the identified nutritional patterns within social and practical settings. Food production, processing and consumption have never been bare subsistence and nutrition, but rather
human actions where individual and collective choice is always at play within certain constraints, and in turn modifies such constraints.

6.2. Principles and Methods

6.2.1. Collagen $\delta^{13}C$ and $\delta^{15}N$

Stable carbon and nitrogen isotopic analyses of human bones are a well established method in the United States and several other research institutes worldwide. Conversely, in many areas of the world, it is only recently becoming part of the standard toolkit of bioarchaeologists interested in investigating diet in prehistoric and historic times. The quantitative nature of stable isotopic analyses, contrasting with the traditional approaches to diet reconstruction long established in archaeology that are qualitative or at best semi-quantitative, makes them a powerful and unique tool. About three decades have passed since stable isotopy was first used to assess the proportion of maize in pre-contact North America (van der Merwe and Vogel 1978), and countless studies have since looked at important nutritional transformations around the world involving radical changes in food procurement: the most successful examples, and still most common applications (Katzenberg and Harrison 1997), are those involving transitions between diets holding a very distinct signature, such as the transitions from Mesolithic fishing to Neolithic farming in Atlantic Europe (Lubell, et al. 1994; Richards and Hedges 1999e); from foraging to maize farming in the Americas (Ambrose 1993: 61-63; Schoeninger and DeNiro 1984; Schoeninger, et al. 1983); the beginning of millet, sorghum, and rice agriculture in Asia and Africa (Pechenkina, et al. 2005; Schoeninger 2005; van der Merwe and Vogel 1983).

The principle on which bone chemistry studies are grounded is that, generally speaking, “you are what you eat”. In other words our body composition is made up by, and reflects, the food we consume. Isotopes are different atoms of the same element that have different mass; this is because they have all the same number of protons and electrons (which have equal but opposite charge), but a different number of neutrons. While electrons have a minute mass, often rounded to none for brevity, neutrons have approximately the same mass as protons, and consequently the total atomic mass changes enough so as to modify the rates
of uptake during reactions. Therefore, each biological organism, directly or indirectly uptaking carbon, has one (or several, depending on different tissues) specific ratio of lighter vs. heavier isotope(s), which is part of its peculiar signature. Certain isotopes are stable, which means that their atomic configuration is not susceptible to change under normal conditions, while others, as $^{14}$C, are radioactive, which means that since their atomic configuration is unstable, a neutron will be lost at a regular pace with the release of energy as radiation (so-called $\beta$-particles).

Carbon (C) has two main stable isotopes: $^{12}$C and $^{13}$C, of which $^{12}$C represents the most common (98.89%), and similarly nitrogen (N) is mostly found as $^{14}$N and $^{15}$N, where the former represents 99.63% of all nitrogen found in nature (Sharp 2007: 8). This has the practical implication that to express meaningfully such minute quantities in ratios that can be accurately recorded and intuitively grasped, rather than using the ratio itself, the conventional way is that of expressing the difference ($\delta$) from a standard value in the ratio of the of the least vs. most frequent isotope. The standards are agreed upon internationally by the scientific community: they are the Pee Dee Belemnitella (PDB) for carbon and the atmosphere (AIR) for nitrogen (Hoefs 1997: 22-24; Sharp 2007: 28-29), and the measurement unit is the parts per thousand or ‘permil’ (‰):

$$\delta^{13}\text{C}_{\text{PDB}} \text{‰}= \left[\frac{^{13}/^{12}\text{C}_{\text{sample}}}{^{13}/^{12}\text{C}_{\text{PDB}}} - 1\right] \times 1000$$

$$\delta^{15}\text{N}_{\text{AIR}} \text{‰}= \left[\frac{^{15}/^{14}\text{N}_{\text{sample}}}{^{15}/^{14}\text{N}_{\text{AIR}}} - 1\right] \times 1000$$

Since both standard material and measurement unit are established and implied, it is not uncommon to omit them so that the typical notation for stable isotope ratios in bioarchaeology turns out to be simply $\delta^{13}$C, $\delta^{15}$N.

The macronutrients we consume (protein, lipids and carbohydrates), are digested, metabolized and used by the body to build tissues, and through this process they carry along the isotopic signature of their origin. Carbon and nitrogen isotope ratios in all organic tissues (including hair, nails, bone, tooth dentine and enamel, flesh, all internal organs) change predictably from source diet to tissues because of differential fractionation. This term refers to the process whereby chemical reactions involving these elements determine the selective uptake of heavier and lighter isotopes in specific ratios. This is due to different atomic mass,
which causes the reactions to occur at different rates. The isotopic signature of different tissues is unique, and the tissue turnover is also different: for instance, while bone is constantly replaced (one of the rare specific assessments is on human femurs: see Hedges, et al. 2007), so that its isotopic composition reflects dietary intake over several years before an individual’s death, other tissues as tooth enamel are not replaced after formation, still others as nails and hair are replaced much faster. Consequently, depending on the target period and research question, different tissues can be used – provided they are available: stable isotopes of bone (both collagen and apatite) have the advantage that rather than mirroring the last meals or the last seasons as do gut contents or hair stable isotopes. Bone allows us to assess quantitatively the components of a standard diet for a long period of time, reflecting a practice as opposed to a temporary behavior or an occasional act, and is thus best suited to trace long-term economic adaptations and trends.

As concerns $\delta^{13}C$, the single largest difference found among food categories worldwide, which is maintained up the food chain, is related to two plant groups: $C_3$ and $C_4$. These groups differ in their photosynthetic pathways, or the way of absorbing carbon and using it to build tissues (Farquhar, et al. 1989: 508-515; Gillon, et al. 1998). This results in two very distinct signatures, averaging about -26‰ in the former and -12‰ in the latter (Ambrose and Norr 1993). From an evolutionary standpoint, $C_3$ plants are the most common, and dominate plant communities in temperate environments at medium to high latitudes. $C_4$ plants are mostly grasses that developed specific traits to adapt to arid, tropical environments. While they were limited to tropical latitudes for most of the Holocene, some of them, due to their nutritional significance, have been utilized and domesticated by humans and spread into new territories. Worldwide, the most relevant subsistence crops pertaining to this group are maize, millet, and sorghum, but other plants have had important nutritional roles in past economies and still do in present ones, either as food or animal fodder (sugarcane, switchgrass, amaranth; for the latter, see Tucker 1986).

Variation of a few points per mil from the approximate values of -26‰ and -12‰ depends in $\delta^{13}C$ on environmental factors such as latitude, altitude, and the location’s slope. Significant geographic $\delta^{13}C$ variation across different areas of Europe has been documented (van Klinken, et al. 2000; 1994), such that would enable us to set apart prehistoric individuals who lived in the Mediterranean from those who lived in the British Isles. Overlaid onto these wide patterns, a more locally-based enrichment of a few points per mil has been documented.
across altitudinal belts within the same region (Körner, et al. 1988; 1991). Variation has also
been documented between different C₃ species, in different parts of the plant (leaves, seeds,
etc.), different heights of the same plant (Leavitt and Long 1986), and in different
microenvironments, identified by the amount of water supply, light, air circulation and soil
factors is the ‘canopy effect’, which makes values lighter near the ground in thick forests
(Heaton 1999; van der Merwe and Medina 1991).

Much of the premise above concerns all stable isotopes on many kinds of tissue.
Bioarchaeologists, with the exception of cases of extraordinary preservation, rarely deal with
soft tissues because they are unlikely to survive the attack of microorganisms. Bone and teeth
instead are often preserved for thousands of years, in favorable conditions. Concerning
collagen, it has been shown by controlled-feeding experiments on mammals that δ¹³C of
organic and mineral portion of bone (respectively collagen and hydroxyapatite or briefly
apatite) does not reflect the same macronutrients in the same way (Ambrose and Norr 1993;
Tieszen and Fagre 1993). Bone collagen, in fact, is mainly an expression of the protein
portion of the diet, because it is mainly synthesized from ingested protein, whereas bone
apatite is a more comprehensive indicator of diet since it is produced from all macronutrients.
This means that if there is no severe protein shortage (Schwarz 2000), collagen in humans
will mostly reflect foods of animal origin, which are much richer in protein. It will reflect
vegetal foods only if alternate sources of protein as meat, dairy and fish were so scarcely
available that the organism had to use plant proteins to synthesize tissues. Linear regression
applied to the relationship between dietary protein and collagen values showed in this regard
a strong relationship, with r²=~72%, and p=0.001(Jim, et al. 2004: 68).

In addition to plant photosynthetic pathway and environment, a further process
determining the isotopic signature in human tissues is fractionation due to physiology: the
selective isotopic uptake in consumers varies by tissue. Collagen δ¹³C values shift about
+5‰ from the vegetal food source; therefore, from standard plant values of -26‰ in C₃
ecosystems, herbivores are around -21‰ for collagen, and pure C₄-feeders show collagen
δ¹³C values around -7‰, about 5‰ from -12‰ in plants; a wide range of values depends on
more complex diets (Ambrose and Norr 1993: 22-26; Lee-Thorp, et al. 1989). Going up the
food chain through carnivore species, δ¹³C values show a much smaller difference, not more
than 2‰, so that this element is not the best tracer to quantify the importance of nutritional resources from different trophic levels for human diet. Human values for fully terrestrial C\textsubscript{3} ecosystems fall approximately around -19‰ (collagen), with differences related to the importance of animal vs. vegetal foods that must be added to the environmental variation discussed above. Nitrogen represents the best choice for this purpose, since average differences between consumed and consumer are usually larger, around 4‰.

Nitrogen is fixed or absorbed by plants, and its values are also passed on up the food chain. Since there is no fractionation in nitrate absorption, values for plants are relatively similar to those in the atmosphere, between δ\textsuperscript{15}N -5 to + 5‰. The main relevant difference in plant physiology is for nitrogen the one between fixers and non-fixers. The former, represented for instance by legumes, are characterized by remarkably depleted (lighter) δ\textsuperscript{15}N values, whereas non-fixers are much higher and, within the same ecosystem, non-overlapping (DeNiro and Hastorf 1985). Environmental factors affect nitrogen isotopic ratios in soils and plants, and consequently in the whole food chain, even more than they affect carbon. After early localized work in Kenya documenting how variation correlated with elevation (Ambrose 1991), recent research has attempted to produce an estimate of several elements. Climate resulted to be the single most important factor, accounting for a range of over 12‰ from circumpolar regions to the Sahara: both temperature and precipitation are strongly related with δ\textsuperscript{15}N, but temperature appears to have the strongest relationship (Amundson, et al. 2003: 31/4-6). This has been studied by Schwarcz et al (1999) at Dakleh Oasis, Egypt, where δ\textsuperscript{15}N values were enriched despite availability of water and irrigation. This implies that climate change at any given point is also a source of variation, as it is for δ\textsuperscript{13}C (Stevens and Hedges 2004). Parent lithology, topography, cultivation and age, all affect δ\textsuperscript{15}N soil between 3-6‰ each, with the relative variation transferred to a great extent to the rest of the food chain (Amundson, et al. 2003: 31/6-31/8). Cultivation raises δ\textsuperscript{15}N values both by depleting the soils of nitrates and so leaving them \textsuperscript{15}N-enriched, and by adding manure fertilizers that are rich in ammonia and as well \textsuperscript{15}N-enriched (Amundson, et al. 2003: 31/8; Bogaard, et al. 2007).

From whichever starting values in soil and plants, at every trophic level fractionation raises the isotopic ratio of about 4‰ (Ambrose 1991: 298-299), so that from plant values around 2‰, herbivores will be at about 6‰ and carnivores at about 10‰ (values that roughly approximate those documented archaeologically in Europe and the Mediterranean). While
these represent organisms in normal conditions, despite some negative evidence in laboratory experiments on mice, there is indication that, trophic level being equal, larger mammals under stress for high temperature and/or starvation may show enriched $\delta^{15}N$ values (Ambrose 2000). Marine ecosystems have much longer food chains, so that the range of variation in $\delta^{15}N$ is much wider. Marine predators show values up to 20‰ in collagen, while fish signatures are generally higher than those of terrestrial animals (Richards and Hedges 1999e; Schoeninger and DeNiro 1984; Schoeninger, et al. 1983). Marine $\delta^{13}C$ values also are often enriched, resulting in overlap with the C$_4$ plants range, so that the best way of setting them apart, and the standard way of presenting the values, is by means of a plot where $\delta^{13}C$ and $\delta^{15}N$ are the x and y coordinates (Figure 61). High $\delta^{13}C$ and low $\delta^{15}N$ indicates C$_4$ plant-based diets, while high $\delta^{13}C$ and high $\delta^{15}N$ indicates marine protein-based diets. The evidence that plants in coastal environments can also be $\delta^{15}N$ enriched, possibly due to marine nitrate deposition (Heaton 1987; Virginia and Delwiche 1982), by several points per mil, is

![Collagen reference isotopic values for Western Europe](image)

*Figure 61. Standard reference values for collagen $\delta^{13}C$ and $\delta^{15}N$ plotted as x and y; values are broadly applicable to prehistoric Western Europe. Values for C$_4$ plants, such as millet, which was not important until the end of the Bronze Age and possibly only later, correspond roughly to those of marine crustaceans and molluscs. Illustration by the author.*
surprisingly little considered in many investigations of coastal subsistence; in fact, in some contexts this could explain what is interpreted as a slight seafood signature (Craig, et al. 2006).

Riverine, lacustrine and lagoonal ecosystems, due to reservoir effects that are particular to individual water bodies, tend to have high $\delta^{15}$N but low $\delta^{13}$C (Fry 1991; Katzenberg and Weber 1999: 654-655; Lanting and van der Plicht 1997: 498-499; Smith and Epstein 1970). They show some variation, though, which can potentially overlap with both marine and terrestrial values. The reservoir effect applies to some extent also to smaller circumscribed seas such as the Mediterranean, and appears impossible to assess accurately without contextual archaeological samples.

6.2.2. Apatite and Tooth Enamel $\delta^{13}$C

Since the beginning of dietary research through stable isotopes, the main focus has changed with the refinement of our understanding of the processes governing their ratios. In the late 1970s, following the observation of consistent offsets between radiocarbon dates obtained on $C_3$ plants versus those obtained on maize, estimating maize contribution to diet was the first anthropologically important goal to be addressed isotopically (Tykot 2006: 132-135), rapidly followed by the estimation of marine contribution to diet (Ambrose and Krigbaum 2003; Katzenberg and Harrison 1997: 267; Tauber 1981). It soon became clear, however, that reconstructed diets fully and exclusively based on protein-rich animal foods were not nutritionally viable (Noli and Avery 1988; Speth and Spielmann 1983), which supported the hypothesis that different macronutrients were routed preferentially toward the formation of different tissues.

This problem had become crucial and was addressed during the 1990s: the early linear model (‘scrambling’ model) suggested that all macronutrients contributed to the synthesis of collagen, which therefore represented the whole diet, while apatite, the mineral component of bone, reflected the energy portion (van der Merwe 1982). Apatite, short for hydroxylapatite, is a carbonate and does not contain nitrogen, so only $\delta^{13}$C is available for dietary reconstruction. Through experimental efforts it became apparent that in reality collagen tended to be preferentially built from protein intake, whereas apatite and tooth
enamel included, and therefore reflected, all components (Ambrose and Norr 1993; Tieszen and Fagre 1993). This selective routing model stood later tests being refined and complemented by the assessment of the relationship of diet with bone cholesterol (Jim, et al. 2004). It has therefore been established that bone apatite will reflect well the values of the whole diet ($r^2=0.99\%, p=0.001$), including therefore all three macronutrients depending on their relative proportion (Jim, et al. 2004: 68).

However, the details of the mechanisms regulating the isotopic fractionation among diet on one hand, and collagen and apatite on the other, are complex and not fully understood; for apatite, besides methanogenesis, which is relevant for ruminants but not for humans, there is still a shift of 2-5‰ that waits for an explanation (Hedges 2003: 74). It appears that the lower the amount of protein in the diet, the more carbohydrates and lipids will contribute to collagen composition, so that its isotopic values (Hedges and van Klinken 2000; Schwarcz 2000) may in some cases be a combination of both ‘scrambling’ and selective routing. Such model is confirmed by the narrowing of the range in the difference between diet component and corresponding bone component ($\Delta \delta^{13}C_{\text{comp}}$, $\delta^{13}C_{\text{comp}}$), which is narrowest in the whole diet to bone apatite fractionation (2.6‰ vs. 7.3‰ in dietary protein to collagen fractionation: Jim, et al. 2004: 69).

Other observations and experiments show that the fractionation documented in mammals between diet $\delta^{13}C$ and bone apatite $\delta^{13}C$ ranges widely from +9.1‰ to up to +14‰ where generally herbivores, and among these ruminants, have higher differences (Ambrose and Norr 1993; Kohn and Cerling 2002). Humans are considered omnivores, so that their diet-to-apatite fractionation may be somewhere in between: for diet $\delta^{13}C$ around -26‰, apatite should be near -14‰, and for diets around -14‰ (such as in C$_4$ ecosystems) apatite will result close to 0‰.

All the same dietary information holds for tooth enamel, which is as well a carbonate. There are two main characteristics that differentiate it from bone apatite, one involving its structure and consequently its preservation potential, another its growth rates and pattern with the implications for dietary interpretation. Since its crystalline structure is much tighter, enamel resistance to diagenesis is much stronger: isotopic signal can be modified (Kohn, et al. 1999; Wang and Cerling 1994), but is likely to remain unaltered especially as the tooth surface is intact (Lee-Thorp 2000). The incremental growth of tooth enamel, its formation within the individual’s youth and its lack of tissue replacement (no turnover) makes it an
indicator of diet in the years of formation, which vary for the different tooth types (Reid and Dean 2006). This can be used to compare with bone values and so doing detect dietary variation by age ($\delta^{13}C$), and residential change (by comparing $\delta^{18}O$ and $^{87}Sr/^{86}Sr$ in tooth versus in bone). The use of tooth enamel from the same individual as bone apatite can also be used to validate values of the latter, which as discussed above does not have the same resistance to degradation and is thus more likely to show a contaminated isotopic signature (Koch, et al. 1997; Kohn, et al. 1999; Wang and Cerling 1994). $^{87}Sr/^{86}Sr$ analyses of tooth enamel, performed in order to trace change in residence, are not included in this study, but being performed by Mrs. Michelle Markovicz at Florida State University, Tallahassee, on the same samples.

6.2.3. Collagen $\delta^{13}C$-Apatite $\delta^{13}C$ Spacing

Related to both collagen and apatite $\delta^{13}C$ is the spacing between them, a parameter that is increasingly used to explore diets that integrates the information provided by both bone component. Lee Thorp et al. (1989), based on analyses of fauna from southern Africa, first documented that herbivores had a larger spacing than carnivores. However, the processes behind such phenomenon were unclear and probably complicated by the variety of environments that included both C$_3$ and C$_4$ plants. Since the experimental studies during the 1990s showed that there was differential routing of dietary macronutrients into collagen and apatite (Ambrose and Norr 1993; Tieszen and Fagre 1993), the data for further investigation and modelling increased. Hedges (2003) has addressed very clearly the separate and connected questions that understanding such difference between $\delta^{13}C_{col-apa}$ in herbivores and carnivores implies: is it due to the isotopic values of the diet or to uneven fractionation due to different physiologic processes, or both? Is variation in $\delta^{13}C_{col}$ or variation in $\delta^{13}C_{apa}$ responsible for the spacing, or is it both? The role of methanogenesis might possibly affect such values in ruminants, but no more than 2‰ has been explained, whereas documented difference in carnivores and herbivores $\delta^{13}C_{col-apa}$ is up to 3-4‰, and even $\delta^{13}C_{diet-apa}$ difference seems to be consistently 2-5‰ higher than modelling predicts (Hedges 2003: 73-76). Data are not fully explained, but the difference in apatite seems to be the main factor determining the spacing (Hedges 2003: 67). However, collagen may also have an effect in herbivores, since a diet scarce in protein could induce the organism to use carbon from lipid
and carbohydrate to synthesize them (Schwarcz 2000). Human diet, fundamentally omnivorous, is assumed to lie between plant- and meat-consumers.

For dietary interpretation, it is important to note that $\delta^{13}C_{col}$ and $\delta^{13}C_{apa}$ taken singularly are directly affected by environmental factors other than diet, since such factors influence the whole food chain, whereas $\delta^{13}C_{col-apa}$, as a mathematical number that transcends direct, non-measurable sources, provides a powerful tool to compare diet across sites.

6.2.4. Apatite $\delta^{18}O$

Oxygen has three stable isotopes, $^{16}O$, $^{17}O$, and $^{18}O$. Their abundance in nature is respectively ~99.760%, ~0.038% and ~0.200%, with the lightest isotope being by far the most common, as observed already for C and N (Sharp 2007: 8, 65). $\delta^{18}O$, similarly to C and N signifies the difference from a the $^{18}O/^{16}O$ ratio of a standard, which in this case can be either the same as $\delta^{13}C$, PDB carbonate, mostly for oceanic, freshwater or biogenic carbonates, or SMOW, Surface Mean Ocean Water, common in most geochemical reports.

The notation equation, and the conversion equation between these systems are:

$$\delta^{18}O_{PDB} = \left( \frac{^{18}O_{sample}}{^{16}O_{PDB}} \right) \times 1000 - 1 \times 1000$$

$$\delta^{18}O_{SMOW} = 1.03091 \left( \delta^{18}O_{PDB} \right) + 30.91$$

In this dissertation, $\delta^{18}O$ with no further notation indicates $\delta^{18}O_{PDB}$. The relationship between rainwater $\delta^{18}O$ on one side, and geographic and climatic factors on the other, has long been recognized. A series of factors including temperature, distance from the ocean source, altitude and latitude, and intensity of rain all interplay in its determination (Fricke and O'Neill 1999; Fricke, et al. 1995; Sharp 2007: 80-86). While temperature was found to be the most important determinant of rainwater $\delta^{18}O$ in temperate regions, in the tropics precipitation appears to be stronger, as suggested for $\delta^{15}N$ (Schwarcz, et al. 1999). The equation relating $\delta^{18}O$ and temperature has been estimated in ~$0.6%e = ~1°C$ for areas between 0°C and 20°C mean annual temperature, whereas the equation relating $\delta^{18}O$ with rainfall in the tropics is ~$-0.013 = ~1 mm$ (Koch 1998: 596-600; Rozanski, et al. 1992). The location of Sardinia is at the border of the temperate and sub-tropical climate areas, with
mean temperatures between 10°C (on the highest mountain tops) and 18°C (over the lowlands and most of the island), and mean annual rainfall between 1200 mm and 400 mm (with similar geographic distribution): since they are also both likely to have oscillated in the past, it is consequently particularly hard to assess the relative contribution of either factor to the $\delta^{18}$O composition recorded in archaeological specimens: although temperature should account for more variation, the degree to which rainfall does is not known in detail. However, a strong linear relationship with annual precipitation has been detected and measured in the Eastern (Bar-Matthews, et al. 2003) and Western Mediterranean (Drysdale, et al. 2004), and both the seasonal climate characterizing Sardinia from the mid-Holocene and the relative similarity of present-day seasonal variation in the Mediterranean supports the choice of assimilating Sardinia to such examples for this purpose.

Animal bone and several materials other than human tissues are used to assess paleoenvironmental conditions, and are increasingly considered as a proxy for paleoclimatic reconstructions. From rainwater, oxygen isotopic signature is transferred to drinking water, which is how most of this signature is absorbed by living organisms, and goes into the composition of tissues, including bone apatite. $\delta^{18}$O is measured on both phosphate and carbonate, although the method to isolate phosphate is more difficult than apatite extraction (Iacumin, et al. 1996; Stephan 2000). Since the strong linear relationship between them has been demonstrated, their use as paleoenvironmental indicator can be considered virtually interchangeable (Kohn and Cerling 2002): fractionation between $\delta^{18}$O$_{\text{water}}$ and bone $\delta^{18}$O$_{\text{phosphate}}$ is 1.0176, and between $\delta^{18}$O$_{\text{water}}$ and $\delta^{18}$O$_{\text{carbonate}}$ 1.0263; (as measured in horse, expressed in SMOW standard, but large mammals are assumed to function the same way because body temperature is similar: Bryant and Froelich 1995). This allows full comparability of the two measurements. Despite the several factors listed above that contribute to specific $\delta^{18}$O values, an overall linear relationship has been confirmed by studies on the global, continental and local scale (Longinelli and Selmo 2003; Stephan 2000).

While carbonate (as phosphate) $\delta^{18}$O in animals can depend on several factors and foremost temperature and humidity, it seems that the more drought-tolerant the species is, the more fractionated the values appear, possibly because a large portion of water is ingested through leaves, which are isotopically enriched (Bryant and Froelich 1995; Sponheimer and Lee-Thorp 1999). Large mammals that are obligate drinkers, as elephants, horses and cows,
and moderate drought-tolerant species as sheep and goat, have values that are related linearly with the isotopic ratios of water (Kohn and Cerling 2002: 465-466):

$$\delta^{18}O_{\text{phosphate}} = 0.9* \delta^{18}O_{\text{water}} + 23 \quad (\delta^{18}O_{\text{SMOW}})$$

Bentley & Knipper (2005) in their extensive mapping of paleoisotopes in southwestern Germany used Longinelli’s equation relating $\delta^{18}O_{\text{water}}$ and $\delta^{18}O_{\text{phosphate}}$, rearranged and modified by adding 8.7‰ according to Bryant’s calculations to convert phosphate values into carbonate, with measurements from pig tooth enamel (Bryant, et al. 1996; Longinelli 1984):

$$\delta^{18}O_{\text{carbonate}} = \delta^{18}O_{\text{phosphate}} + 8.7\%e \quad (\delta^{18}O_{\text{SMOW}})$$

$$\delta^{18}O_{\text{water}} = 1.163*\delta^{18}O_{\text{carbonate}} - 39.07 \quad (\delta^{18}O_{\text{SMOW}})$$

Specific archaeological applications using human bone and tooth enamel include the assessment of mobility, patterns of residence and weaning (White, et al. 2004; Wright and Schwarcz 1998). In this project, potential seasonal mobility and climate change were expected to be the two main determinant factors and relatedly the questions to address.

6.3. Stable Isotopes and Diet in Western Mediterranean Prehistory

A correct interpretation of the isotopic values in dietary terms, in the particular context of western Mediterranean prehistory, necessitates the consideration of the specific resources available, and especially those that archaeology has documented as being used as food items. Food production and consumption between the 6th and the 2nd millennia BC is characterized by the spread of the Neolithic suite of domesticated animals and crops, which apparently were adopted in different tempos and combinations in different regional contexts across Europe (Bogucki 1996; Price 2000). While some areas apparently relied on foraging until relatively late, others seem to have adopted quickly and thoroughly the Neolithic economic patterns (Richards, et al. 2003c). There is evidence that, in the Mediterranean, reliance on fishing never approached the importance it had in the Atlantic coasts and the
Baltic area (Lubell, et al. 1994; Richards and Hedges 1999e; Richards, et al. 2003b), although the quality of the evidence is not homogeneous.

Domesticated animals and crops spread from the Near East, mostly through coastal routes along Greece, the Italian Peninsula on both the Tyrrhenian and Adriatic sides, and then down the coast of the Iberian peninsula and the Corsican-Sardinian complex. Due to environmental factors, on the African side Neolithization took the form of a shift to reliance on pastoralism rather than on agriculture (Phillipson 2005: 165-181; Smith 1992). It seems that at several locations domesticated animals, namely sheep, goat, pig and cattle, were adopted before farming. The importance of agriculture was still variable in the 6th and 5th millennia BC, and became more generalized only later, while in some areas pastoralism possibly became more important starting in the 4th millennium. This trend may have been favored by climate change, and/or by the exploitation of secondary animal products such as milk and labor in the form of plow traction (Sherratt 1981, 1994), at different paces and in different ways across the western Mediterranean and Europe, in turn according to the local environmental and socio-cultural contexts.

Based on lack of evidence in material culture and on a growing body of isotopic measurement, it seems established that in the Late Neolithic through Bronze Age exploitation of seafood was nutritionally negligible. Measurements of δ13C and δ15N as documented in present-day western Mediterranean marine ecosystems (Badalamenti, et al. 2002; Pinnegar and Polunin 2000; Pinnegar, et al. 2003; Polunin, et al. 2001) appear to be variable but comparable to those in the Atlantic Ocean (synthesized by Richards and Hedges 1999e), ranging from human-like to more enriched values, up to δ13C = −16‰. Thus, if fish consumption was substantial, it would result in even more enriched values, due to trophic level effect, as is the case for Mesolithic populations in the Atlantic (García Guixé, et al. 2006; Richards and Hedges 1999e; Richards, et al. 2003c). Such distinctiveness makes it relatively easy to pinpoint the presence of a substantial contribution of seafood, a presence that has not been found in the prehistoric Mediterranean. It is true that coastal marine ecosystems are affected by a variety of variables: the importance of freshwater discharge is even shown by research in the Baltic, which documented substantial variability in δ15N values in different areas, related to closeness to a power plant (Hansson, et al. 1997). Even if there were of course no power plants in prehistory, some variation near river mouths is expected due to the local ecosystems being affected by water discharge. However, no radical
variation that can be related to substantial reliance on seafood has been ascertained in human isotopic values from prehistoric Mediterranean sites (Figure 62).

This is not surprising in inland mediterranean and Near Eastern sites, as in Neolithic Anatolia at Çatalhöyük (Richards, et al. 2003a) and Nevalı Çori (Lösch, et al. 2006), in inland Greece both in the Neolithic and in the Bronze Age, at sites as Spathes, Rymnio, Makrigialos (Triantaphyllou 2001: 133-141), Theopetra, Tharrounia, Kouveleiki (Papathanasiou 2001: 75-78, 38-39; 2003), Tzamala (Tykot 2003). However, this appears to be the case also in insular and coastal settings such as Bronze Age Crete and the Aegean, as Gerani, Armenoi, Mycenae (Richards and Hedges 1999a, b, c, d). At Mycenae, which can be considered virtually coastal (van Andel, et al. 1990: 385), only the few individuals buried in monumental tombs show values compatible with some consumption of fish (Richards and Hedges 1999c, d). In Greece, Papathanasiou’s (2003) research, explicitly addressing

![Figure 62. Map of the central Mediterranean showing the location of Sardinia and the prehistoric sites that have been analyzed for δ¹⁵N and δ¹³C in the area. Sites considered range from the Paleolithic to the Early Iron Age.](image-url)
variation between inland and coastal areas spanning the Neolithic (late 7th to early 4th millennium BC), revealed that the protein portion of the diet was consistently based on terrestrial plants and animals, with some possible evidence for a very limited importance of marine resources. Further preliminary evidence from Hagios Kharalambos, as well in Crete (Richards, et al. 2007) yielded similar results. In the central-western Mediterranean, similar δ\(^{13}\)C and δ\(^{15}\)N values compatible with terrestrial C\(_3\) protein have been documented in coastal environments such as the Maltese archipelago from around 4000 BC to the 3rd millennium BC (Richards, et al. 2001; Stoddart, et al. in press). Similar data have been produced from the Balearic islands between the 4th millennium BC to the 1st century AD (Davis 2002; Van Strydonck, et al. 2002), from Middle and Late Neolithic France (Le Bras-Goude, et al. 2006a; Le Bras-Goude, et al. 2006b) and from several locations on the Italian peninsula dating to Neolithic through Copper Ages, including a substantial group from the site of La Selvicciola (Tykot and Robb in preparation). In conclusion, the overall evidence is that the consumption of seafood ranged from limited to none.

Besides small differences, it is evident that overall quantity of marine food can be estimated to be negligible (Craig, et al. 2006), in line with archaeological evidence, up to historic and especially Roman times. Only possible exception for post-mesolithic prehistoric times is Gatas, in Almería (Spain), a Bronze Age site whose average δ\(^{13}\)C value, -18.1‰, has been related to some consumption of seafood (Craig, et al. 2006). However, only δ\(^{13}\)C is reported: besides the admittedly unlikely possibility of millet, whose presence is documented in central Europe as early as the Early Bronze Age (Le Huray and Schutkowski 2005: 143), considering the geographic pattern detected in Europe of enriched δ\(^{13}\)C on a north-south gradient (van Klinken, et al. 2000), which broadly corresponds to rainfall patterns, I believe that this result could be rather attributed to the extreme aridity of southeastern Spain, particularly in the coastal area. In fact, average bone and wood δ\(^{13}\)C from Spain as a whole has been measured to be between about 2‰ lighter than in Great Britain and the Netherlands, and 1‰ lighter even compared to that of Italy and former Yugoslavia (van Klinken, et al. 1994).

Given the small range of isotopic values, it is very difficult and probably unreliable to assess the contribution of animal versus plant foods to the diet analyzing collagen alone. Apatite is still seen as suspicious by many researchers because it lacks accurate quantitative indicators of preservation (see above). However, unlike East Asia, Africa and the Americas,
where the presence of C₄ plant species makes it easier to trace the take-off of economically important domesticated crops, the cereals cultivated in prehistoric Near East and in the Mediterranean have δ¹³C and δ¹⁵N close to wild plants. This, coupled with the little exploitation of marine resources, makes most late prehistory western Mediterranean collagen values cluster within δ¹⁵N 9.0 ± 2.0‰ and δ¹³C 19.3 ± 1‰. Broadly speaking, δ¹⁵N are more depleted in the Aegean area than they are in the central-western Mediterranean, which could reflect a more plant-based agricultural diet vs. higher portion of animal protein. However, the effects of climatic variation have not been systematically incorporated in the interpretive efforts.

Apatite δ¹³C and the spacing between collagen and apatite are consequently indispensable to detect significant dietary change, and specifically the question that becomes the main nutritional and economic issue in Mediterranean prehistory: the relative importance of plant vs. animal foods, of farming vs. herding, and the role of secondary products. The δ¹³C_{col-apa} spacing allows us to complement different dietary components, and so ‘triangulate’ a reconstruction with distinct and integrated kinds of information. As discussed above, larger spacings correspond to plant-based diets and smaller spacings to carnivorous diets (Hedges 2003; Jim, et al. 2004; Lee-Thorp, et al. 1989). The clustering of collagen values also means that variation due to environment may be more important than the dietary signature, and without control samples that allow to detect ecosystem-wide shifts in isotopic ratios (faunal and vegetal samples from the same contexts), it is impossible to rely on them to assess dietary variation between populations –whereas intra-site patterns remain as valid.

6.4. The Project: Materials and Sampling Criteria

In order to address the research questions outlined above, the first step was by necessity a careful sampling strategy. A necessary condition for a good sampling strategy was a good knowledge of the available and accessible skeletal collections and relative contextual information. Preliminary work was therefore aimed at documenting skeletal collections’ existence, location, conditions and physical accessibility. This was done through research in different ways and directions: the main local archaeological journals (Studi Sardi, Quaderni della Soprintendenza Archeologica per le Province di Cagliari e Oristano, Quaderni della Soprintendenza Archeologica per le Province di Sassari e Nuoro, Nuovo
Bullettino Archeologico Sardo) and main synthetic volumes (Contu 1997; Lilliu 1988a; Webster 1996) were systematically examined as a starting point. More information was identified in extensive “snowfall” bibliographic research (branching from source to source). During the research stays in Sardinia, unpublished inventories at the archaeological resources state agencies (Soprintendenze Archeologiche) in Cagliari, Sassari and local facilities, were used when available. More inventories of available collections and rare publications were provided by Dott.ssa Rosalba Floris, at the Department of Experimental Biology, Anthropology section, of the University of Cagliari. For key sites, the archaeologists who directed the excavations, often unpublished, were contacted for information on the collections and contexts. This served as groundwork to design the overall sampling strategy appropriate for our questions. Furthermore, it laid the foundations for the prehistoric section of a comprehensive catalog of Sardinia’s human remains collections, which should become an important research tool for future scholars. This project, supervised by Prof. E. Marini and Prof. G. Floris and in collaboration with doctoral student Dott. M. Lodde (Dept. of Experimental Biology, University of Cagliari), aims at rendering the database available online for retrieval and sharing of scholarly data.

Few publications by local archaeologists are available in electronic format. So, besides those available at the USF Library and the privately-owned resources, most information was obtained at university libraries and public libraries in Cagliari, and through the USF Interlibrary Loan service. Site sampling, sample selection and collection, despite the planning efforts, was not always sequential, and involved some adjustments due to unpredictable conditions. For instance, some collections were formally held at public institutions but actually inaccessible, some collections were not found where they were supposed to be stored, others were unexpectedly found where they were not.

Sites with reliable stratigraphy and/or secure cultural attribution were selected, the majority coming from collective rock-carved tombs, and fewer from caves, pits, and cists. Wherever possible, sampling was also done by age and sex subgroups, so as to generate information on social aspects within populations and avoid bias from differential sampling of such subgroups in different collections. In one case, despite the collective nature of the burial, the presence of reliably associated grave goods has allowed me to discriminate diet by status (Iscalitas). As the main target of this project is detecting change over time, the sampled area was limited to southern Sardinia to avoid variation related to geographic distance. High
altitude, a source of isotopic variation particularly for $\delta^{18}$O, but also for $\delta^{13}$C and $\delta^{15}$N, is not an issue, because all sites are lower than 500 m asl. To account for the intake of seafood, and as a further control for local-scale geographic variation, one inland and one coastal site was selected for each phase (only for the Bell Beaker phase there were no coastal sites available).

A total of 171 human individuals have been sampled from 14 burial sites (Table 9) from the southern half of the island (Figure 63), for analyses of bone collagen and apatite. Human tooth enamel samples were analyzed (from 32 of the same individuals), for comparison with the bone tissue. Since most samples were part of collections composed of disarticulated remains from collective burials, one skeletal element was selected, in order to insure that I was not sampling the same individual more than once. Cranial bones were preferred in most cases because they can provide a wealth of additional information on sex, age, and health. Exceptions are the group of Scaba ’e Arriu A, where the cranial specimens were limited in number, so pelvic bones were chosen, and the groups of Seddas de Daga and sa Duchessa, which were represented by femurs.

Taking advantage of the fact that teeth grow incrementally in layers (Figure 64), research on animal teeth in order to trace seasonal variation in diet has seen recently a fast progress (Balasse 2003; Balasse, et al. 2002; Balasse, et al. 2001; Balasse, et al. 2003). While little has been done on human tooth microsampling, a pilot study designed to detect short-term dietary variation has shown the potential of such method (Wilson, et al. 2001). Therefore, a pilot section of the dissertation project aimed at further testing the method applied to the detection of possible patterns of variation compatible with seasonal mobility. Physiology has been shown to be important in affecting $\delta^{15}$N isotopes during adolescence (O’Connell and Prentice forthcoming; White and Schwarcz 1994: 177), but no such evidence exists for $\delta^{13}$C, therefore I assume here that it should indicate a change in diet. Variation in $\delta^{18}$O could reflect the difference in temperature at the time of formation and the duration of breastfeeding. In fact, due to the trophic level effect, $\delta^{13}$C is expected to be enriched in earlier teeth, and $\delta^{18}$O is too, because the mother’s milk is a large proportion of ingested water, and its signature is heavier (Roberts, et al. 1988; Wright and Schwarcz 1998: 3-4). Four third molars were selected from different individuals within the Early Bronze Age layer of the Padru Jossu burial, since this is the phase when, based on the archaeological literature, heavier reliance on herding and mobility would have occurred.
Figure 63. Map showing the location of sites where the analyzed skeletal remains were excavated. Map by 
the author, based on cartographic material from S.A.R. Sardegna consortium, with kind permission.
Table 9. Human bone samples per each site. Full information on the specific burial is here provided, while it is omitted for brevity elsewhere.

<table>
<thead>
<tr>
<th>Site</th>
<th>n</th>
<th>Period</th>
<th>Cultural Phase</th>
<th>Burial Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>S. Benedetto, tomb II</td>
<td>16</td>
<td>Late Neolithic</td>
<td>Ozieri</td>
<td>Rock-carved tomb</td>
</tr>
<tr>
<td>Montessu, tomb XV</td>
<td>1</td>
<td>Late Neolithic (?)</td>
<td>Ozieri</td>
<td>Rock-carved tomb</td>
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<td><strong>Total Late Neolithic</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cannas di Sotto, tomb 12</td>
<td>6</td>
<td>Early Copper Age</td>
<td>Filigosa/Abelzu</td>
<td>Rock-carved tomb</td>
</tr>
<tr>
<td>Scab’e Arriu corridoio (A)</td>
<td>14</td>
<td>Early Copper Age</td>
<td>Filigosa/Abelzu</td>
<td>Rock-carved tomb</td>
</tr>
<tr>
<td>Serra Cannigas, tombs A and B</td>
<td>5</td>
<td>Early Copper Age</td>
<td>Filigosa/Abelzu</td>
<td>Cist</td>
</tr>
<tr>
<td>Mind’e Gureu</td>
<td>1</td>
<td>Early Copper Age</td>
<td>Filigosa/Abelzu</td>
<td>Cist</td>
</tr>
<tr>
<td>S. Caterina Pittinuri</td>
<td>10</td>
<td>Early Copper Age</td>
<td>Filigosa/Abelzu</td>
<td>Rock-carved tomb</td>
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<td><strong>Total Early Copper Age (Post-Ozieri)</strong></td>
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<td>Via Basilicata, tombs I and IV</td>
<td>2</td>
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<td>Monte Claro</td>
<td>Rock-carved tomb</td>
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<tr>
<td>Via Trentino tomb I</td>
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<td>Rock-carved tomb</td>
</tr>
<tr>
<td>Seddas de Daga, cave II</td>
<td>7</td>
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<td>Monte Claro</td>
<td>Natural cave</td>
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<tr>
<td>Su Stampa ‘e Gianniccu Meli</td>
<td>9</td>
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<td>?</td>
<td>Natural cave</td>
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<tr>
<td>Scab’e Arriu cella (M)</td>
<td>13</td>
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<td>Monte Claro</td>
<td>Rock-carved tomb</td>
</tr>
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<td>Monte Claro</td>
<td>Rock-carved tomb</td>
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<td>Bonnanaro B</td>
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<tr>
<td>Is Aruttas</td>
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<td>[Late Bronze Age]</td>
<td>Nuragic</td>
<td>Natural cave</td>
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<td>[Middle Ages]</td>
<td>Giudicale</td>
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<td>?</td>
<td>?</td>
<td>Rock-carved tomb</td>
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<tr>
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<tr>
<td><strong>TOTAL INDIVIDUALS</strong></td>
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</tbody>
</table>

*These individuals were dated by associated materials to the Early Bronze Age as those found in tomb XXXIII; since the AMS date from tomb XXXIII turned out to be medieval, the date for tomb XXXII is unreliable.

To start constructing a local isotopic baseline in addition to faunal analyses from elsewhere in the Mediterranean, 30 terrestrial faunal samples from some of the archaeological sites have also been collected (Table 10). Nine marine animal and eight botanical modern samples were taken as a proxy for categories not available as
archaeological specimens, to integrate modern data from other locations with at least a small sample of local values.

Radiocarbon dating of several bone samples is another important part of the project (Table 11). The relevance lies in obtaining direct dating of samples from collections recovered in contexts stratigraphically suspect, or from collections that had only a relative chronology based on reliable stratigraphy, and/or for better resolution in case of multi-layered archaeological deposits. The importance of these dates is, however, much more substantial, since absolute chronology of Sardinian prehistory, particularly before the Bronze Age, is extremely loose due to the lack of measurements and to the different material culture aspects within the period 4000-1900 BC. These dates increase substantially the total $^{14}$C dates previously available for Sardinia for the whole timespan (Contu 1998; Cosseddu, et al. 1994b; Sanna, et al. 1999; Tiné 1992b; Tykot 1994). Part of the samples was sent and part was prepared with my collaboration through an internship at the University of Arizona, where I have worked in May 2005 supervised by Dr. G. Hodgins.

Among the results of dating, part of the original sampling design was modified. The eleven individuals from Is Aruttas, considered Late Neolithic based on pottery association, turned out to belong to the Middle-Late Bronze Age, consequently falling out of the range of
Table 10. Faunal and botanical samples

<table>
<thead>
<tr>
<th>Site</th>
<th>n</th>
<th>Period</th>
<th>Species</th>
<th>Common Denomination</th>
</tr>
</thead>
<tbody>
<tr>
<td>S. Caterina di Pittinuri, corridor</td>
<td>5</td>
<td>Early Copper Age</td>
<td><em>Sus s.</em></td>
<td>Pig</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Early Copper Age</td>
<td><em>Ovis/Capra</em></td>
<td>Sheep/Goat</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Early Copper Age</td>
<td><em>Prolagus s.</em></td>
<td>Prolagus</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>Early Copper Age</td>
<td><em>Cervus e.</em></td>
<td>Deer</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>Early Copper Age</td>
<td><em>Vulpes v.</em></td>
<td>Fox</td>
</tr>
<tr>
<td>Scab'e Arriu</td>
<td>5</td>
<td>Early Copper Age</td>
<td><em>Bos t.</em></td>
<td>Cattle</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Early Copper Age</td>
<td><em>Sus s.</em></td>
<td>Pig</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>Early Copper Age</td>
<td><em>Ovis/Capra</em></td>
<td>Sheep/Goat</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Early Copper Age</td>
<td><em>Prolagus s.</em></td>
<td>Prolagus</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>Early Copper Age</td>
<td><em>Canis f.</em></td>
<td>Dog</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>Early Copper Age</td>
<td><em>Vulpes v.</em></td>
<td>Fox</td>
</tr>
<tr>
<td>Iglesias-Via Eleonora</td>
<td>1</td>
<td>19th century AD</td>
<td><em>Sus s.</em></td>
<td>Wild boar</td>
</tr>
<tr>
<td><strong>TOT. Terrestrial Animals</strong></td>
<td>30</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cabras lagoon</td>
<td>1</td>
<td>Contemporary</td>
<td><em>Mugil</em></td>
<td>Gray mullet</td>
</tr>
<tr>
<td>Gulf of Cagliari</td>
<td>1</td>
<td>Contemporary</td>
<td><em>Merluccius merluccius</em></td>
<td>Cod</td>
</tr>
<tr>
<td>Sardinian coast</td>
<td>1</td>
<td>Contemporary</td>
<td><em>Mullus barbatus</em></td>
<td>Red mullet</td>
</tr>
<tr>
<td>Corsican coast</td>
<td>1</td>
<td>Contemporary</td>
<td><em>Aristeus antennatus OR Aristeomorpha foliacea</em></td>
<td>Squid</td>
</tr>
<tr>
<td>Matzaccara lagoon</td>
<td>1</td>
<td>Contemporary</td>
<td><em>Mytilus galloprovincialis</em></td>
<td>Mussel</td>
</tr>
<tr>
<td>Matzaccara lagoon</td>
<td>1</td>
<td>Contemporary</td>
<td><em>Chamelea gallina OR Tapes decussatus</em></td>
<td>Clam</td>
</tr>
<tr>
<td>Sardinian coast</td>
<td>1</td>
<td>Contemporary</td>
<td><em>Alloteuthis media OR Loligo vulgaris</em></td>
<td>Clam</td>
</tr>
<tr>
<td>Sardinian coast</td>
<td>1</td>
<td>Contemporary</td>
<td><em>Anguilla anguilla</em></td>
<td>Eel</td>
</tr>
<tr>
<td>Sardinian coast</td>
<td>1</td>
<td>Contemporary</td>
<td><em>Xiphias gladius</em></td>
<td>Swordfish</td>
</tr>
<tr>
<td><strong>TOT. Marine Animals</strong></td>
<td>9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abba ’e Perdu (Tertenia)</td>
<td>1</td>
<td>Contemporary</td>
<td><em>Triticum d.</em></td>
<td>Wheat</td>
</tr>
<tr>
<td>Abba ’e Perdu (Tertenia)</td>
<td>1</td>
<td>Contemporary</td>
<td><em>Ordeum v.</em></td>
<td>Barley</td>
</tr>
<tr>
<td>Sarrala (Tertenia)</td>
<td>1</td>
<td>Contemporary</td>
<td><em>Faba v.</em></td>
<td>Faba bean</td>
</tr>
<tr>
<td>Tronciu (Tertenia)</td>
<td>1</td>
<td>Contemporary</td>
<td><em>Pistacia</em></td>
<td>Lentisk</td>
</tr>
<tr>
<td>Tronciu (Tertenia)</td>
<td>1</td>
<td>Contemporary</td>
<td><em>Quercus i.</em></td>
<td>Oak/Acorn</td>
</tr>
<tr>
<td>Tronciu (Tertenia)</td>
<td>1</td>
<td>Contemporary</td>
<td><em>Olea</em></td>
<td>Wild olive</td>
</tr>
<tr>
<td>Tronciu (Tertenia)</td>
<td>1</td>
<td>Contemporary</td>
<td><em>Myrtus c.</em></td>
<td>Myrtle</td>
</tr>
<tr>
<td>Su Tettioni (Tertenia)</td>
<td>1</td>
<td>Contemporary</td>
<td><em>Avena s.</em></td>
<td>Oat</td>
</tr>
<tr>
<td><strong>TOTAL Plants</strong></td>
<td>8</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

This study. A similar outcome was produced by the dating of one of three individuals from tomb 33 at Montessu, which were considered to date to the Early Bronze Age and turned out to be Medieval. This also cast doubt on the two individuals from tomb 32, for which similar relative chronology had been suggested, and therefore these were not considered in discussing the prehistoric dietary reconstruction. Instead, an unpublished date from su
Table 11. AMS $^{14}$C dating of the sites in the project with original attribution based on contextual data

<table>
<thead>
<tr>
<th>Site</th>
<th>Attributed period</th>
<th>Sites already $^{14}$C dated (2σ)</th>
<th>Samples radiocarbon dated</th>
</tr>
</thead>
<tbody>
<tr>
<td>S. Benedetto</td>
<td>Late Neolithic (Ozieri)</td>
<td>3941-3532 cal. BC (Sanna et al. 1999)</td>
<td>0</td>
</tr>
<tr>
<td>Montessu</td>
<td>Late Neolithic (Ozieri) layer</td>
<td></td>
<td>0 (no collagen)</td>
</tr>
<tr>
<td>Is Aruttas</td>
<td>Final Late Neolithic (Ozieri)</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Cannas di Sotto</td>
<td>Early Copper Age (Filigosa/Abealzu)</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>S. Caterina di Pittinuri</td>
<td>Early Copper Age (Filigosa/Abealzu)</td>
<td>2916-2153 cal. BC (Marini et al. 1997)</td>
<td>1</td>
</tr>
<tr>
<td>Mind’e Gureu</td>
<td>Early Copper Age (Filigosa/Abealzu)</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Serra Cannigas</td>
<td>Early Copper Age (Filigosa/Abealzu)</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Scab’e Arriu</td>
<td>Early Copper Age (Filigosa/Abealzu) layer</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Scab’e Arriu</td>
<td>Copper Age (Monte Claro) layer</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Seddas de Daga</td>
<td>Copper Age (Monte Claro)</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Via Basilicata</td>
<td>Copper Age (Monte Claro)</td>
<td></td>
<td>0 (no collagen)</td>
</tr>
<tr>
<td>Via Trentino</td>
<td>Copper Age (Monte Claro)</td>
<td></td>
<td>0 (no collagen)</td>
</tr>
<tr>
<td>Su Stampu ’e Giuannicu Meli</td>
<td>Early Bronze Age (Bonnanaro A)</td>
<td>2847-2459 cal. BC (unpubl., raw data from R. Floris pers. comm.)</td>
<td>0</td>
</tr>
<tr>
<td>Padru Jossu</td>
<td>Copper Age (Monte Claro) layer</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Padru Jossu</td>
<td>Copper to Early Bronze Age (Beaker A) layer</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Padru Jossu</td>
<td>Early Bronze Age (Beaker B/Bonnanaro A) layer</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Iscalitias</td>
<td>Early Bronze Age (Bonnanaro A)</td>
<td>2290-1899 cal. BC (Manunza 1998)</td>
<td>1</td>
</tr>
<tr>
<td>Montessu</td>
<td>Early Bronze Age (Bonnanaro A) layer</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Concali Corongiu ’Acca II</td>
<td>Early Bronze Age (Bonnanaro A)</td>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>

TOTAL SAMPLES 16

Stampu ’e Giuannicu Meli, kindly shared by Dott.ssa Rosalba Floris after sampling, pushed back the chronology of the collection, which was associated with Early Bronze Age pottery but turned out to belong fully to the Copper Age.

6.5. The Sampled Populations and Their Context

All collections sampled are listed in the table below (Table 12). They were collected with the collaborators who facilitated on-site sample removal by providing advice in order to be as least destructive as possible to the skeletal remains for future osteological analyses. Their role was also crucial in supplying first-hand osteological information, necessary to sample meaningfully based on the availability of sex and age subgroups. When the remains had not been analyzed, this was particularly important, though in other cases such information was as well very useful in order to integrate or rectify data that were already available but obtained using older methods.
<table>
<thead>
<tr>
<th>Site</th>
<th>Collaborator</th>
<th>Institution</th>
<th>Excavator</th>
<th>Institution</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Is Aruttas</td>
<td>Dr. J.F. Beckett (&amp; Dr. O. Fonzo)</td>
<td>UCam</td>
<td>Prof. E. Atzeni</td>
<td>UCag-Arch</td>
<td>Germanà 1980, Germanà 1982, Germanà 1995:55-64</td>
</tr>
<tr>
<td>S. Benedetto</td>
<td>Prof. R. Floris</td>
<td>UCag-Bio</td>
<td>Prof. E. Atzeni</td>
<td>UCag-Arch</td>
<td>Germanà 1995: 51-2; Maxia &amp; Atzeni 1964, Floris 2001</td>
</tr>
<tr>
<td>S. Caterina</td>
<td>Dr. El. Usai</td>
<td>UCag-Bio</td>
<td>Dr. L. Usai</td>
<td>Sopr.SS</td>
<td>Cocco &amp; Usai 1988; Bufia et al. 1995, Marini et al. 1997a &amp; 1997b</td>
</tr>
<tr>
<td>Pittinuri</td>
<td>Dr. J.F. Beckett</td>
<td>UCam</td>
<td>Dr. V. Santoni &amp;</td>
<td>Sopr.Ca</td>
<td>Santoni &amp; Usai 1995</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Dr. L. Usai</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cannas di Sotto</td>
<td>Dr. J.F. Beckett</td>
<td>UCam</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scab'e Arriu</td>
<td>Dr. O. Fonzo</td>
<td>LArcV</td>
<td>Dr. Em. Usai</td>
<td>Sopr.Ca</td>
<td>Badas &amp; Usai 1989, Usai 1998; Ragucci &amp; Usai 1994;</td>
</tr>
<tr>
<td>Serra Cannigas</td>
<td>Dr. J.F. Beckett</td>
<td>UCam</td>
<td>Prof. E. Atzeni</td>
<td>UCag-Arch</td>
<td>Atzeni 1995; Usai 2005</td>
</tr>
<tr>
<td>Mind'e Gureu</td>
<td>Dr. O. Fonzo</td>
<td>LArcV</td>
<td>Dr. Em. Usai</td>
<td>Sopr.Ca</td>
<td>Fonzo &amp; Usai 1997</td>
</tr>
<tr>
<td>V. Basilicata</td>
<td>Dr. J.F. Beckett</td>
<td>UCam</td>
<td>Prof. E. Atzeni</td>
<td>UCag-Arch</td>
<td>Atzeni 1967, 1985, 1986</td>
</tr>
<tr>
<td>V. Trentino</td>
<td>Dr. J.F. Beckett</td>
<td>UCam</td>
<td>Prof. E. Atzeni</td>
<td>UCag-Arch</td>
<td>Atzeni 1967, 1985, 1986</td>
</tr>
<tr>
<td>Seddas de Daga</td>
<td>Dr. J.F. Beckett</td>
<td>UCam</td>
<td>Prof. L. Alba</td>
<td>President, ASI</td>
<td>Alba 1999</td>
</tr>
<tr>
<td>Su Stampu 'e Gianniccu Meli</td>
<td>Prof. R. Floris</td>
<td>UCag-Bio</td>
<td>Dr. D. Salvi</td>
<td>Sopr.Ca</td>
<td>Unpublished data</td>
</tr>
<tr>
<td>Montessu</td>
<td>Dr. J.F. Beckett</td>
<td>UCam</td>
<td>Prof. E. Atzeni &amp;</td>
<td>UCag-Arch</td>
<td>Abatzeni 1972, Forresu 1993; Atzeni 2000</td>
</tr>
<tr>
<td>Concali 'e Corongiu Acca II</td>
<td>Prof. R. Floris</td>
<td>UCag-Bio</td>
<td>Prof. C. Maxia</td>
<td>Former UCag</td>
<td></td>
</tr>
</tbody>
</table>

UCam = Department of Archaeology, University of Cambridge
UCag-Bio = Dipartimento Biologia Sperimentale, Università di Cagliari
UCag-Arch = Dipartimento Scienze Archeologiche e Storico-Artistiche, Univ. di Cagliari
LArcV = Laboratorio di Archeologia, Villanovaforru, Sardinia
Sopr.Ca = Archaeologist, Soprintendenza Archeologica province Cagliari e Oristano
Sopr.SS = Archaeologist, Soprintendenza Archeologica province Sassari e Nuoro
ASI = Associazione Speleologica Iglesias

Following the table, I summarize the contextual information relative to each of the sites, in order to provide details on material culture, chronology and specific aspects of preservation and ritual.
6.5.1. Is Aruttas (Cabras)

The site is a small natural cave accessible by means of two modified entrances (its meaning is “the caves” in Sardinian), located at a few hundred meters from the Sardinian Sea and a few miles from the currently brackish water Cabras Lagoon. Thorough archaeological information regarding the site of Is Aruttas is yet to be published and likely never will. The context was looted and its cultural-chronological attribution was drawn from the apparently homogenous cultural materials that were associated with the skeletal remains. In reality, only a 20-cm-thick layer containing human bones is reported, which was probably not undisturbed, and the artifacts, assigned to a late phase of the Ozieri period, were admittedly few (Atzeni, pers. comm. in Germanà 1995: 61). This cultural phase, in the late 1970s when the attribution entered the literature, included also what is now referred to as Sub-Ozieri, the Copper Age southern Sardinian evolution of the Ozieri ceramic style; the artifacts, unpublished, are therefore likely to belong to this later time. Remains of 25 individuals were found in burial arrangements evaluated by Atzeni to be both primary and secondary. The population of Is Aruttas (Germanà 1980b, 1982a) included 28% immature individuals. Six cranial remains (24%) showed cribrum orbitalia. Occlusal wear is reported in 25% of the individuals in direct relationship with age, and caries occurrence was documented at 3.7% (Germanà 1995: 64). The general picture the paleopathologist has drawn of this group is that of a healthy population, with balanced and rich nutrition. Among the faunal remains – as well unpublished – several specimens of Prolagus were identified, and one vertebra of whale (Germanà 1995: 55-64). The importance of this collection lay in its being the only large collection attributed to the Late Neolithic other than San Benedetto, but one AMS date obtained directly on bone, compatible with the Late Bronze Age Nuragic, puts such attribution in question (1433-1130 cal BC 2σ). Therefore, the isotopic data are reported but not considered in the reconstruction of the economy between 4000-1900 BC.

6.5.2. San Benedetto (Iglesias)

The tomb II of the rock-carved necropolis named San Benedetto is of utmost importance for the Neolithic of Sardinia, because it is the only published intact burial that belongs reliably to the Ozieri phase (Maxia and Atzeni 1964). Most tombs of the domu de janas type, as explained in chapter 4, have been utilized by the same groups for centuries
well into the Copper Age, and in most cases even later. AMS dating confirmed the
chronological placement in the first half of the 4th millennium BC (raw date in Floris 2001:
3941-3532 cal BC 2σ). In 1961, the site was discovered and partially damaged by excavation
for agricultural improvements on a schist hill slope at approximately 500 m asl (although no
maps in the literature mark the exact location). After archaeologists documented and
recovered contexts and materials, it was re-buried, so it is no longer accessible. Tomb II
consists of three rooms arranged in an irregular cross pattern around a central space
connected to the entrance; all rooms still had the sealing slabs in situ, in the original
placement or slightly moved (Atzeni 2001a; Maxia and Atzeni 1964). The disarticulated
remains of 35-40 individuals were recovered in all rooms, with crania and long bones placed
in evidence and along the sides. Occlusal wear was present but not frequent, while caries
occurrence (7%: Germanà 1995: 51-52) is within the range typical of agricultural societies.
This site is important for the whole picture of the isotopic record, due to its being the only
collection dating to the Late Neolithic Ozieri (ca. 3850-3300 BC).

6.5.3. Montessu (Villaperuccio)
One of the largest rock-carved necropolises on the whole island, the site was used for burial
and ceremonial purposes from the Late Neolithic through the Middle Ages; all prehistoric
cultural phases are represented among the approximately 40 tombs, many of them articulated
in several rooms: their plans are either circular, with “oven-shaped” curved ceiling and the
intermediate ceremonial room (anticella), or roughly rectangular, with long access corridor,
representing the two phases of the continuum along the Ozieri/Post-Ozieri tradition of domus
de janas (Atzeni 1972; Forresu 2000). Peculiar to this site, which represents one of the rare
clusters of complex and decorated tombs in southern Sardinia if compared with the North, is
the presence of three larger tombs (so-called “tomb-sanctuaries”: tombs 7, 10 and 33), where
the entrance and the vestibular room is expanded into wide spaces for ritual activities, with
cupules and hearths carved in the rock pavement (Atzeni 1981; Forresu 2000: 83). While
human remains are barely mentioned in the brief preliminary reports that unfortunately make
up all the literature on this outstanding site, access to the recovered skeletal remains, and
information on their context, were obtained by visiting and interviewing Dott. Remo Forresu,
co-director of many excavations at the site, currently director of the nearby Museo
Archeologico di Santadi. The skeletal materials have not been analyzed and in some cases they have not been cleaned yet, but human bones from four contexts, judged potentially reliable based on such oral information, were sampled in 2004 for isotopic analyses. AMS dating devided these remains of their informative importance relative to the present dissertation (Table 13): the attribution of the individual from tomb 10 to the Middle Bronze Age (out of the 3850-1900 BC range and included only for the purpose of comparing different phases at the same site) was somewhat confirmed, although it appeared slightly later than expected; one out of five attributed to the Early Bronze Age turned out to be Medieval (cal AD 888-1151 2σ), so casting doubt on the reliability of the rest; the one attributed to the Late Neolithic did not yield any collagen and remains therefore as well uncertain. Therefore, these were also not taken into account in the paleoeconomic reconstruction of the examined period.

6.5.4. Santa Caterina di Pittinuri (Cuglieri)

Located north of Oristano, at a few km from the current coastline (which may have been further away in the time the tomb was carved), it is an isolated domu de janas organized in four rooms, the first being the anticella (room A: see plan in figure 35), preceded by a corridor. Accidentally discovered in occasion of the construction of a road, the tomb was excavated in two campaigns, in 1985 and 1992 (Buffa, et al. 1995). All cultural

Table 13. Chronology of the bone samples from Montessu collected for isotopic analyses (cultural attribution courtesy of Dr. R. Forresu)

<table>
<thead>
<tr>
<th>Tomb</th>
<th>Cultural attribution</th>
<th>Corresponding chronology (Tykot 1994)</th>
<th>AMS dating outcome</th>
<th>AMS dating cal 2σ range*</th>
<th># indiv. sampled for isotopes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tomb 15</td>
<td>Late Neolithic (Ozieri)</td>
<td>Ca. 4000-3200 BC</td>
<td>No collagen: not confirmed</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Tomb 32</td>
<td>Late Beaker/ EBA (Bonnanaro A)</td>
<td>Ca. 2200-1900 BC</td>
<td>No dating: not confirmed</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Tomb 33</td>
<td>Late Beaker/ EBA (Bonnanaro A)</td>
<td>Ca. 2200-1900 BC</td>
<td>Incompatible: Medieval</td>
<td>AD 888-1151</td>
<td>3</td>
</tr>
<tr>
<td>Tomb 10</td>
<td>MBA (Bonnanaro B)</td>
<td>Ca. 1900-1600 BC</td>
<td>Partially compatible: confirmed</td>
<td>1730-1440 BC</td>
<td>1</td>
</tr>
</tbody>
</table>

*For full information on these dates, see table 30.
materials point to its carving and use during the Copper Age; utilization lasted through two phases as represented by the difference in pottery shapes, decoration and conditions: the earlier, represented by the basal layer of the *anticella*, is characterized by open, middle-sized vessels, all in fragments, with some degree of incised and impressed decoration. The later phase, documented in the upper layer of the *anticella* and in the corridor, shows mostly small cups for individual consumption and closed shapes for liquids, largely undecorated, often intact and laid along the walls (Cocco and Usai 1988: 13-16). Using the phases suggested by Melis, the upper layer corresponds to groups C-D and D (labeled as a transition between Filigosa and Abealzu), and represents the very last aspect of the Ozieri ceramic tradition. The previous phase, not included in her study, due to the prevalence of bowl-like vessels is to be assigned to phases B-C and C (fully within the Filigosa aspect: Melis 2000d: 54-55).

Common to both phases are offerings of animal parts, the overwhelming majority being pig mandibles (Fonzo, personal communication 2006); these faunal remains, curated at the Laboratorio di Archeologia in Villanovaforru, were also sampled for isotopic analyses. The three smaller rooms were used as permanent funerary space, with abundant skeletal remains and few artifacts, mostly objects for personal use or adornment (arrowpoints and silver rings), but little pottery. The osteological study, still largely unpublished, shows that all skeletal elements are represented; an MNI of approximately one hundred individuals was calculated from bones, while over 250 were calculated from teeth, many of which were loose, and probably pertain to several generations including the earliest ones not represented by bone remains (Marini, et al. 1997a; 1997b). In fact, the two available radiocarbon dates, one already published, one in this study, cover a long timespan (3355-3030 and 2916-2153 cal BC 2σ). While teeth were studied at the Università La Sapienza in Rome by Prof. Alfredo Coppa and colleagues, only sorting and preliminary analysis were performed on bones in Cagliari. They are currently unavailable because they are stored in the *Magazzini Militari*, a building that is interdicted due to health and safety concerns. Luckily, a limited number of cranial specimens from room C had not been taken back there with the rest, and were therefore available for sampling at the Department of Experimental Biology of the University of Cagliari. The little information available on pathologies represented in this population concerns its poor dental health: the rate of caries, about 18%, represents an anomalously high frequency (Coppa unpublished), which points to high consumption of fruits. Alternatively, since there is no other evidence for this, consumption of processed cereals could also be
accounted for such numbers. Further discussion of dietary reconstruction is below, in the integration with the isotopic results.

6.5.5. Cannas di Sotto (Carbonia)

The site is a vast necropolis of still mostly unexcavated *domus de janas*, located on a low limestone plateau partially incorporated by development into the urban area of the city of Carbonia. Survey and partial excavation of tomb 12 was carried out in 1983. Only the corridor and one room of the tomb was brought to light, so that the extent and complexity of the whole structure is unknown, and only a preliminary report with site plan and select materials has been published (Santoni and Usai 1995: 53-55). Since no materials of classic Ozieri style were recovered, the carving and occupation of the tomb dates to the Copper Age. Since the ossuary-room is directly past the corridor and entrance, the excavated portion may have represented at some point the ritual area (*anticella*) that possibly later became funerary when ritual activities moved outside (see chapter 4.). Interestingly, no animal remains are mentioned, besides a few bone tools and shells. Human remains, disarticulated, were recovered in no apparent meaningful order in the room, mixed with compact infiltrated soil, pottery, and lithic tools, and one female figurine. The ceramic phase represented is recognized by the excavators as Sub-Ozieri through Filigosa-Abealzu (Santoni and Usai 1995: 58-64), and pertains to Melis’s groups A through C (Melis 2000d: 152), earlier than Santa Caterina di Pittinuri’s main documented phases according to her sequence. This skeletal collection is therefore important as a sample of the Post-Ozieri and early Filigosa phase in the Southwest, and the AMS date fits an early phase of the Copper Age (3349-3023 cal BC 2σ).

6.5.6. Scaba ’e Arriu (Siddi)

The site is located on gentle slopes on the east side of a group of hills in the Marmilla region. Accidentally discovered in 1983 during works for private construction near the town of Siddi, the structure is a rock-carved tomb with longitudinal plan, articulated in corridor, *anticella* and funeral room (Badas and Usai 1989). When excavated, the inner burial room was found occupied by Monte Claro pottery and remains, while earlier pottery of Ozieri and
Post-Ozieri tradition was concentrated in the bottom layers of the anticella and of the corridor. The remains of the inner room had been cleared and moved in the anticella, to the sides of a newly built megalithic corridor leading straight to the entrance of the burial room; the roof of the anticella had also partially collapsed (Usai 1998). The tomb, rather than “violated” by “Filigosa and Abealzu peoples” (Usai 1998: 34), was likely used by the same community, that had ancestral links with the first builders who used Ozieri-style pottery, with no discontinuity but a gradual transformation in ceramic style and material culture (see chapter 4). The break is instead apparent with the users of Monte Claro pottery, who cleared the earlier remains and modified the whole structure of the tomb, apparently based on different cult perspectives spreading in the advanced Copper Age. No more offerings of animals are observed in this context, nor lithic utensils accompanying the deceased (Ragucci and Usai 2004: 152-180). There is a tendency for distinction and maintenance of individuality in death, with the separation of select remains into cists arranged within the chamber, and into large jars (Usai 1998: 34-35).

On the other hand, the pottery cleared along the earlier remains and found in the anticella and corridor pertains mostly in the phase C (Filigosa II) within Melis’ ceramic framework, with some evidence for earlier and later types (Melis 2000d: 153), and lithic industry is rich and comparable to that of other Copper Age contexts. The importance of the skeletal remains from this site for stable isotopic analyses is great, because it allows us to measure values across two different cultural-chronological phases, overcoming the comparative problem of environmental variability between sites. Three AMS dates enabled me to pinpoint the chronology of the change in pottery style and burial practices, with the Post-Ozieri centered around the 29th-28th century (2902-2634 and 3017-2712 cal BC 2σ), and the Monte Claro around the 26th-25th (2620-2350 cal BC 2σ), with a possible hiatus that would need further chronological testing. Furthermore, this site is crucial since the presence of faunal remains, analyzed by Dott.ssa O. Fonzo, enables us to reconstruct more reliably the foodchain and so identify the protein sources of the human diet more accurately.

6.5.7. Serra Cannigas (Villagreca, Nuraminis)

No accurate information is available regarding the context of this site, a burial that yielded a wealth of artifacts including pottery, lithics, and probably the highest concentration
of metal jewelry and tools in Sardinian prehistory. Apparently it consisted of two lithic cists or tombs (A and B) carved in shallow and soft calcareous rock, which were devastated by plowing. Many of the materials were never recovered, and likely found their way to private collections (Atzenei 1985). The metal finds included several silver spirals and rings, and copper daggers (Usai 2005b: 261). Pottery finds showed a wealth of shapes all attributed to the Copper Age Post-Ozieri tradition, ranging from Melis’ group A-B through C-E, witnessing to a long timespan of utilization. The burials were collective, but the skeletal remains salvaged have never been analyzed. The presence of partially burnt bones may indicate cremation but also could result from later use of the tomb, or even from wild fires after erosion of the topsoil. Among the details of recovery learned from interviewing the archaeologist who directed the operations is the presence of a third series of teeth recognizable in several cranial specimens (Atzeni, personal communication Nov. 2004). However, no such specimens were found in the recovered material at the time of sampling. The one AMS date obtained from bone tissue (3080-2710 cal BC 2σ) fits the general time range of the Post-Ozieri style.

6.5.8. Mind’e Gureu (Gesturi)

The exact location of this burial is not reported; the skeletal remains and associated artifacts were accidentally discovered during private construction works, handed over to archaeologists, and later published. No contextual data are known, so that the attribution was based on the ceramic style (Fonzo and Usai 1997), to be later confirmed by the AMS date that was obtained directly from the bone tissue of the one cranium recovered with the materials (2620-2287 cal BC 2σ). The phase appears to be the last Post-Ozieri aspect, labeled Abealzu by the authors (see chapter 4), which can be attributed to the phase C (Filigosa II) according to Melis (2000d: 153): it is close to the cultural material assemblage from the later layer at Santa Caterina di Pittinuri and to much of the Post-Ozieri materials at Scab’e Arriu. The dating, much later than the earliest Monte Claro dates and even slightly later than the one date from the Monte Claro phase at Scab’e Arriu itself, demonstrates clearly that the two ceramic styles were partially contemporaneous, potentially for a few hundred years.
6.5.9. Via Basilicata and Via Trentino (Cagliari)

These two denominations belong to the same necropolis, documented piecemeal during the 20th century over a wide area deeply transformed by development in the expansion of the city of Cagliari, comprehensively known as Sa Duchessa. The tombs are at the foot of the several hills that characterize this currently urban landscape, alternating with fertile alluvial soils. Likely connected to the dwellings found uphill near the present-day College of Literature and Philosophy of the University of Cagliari, all tombs were of the same basic type, carved in the sedimentary rock, with a vertical shaft and one or three rooms arranged horizontally. Rooms are irregularly circular or oval-shaped, and inhumations are single or in small groups. The individuals sampled for isotopic analysis are from tombs 1 and 4 in Via Basilicata (Atzeni 1967), and from tomb 1 in Via Trentino (Atzeni 1985). Burial arrangement is quite standardized, with bodies lying flexed on the left side, with one or several vessels near the head. The remains are invariably in very bad conditions, due to water leakage into the tomb and roof collapse that in some cases is likely to have occurred near the time of carving (Atzeni 1967, 1985, 1986). As expected, virtually no collagen was preserved, which besides the stable isotopic analyses also prevented AMS dating.

6.5.10. Seddas de Daga (Iglesias)

This natural cave utilized as a burial location was discovered by a collapse of the limestone rock matrix that opened up an entrance, in 1974. Looting followed the discovery, so that when speleologists and archaeologists were able to reach the site, they could only document the devastation and collect sherds and bones. The cultural attribution is based on the mixture of skeletal remains with sherds that pertain to the same culturally homogeneous aspect, that of Monte Claro (Alba 1999). Among the bones recovered and stored, mostly large fragments, were crania, vertebrae and long bones, belonging to at least 13 individuals. However, it is reported that at the time of discovery the crania were 17 and they are described as arranged in a circle; furthermore, trepanation was also recorded, although many of these remains have long disappeared (Fruttu and Petrone 1982: 2). AMS dating did confirm the attribution to the chronological phase assigned on stylistic grounds (2866-2493 cal BC 2σ).
6.5.11. Su Stampu 'e Giuanniccu Meli (Villaputzu)

Recent excavation, soon to be published, documented a burial context in a natural cave near the east coast of Sardinia, in the area named Quirra. The cave had been devastated by later reuse (until recently as a shelter for pigs) and possibly looting, besides the infiltration of water that covered many of the artifacts and bone remains with a layer of concretions (Donatella Salvi, personal communication Nov. 2004). Human remains were in highly fragmentary conditions and very friable, and this condition of advanced degradation was confirmed by the poor preservation of collagen. The cultural-chronological attribution of the ceramic sherds pointed to the Bonnanaro A Early Bronze Age aspect (end 3rd-beginning 2nd millennium BC). However, the unpublished AMS date from the University of Lecce (Italy), graciously shared by Dott.ssa Rosalba Floris, placed the sample, provided by the University of Cagliari Department of Experimental Biology, in the early-to-mid 3rd millennium BC (2847-2459 cal BC 2σ, with higher probability in the later part of the period: 2577-2477 cal BC 1σ). Since even the 25th century BC seems too early for a precocious appearance of Bonnanaro A pottery on the East coast, this is to be considered another example of skeletal remains found in caves in disturbed stratigraphies with misleading cultural material associations. In this case the attribution was wisely tested through radiocarbon, and fortunately skeletal remains are still within the time range of the present study, despite their being several hundred years earlier.

6.5.12. Padru Jossu (Sanluri)

The grave of Padru Jossu was discovered during digs for irrigation, and excavated in 1980. It consists of a large approximately rectangular pit, with a raised surface on one side, and a few niches. It yielded abundant skeletal remains and artifacts, including pottery, metal items, and rich ornaments made of shells, stone and teeth (Ugas 1982b, 1989). Several layers were accurately documented, with some individuals in partial articulation, witnessing to an occupation lasting through at least three different cultural phases: Monte Claro (very thin basal layer, with a few bone fragments and potsherds), Bell Beaker, and Bonnanaro A, spanning approximately 2700 to 1900 BC according to the current chronology (Tykot 1994).

While the excavator believes it to be an underground rock-carved tomb (type domu de janas) whose friable roof collapsed (Ugas 1982b: 19), a comparison with a site excavated
in mainland Italy that shows stringent similarities in spatial organization and burial customs may suggest that it was an open-air pit for ceremonies related to the dead (Fosso Conicchio: Fugazzola Delpino and Pellegrini 1999). Moreover, the custom of keeping a funerary site open is proposed also by Manunza (2000; 2005: 148-149) for the pit grave of Iscalitas (Soleminis), which pertains to the Bonnanaro A aspect, considered a later outcome of the Bell Beaker. The importance of the site lies in its wide repertoire of artifacts (Ugas 1998) for material culture aspects previously documented only by early-20th century excavations that did not meet modern stratigraphic standards.

Unfortunately, the wealth of anthropological information that the osteological study would yield is not available: most of the remains lie in boxes since the moment they were unearthed. Nineteen crania were randomly sampled for cranial measurements from the three layers: one from the Monte Claro layer, 5 from the ‘decorated’ Bell Beaker layer, 13 from the ‘undecorated’ Bell Beaker layer (Germanà 1982b, 1987; 1995: 90-91, 101-104), which the majority of scholars assimilate to an early aspect of the Early Bronze Age Bonnanaro A; unfortunately, this study did not involve any post-cranial specimens nor did it target any specific paleopathological or behavioral element understandable from the skeleton. Interestingly, two out of five Beaker A individuals had atrophy or agenesis of the same tooth, and 6 out of all 19 individuals showed cribrum orbitalia (Germanà 1987), which are likely related to nutrition poor in protein or vitamins, or to parasites (see chapter 5).

Animal offerings were present in both main layers, in some cases as halved or whole immature animals, with mostly ovicaprids and no cattle in the Beaker layers, and some specimens of pig and cattle with sheep/goat still dominant in the Early Bronze Age layers. Whole animals were common in phase A and absent in phase B (Sorrentino 1982; Ugas 1998: 277). This was interpreted as reflecting a slight increase in agricultural activities within a mostly pastoral context (Ugas 1982b: 21). The presence of several individuals from two phases makes this site, together with Scab’e Arriu, one of the most important for the research project, which also justifies the number of AMS dates deemed appropriate to maximize the information potential coming from the biochemical investigation. Five determinations (Table 14) enabled us to pinpoint, with the best accuracy up to now, the timing of ceramic styles and cultural change they tend to be associated with.
Table 14. Chronology of the bone samples from Padru Jossu collected for isotopic analyses (cultural attribution based on stratigraphic information in Ugas 1982 and Germanà 1987).

<table>
<thead>
<tr>
<th>USF Lab # and Specimen #</th>
<th>University of Arizona Lab #</th>
<th>Cultural attribution</th>
<th>Chronolog. phase (Tykot 1994)</th>
<th>2σ range*</th>
<th>1σ range*</th>
</tr>
</thead>
<tbody>
<tr>
<td>USF # 6906 (cr. 67)</td>
<td>AA72790</td>
<td>Late Copper Age</td>
<td>Ca. 2700-2200 BC</td>
<td>2561-2234 cal BC</td>
<td>2469-2345 cal BC</td>
</tr>
<tr>
<td>USF # 9562 (cr. 52)</td>
<td>AA72153</td>
<td>Late Copper Age</td>
<td>Ca. 2700-2200 BC</td>
<td>2463-2155 cal BC</td>
<td>2432-2206 cal BC</td>
</tr>
<tr>
<td>USF # 6904 (cr.70-71)</td>
<td>AA72152</td>
<td>Late Copper Age</td>
<td>Ca. 2700-2200 BC</td>
<td>2463-2155 cal BC</td>
<td>2433-2207 cal BC</td>
</tr>
<tr>
<td>USF # 6908 (cr. 36)</td>
<td>AA72792</td>
<td>Early Bronze Age</td>
<td>Ca. 2200-1900 BC</td>
<td>2430-2044 cal BC</td>
<td>2287-2144 cal BC</td>
</tr>
<tr>
<td>USF # 6907 (cr. 3)</td>
<td>AA72791</td>
<td>Early Bronze Age</td>
<td>Ca. 2200-1900 BC</td>
<td>2461-2152 cal BC</td>
<td>2397-2205 cal BC</td>
</tr>
</tbody>
</table>

*For full information on these dates, see table 30.

6.5.13. Iscalitas (Soleminis)

The site, reported in the literature as Is Calitas, is a pit grave dug on a low hill in an area bordering the plains around Cagliari. Agricultural works for planting a vineyard uncovered bones and sherds, and upon call by local amateur archaeologists the Soprintendenza proceeded to salvageing the information with a scientific excavation in 1995 (Manunza 1998, 2005). The grave yielded Early Bronze Age cultural materials of Bonnanaro A style and a large number of human remains, found mostly as disarticulated elements, with a small number of partially or totally articulated skeletons (Buffa, et al. 2000; Manunza 1998). Two close radiocarbon dates on bone are available, from top and bottom layers of depositions (2290-1899 and 2286-2027 cal BC 2σ). No clear discontinuity was detected in the depositions, which must have continued regularly until the end of utilization. The excavator suggests that during this time the tomb was left open: this would be compatible with its being shallow (about 75 cm), with the skeletons tightly packed but disarticulated and seemingly pushed eastward, and the presence of a ‘midden’ of stones. In one case, a tripod appeared intentionally laid on a small stone slab, which would imply it was standing inside the pit (Manunza 2005: 148). No animal offerings were recovered, while beside the pottery and personal ornaments, about a hundred obsidian flakes were also found. The bare material of these simple flakes, which contrasts with the arrowpoints and formal tools accompanying the dead in previous times, has been interpreted as still holding some special meaning in
times of transition between different symbolic-prestige goods, in an age when tool-making by knapping was already declining but obsidian was still somewhat valued (Manunza 2005: 149). The accurate excavation made it possible for this site to document reasonable associations between some human remains and artifacts. This in turn allowed us to assess status by associated grave goods and test isotopically the presence of different diets according to social conditions. The relatively low caries (3%) and high occurrence and degree of occlusal wear also provided an indication of diet, which according to common interpretations would indicate low consumption of processed starch and carbohydrates (Usai, et al. 2005).

6.5.14. Concali Corongiu ’Acca (Villamassargia)

This site is a natural cave, located in the Sardinian southwest, where human remains and pottery were recovered, but no accurate contextual information or stratigraphy was ever published. In fact, from the literature it was even problematic to reconstruct which cave the remains exactly come from, since two with the same name, indicated with I and II, a few tens of meters apart, yielded archaeological materials. According to Atzeni (1981: xxiii ; 1996a), cave II was already an Early and Middle Neolithic site; cave I yielded Late Neolithic, Late Copper Age Monte Claro, and Bell Beaker materials (Atzeni 1981: xxiii; Ferrarese Ceruti 1981a: lvi, lviii), but both caves were used in the Early Bronze Age by Bonnanaro A groups (Ferrarese Ceruti 1981a: lxvi). However, in early notes (Ferrarese Ceruti 1974a; b: 143-144, note 56), it is in cave II that a wealth of pottery dating the the Early Bronze Age was recovered after the discovery of the site on March 31, 1973, by the Associazione Speleologica Iglesiente. Some pottery represents already an autonomous evolution from shapes that are strictly parallel to Polada types (see chapter 4 on ceramics), which may indicate a somewhat later occupation as compared to the previous Bonnanaro A sites. One AMS date was obtained directly from bone (2202-1963 cal BC 2σ), which confirms the chronology. Among the few cranial specimens, there was a high occurrence of remarkable diploic thickening (Germanà 1995: 130; Maxia and Floris 1961), a hyperostotic condition which is commonly believed to be a symptom of anemia as cribræ, but could also be connected to vitamin C deficiency or parasites.
6.6. Methods

6.6.1. Sample Collection

Authorizations to remove the bone samples and analyze them abroad were granted by the Soprintendenza Archeologica per le Province di Cagliari e Oristano. Sample collection took place in collaboration with Dott.ssa R. Floris, Dott.ssa E. Usai (Università di Cagliari), Dr. O. Fonzo (Laboratorio di Archeologia, Villanovaforru, Sardinia), and Dr. J.F. Beckett (University of Cambridge-UK), so as to remove bone samples from locations not important for potential future morphometric studies, and to have osteological data on the remains not previously studied. In some cases, even though sex and age had been assessed previously, this was redone to acquire as much as possible consistency of methods. A few grams of bone per individual were removed with a portable Dremel professional drill with speed control. Each sample was bagged, labeled and cataloged. Contamination during or after sampling is not an issue with such procedures, since the preparation removes fundamentally anything that is not collagen, apatite or possible preservatives (see below).

6.6.2. Sample Preparation

Approximately 1 gram of whole bone was selected per each individual, physically cleaned with dental tools from visible soil or concretions, ultrasonically cleaned and dried. Approximately 10 mg of bone powder were removed by drilling and milling, weighed and collected to be prepared for apatite analysis. Collagen preparation is a variation of well tested procedures (Ambrose 1990, 1993): starting from the ~1 g bone chunk, after soaking it in a glass jar for ~24 hours in 50 ml of 0.1 mol/L NaOH aq. to remove humic acid contaminants, it was isolated by demineralization by soaking in 50 ml of 2% HCl aq. in two or more ~24-hour baths, depending on the necessity for more reaction. After the first bath, samples were often cut into smaller pieces as required to favor penetration of the solution. After demineralization, another ~24 hours in NaOH removed contaminants that may not have been removed when the bone was whole. Visual qualitative indicators of the demineralization are the color of the solution and the presence of bubbles on the surface. Visual assessment of collagen preservation in this way is possible throughout the process, unlike procedures involving the grinding of bone into powder and its gelatinization (Ambrose 1993; Tykot
In order to remove lipids, samples were then immersed for ~24 hours in 50 ml of a solution made of methanol, chloroform, and d.i. water in proportions of 2:1:0.8 (~52.6%, 26.3%, 21.1%). Each sample was rinsed at every step involving a change in solution. The use of mild HCl (2%) allows the recovery of collagen even from bone that is physically degraded (Tykot 2004), and has the attached advantage of improving safety for lab workers. The extracted material, which is as close as possible to pure collagen, consists of pellets, or pseudomorphs; they are transferred into vials, oven-dried at ~65°C for at least 12 hrs or more if necessary, and weighed to calculate concentrations (collagen yields).

The preservation, and thus results reliability, of collagen samples from 132 individuals (both human and faunal) has been assessed using conventional parameters that include collagen concentration, or % yield, the concentration of N and C in collagen, and the ratio of C:N (Ambrose 1990). Specifically, according to experimental tests, N yield in well preserved collagen was higher than 4.8%, and when lower than 0.5% collagen was always diagenetically altered; C yield was above 13% in well preserved collagen, and constantly lower than 3.5% in degraded collagen. A C:N ratio between 3.4-3.6 and 2.9 has been shown to indicate faithfully good preservation, with the first limit being different according to different studies (Ambrose 1990: 447; Schoeninger, et al. 1989). Since the visual assessment method was used, integrated by the collagen yield from whole bone, and the analyzer was not available at the beginning of this project, the rest of the samples (64 individuals) were evaluated without the C:N ratio and C and N concentration parameters.

Concerning collagen yields, a concentration under 1% is commonly considered indication of potentially degraded collagen. Some experimental data suggest a higher percent (3.5% in Ambrose 1990), but 1% is widely accepted in studies using the pulverization-gelatinization method (e.g. Honch, et al. 2006; Le Huray and Schutkowski 2005; Papathanasiou 2003). Therefore, yields of 1% and even 0.5% can be safely considered as terms “supra quem” collagen is reliably preserved, if the difference in preparation is taken into account: in fact, it involves the potential loss of some collagen during rinsing, which the pulverization-gelatinization method avoids. Consistency of yields and lack of other systematic indicators of diagenesis, such as the relationship between yields and isotopic values, can also indicate when the isotopic signature is not preserved. Investigating the existence of correlations between the several parameters and the isotopic values themselves is a further test.
To isolate the apatite, 10 mg of bone powder are treated with a ~72-hour bath in 1.5ml of 2% NaOCl (bleach) which dissolves the organic portion; non-biogenic carbonate is removed by soaking the sample for ~24 hours in a 1.0 mol/L buffered acetic acid/sodium acetate solution. A study published after preparation had started shows that soaking times of ~4 hours in lower concentration acetic acid (0.1M) is sufficient and apparently even better to avoid the danger of recrystallization (Garvie-Lok, et al. 2004: 771-775); however, the shifts observed between results obtained with the two preparation methods meant that changing procedure would render samples processed in different ways not comparable, so the decision was made to keep using the traditional method for all samples. Attention was paid to be as consistent as possible with the ratio of sample to solution quantity and soaking times, which have been shown to be important for consistency of results (Garvie-Lok, et al. 2004; Koch, et al. 1997; Lee-Thorp and Sponheimer 2003). Apatite is undoubtedly less reliable if compared to the quantitative indicators available for collagen, and to the resistance of tooth enamel to contamination. Due to the crystalline structure of carbonate, exogenous carbonates dissolved in the soil matrix can recrystallize replacing lost carbon, so contaminating the original isotopic signature (Sharp 2007: 133-138). Although there is no quantitative proof that removal of such non-biogenic carbonate is complete, the procedures used have been shown to produce reliable results (Lee-Thorp and van der Merwe 1991; Nielsen-Marsh and Hedges 2000a). The assessment of the integrity of samples through the carbonate yield measured after each preparation step (Nielsen-Marsh and Hedges 2000b), and in the absence of soil samples, the viability of the isotopic values themselves, can be used as secondary proxies for preservation. It has been shown that bone mineral has the potential to retain original isotopic signatures, and it has been suggested that in certain conditions recrystallization can even favor this preservation, rather than contaminating the sample (Lee-Thorp and Sponheimer 2003).

6.6.3. Analysis by Mass Spectrometry

Mass spectrometers are instruments dedicated to the detection of mass differences in the molecules of gases. While the principles and basic functioning has not changed since the 1960s, several improvements allowed scientists to use the instruments to perform isotopic measurements routinely. Samples are bombarded and positively ionized; they are then
accelerated by a magnet that deflects their trajectory according to the specific molecular mass (different for each element and isotope targeted); these molecules are then counted in collectors. The system to introduce the sample gas into the spectrometer can be dual-inlet or continuous-flow. The latter, devised in the late 1970s, despite its being slightly less precise than the dual-inlet, improved the rapidity of analysis and reduced considerably the required sample size. This system also allows to analyze C and N isotopes together (for further details see Sharp 2007: 30-33).

In the present project, 1 mg per sample of the end product of collagen preparation was weighed, placed in tin capsules, and analyzed in continuous-flow mode with a Carlo-Erba 2500 Series II CHN analyzer, coupled with a ThermoFinnigan Delta+XL stable isotope ratio mass spectrometer. Precision ($2\sigma$) is better than $\pm 0.3\%$ for $\delta^{15}\text{N}$ and $\pm 0.2\%$ for $\delta^{13}\text{C}$. Concerning the apatite samples, 1 mg of the powder prepared as described above was analyzed on another ThermoFinnigan Delta+XL mass spectrometer, in dual-inlet configuration, equipped with a Kiel III individual acid bath carbonate system. Precision ($2\sigma$) is in this case better than $\pm 0.04\%$ for $\delta^{13}\text{C}$ and $\pm 0.06\%$ for $\delta^{18}\text{O}$. Samples of isotopically known materials, urea for collagen and Carrara marble for apatite, are used as working standards by being input at regular intervals during each run of samples. Both mass spectrometers are located at the Paleo Lab, University of South Florida, St. Petersburg campus, where samples were taken, and analyses were performed under supervision of Mr. Ethan Goddard, Associate in Research and Dr. David Hollander, Associate Professor and director.

6.6.4. Statistical Analysis

The results were studied statistically with Statgraphics Plus (professional edition), after the transformation of most of them to account for microclimatic-geographic variation. Most phenomena were studied and illustrated through basic descriptive statistics, with biplots of collagen $\delta^{13}\text{C}$, apatite $\delta^{13}\text{C}$, collagen $\delta^{15}\text{N}$, collagen-apatite $\delta^{13}\text{C}$ spacing, $\delta^{18}\text{O}$, multiple box-and-wisker plots of single classes of data. Basic statistical parameters, such as means and standard deviations were calculated for all the investigated groups and subgroups, and when needed the significance of differences between groups was also studied statistically.
Correlation analysis was used to test the relationship between variables and verify that the transformation of the data made them change significantly as expected.

A note to the reader: the notation of standard deviation values in this dissertation as ± units ‰ is not strictly speaking correct since it is a mathematical abstraction and not a quantity of permils, percents, nor anything else. I decided to use it anyway in charts and descriptive statistics, given its usefulness and reliability in order to have a visual idea of the variation of each group and following its widespread use in the literature.
Chapter 7. Results

7.1. Preservation of Stable Isotopic Signal

7.1.1. Bone Collagen Preservation

Collagen preservation and the reliability of its isotopic signature has been assessed by means of several parameters commonly used, as discussed in the section on methods in chapter 6. A number of samples, already analyzed before 2005, were evaluated through visual assessment, collagen yields, and consistency of isotopic results themselves, whereas for a second group of samples the C:N ratio analyzer became available, and this also allowed a comparison of the different preservation parameters.

Out of the 171 individuals originally sampled, not all could be analyzed: one (#6991) had preservative glue that could not be eliminated with any of the available solvents (distilled water, methanol, chloroform, acetone), the rest was lost while being processed or analyzed, or did not yield enough collagen. A total of 150 individuals were therefore successfully analyzed for stable isotopes in collagen. Out of the total, 29 samples had collagen concentrations lower than 0.5%; nine of these were analyzed anyway, and most of them had isotopic values comparable with those better preserved.

Yields were highly variable by group (Figure 65), likely reflecting the wide variety of taphonomic histories at each site. The range of their average (Table 15) is from 0.0% for the single-individual group of Montessu, tomb 15, possibly Late Neolithic but of unreliable attribution, to 14.5 ± 1.4% for Is Aruttas, which AMS dating placed later than the subject period. Within the period 4000-1900 BC, yield was between nearly zero (0.1 ± 0.1%) for the necropolis at Sa Duchessa (Cagliari) and 8.6 ± 2.4% for the cave of Seddas de Daga. Even different layers within the same deposit, such as the phases A and B at Padru Jossu, show
Figure 65. Box-and-whisker plot of collagen % yield by group. Reference percentage in fresh bone is ~20%. Gray area and italics indicate later samples or samples of uncertain date, analyzed as part of this project but not included in the dietary reconstruction of the subject period. Blue squares indicate outliers.

Table 15. Means of bone collagen yields by group (values in italics belong to groups outside the time range targeted by this study).

<table>
<thead>
<tr>
<th>Groups</th>
<th>n</th>
<th>m</th>
<th>s.d.</th>
</tr>
</thead>
<tbody>
<tr>
<td>San Benedetto</td>
<td>16</td>
<td>5.0</td>
<td>3.5</td>
</tr>
<tr>
<td>Cannas di Sotto</td>
<td>6</td>
<td>2.7</td>
<td>2.8</td>
</tr>
<tr>
<td>Serra Cannigas</td>
<td>5</td>
<td>1.6</td>
<td>2.2</td>
</tr>
<tr>
<td>Santa Caterina</td>
<td>9</td>
<td>2.0</td>
<td>1.8</td>
</tr>
<tr>
<td>di Pittinuri</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scaba ‘e Arriu A</td>
<td>14</td>
<td>4.8</td>
<td>1.6</td>
</tr>
<tr>
<td>Scaba ‘e Arriu M</td>
<td>13</td>
<td>5.7</td>
<td>2.2</td>
</tr>
<tr>
<td>Seddas de Daga</td>
<td>7</td>
<td>8.6</td>
<td>2.4</td>
</tr>
<tr>
<td>Su Stampu ‘e Giuanicu Meli</td>
<td>9</td>
<td>3.2</td>
<td>4.5</td>
</tr>
<tr>
<td>Sa Duchessa</td>
<td>3</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Mind’e Gureu</td>
<td>1</td>
<td>0.5</td>
<td>0.0</td>
</tr>
<tr>
<td>Padru Jossu M</td>
<td>1</td>
<td>1.8</td>
<td>0.0</td>
</tr>
<tr>
<td>Padru Jossu A</td>
<td>19</td>
<td>5.7</td>
<td>6.3</td>
</tr>
<tr>
<td>Padru Jossu B</td>
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<td>1.2</td>
</tr>
<tr>
<td>Iscalitas</td>
<td>29</td>
<td>1.6</td>
<td>0.8</td>
</tr>
<tr>
<td>Concali Corongiu</td>
<td>5</td>
<td>3.5</td>
<td>4.1</td>
</tr>
<tr>
<td>Acca t.10</td>
<td>1</td>
<td>2.5</td>
<td>0.0</td>
</tr>
<tr>
<td>Is Aruttas</td>
<td>11</td>
<td>14.5</td>
<td>1.4</td>
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<tr>
<td>Montessu t.33</td>
<td>3</td>
<td>14.0</td>
<td>5.4</td>
</tr>
<tr>
<td>Montessu t.32</td>
<td>2</td>
<td>4.4</td>
<td>6.2</td>
</tr>
<tr>
<td>Montessu t.15</td>
<td>1</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

* Groups in italics are later samples or samples of uncertain date.
high variability. Several groups also show a high standard deviation, again indicating different microenvironments within the same collective burial, which determined conditions conducive to differential preservation. At the site of Padru Jossu, this is evident both between phases and within the phase A. There is no clear relationship between collagen yield and age. Except for the youngest groups (Is Aruttas and the few medieval individuals from Montessu), there is no trend visible for groups dating between 4000 and 1900 BC as the box-and-whisker plot shows (Figure 65), which confirms, as expected, that age alone is not a good predictor of preservation.

The archaeological specimens of fauna from the two collections sampled showed different preservation. Among the species at Santa Caterina di Pittinuri, pig bones were in poor condition: three out of five samples did not have enough collagen left, one yielded abnormal C% and no signal for N, indicating the isotopic values were not reliable. So, only part of all the specimens (7 out of 11) yielded collagen for the mass spectrometry.

![Figure 66. Scatterplot of C% vs. N% in human samples: a close-up of the values between N% = 10 and 30 and C% = 20 and 50, showing the systematic instrumental error of the elemental analyzer that increased N% in several samples, causing C:N ratios to drop with no relationship with the isotopic values.](image)
measurement. At the site of Scaba ’e Arriu, all specimens except a *Prolagus* femur (17 out of 18) yielded enough collagen and good preservation parameters. The average yield for samples that were analyzed was 4.9 ± 3.0%.

Part of the human individuals (87 out of the 171 left with the exclusion of the one with resistant preservative) and the faunal samples were analyzed after the C:N ratio analyzer became available, which allowed a better consideration of the preservation indicators. On the other hand, several samples had a background signal that, by increasing the N reception, caused several ratios to decrease abnormally (Figure 66). Therefore, while their good preservation can be reliably assessed, this inconveniency prevents a representative statistical comparison between different parameters.

Apart from these general observations, some samples may be considered slightly suspect, on a case-by-case basis. Replicate 2 of sample #9520 had very high nitrogen due to instrumental incorrect reading; its C:N ratio, however, 1.87, is beyond the range that can be reliably attributed to instrumental error: it is therefore not considered for dietary reconstruction. Sample #8679, replicate 1, despite a normal C:N ratio, had N% = 36.35 and C% = 82.93, both out of the normal range, and so is not considered for dietary reconstruction. The mass spectrometer did not detect any peak for samples #9552, replicate 1, #6989, replicate 1, #7010, replicate 2, and #7014, replicate 2. No N peaks were detected for both #8667 replicates, no peaks at all for both #8669 replicates; these last two samples, both faunal, also had δ¹³C values definitely out of the animal range, and are clearly degraded (in fact, several samples from the same group had low yields and poor preservation). In one case (#8685, replicate 2), the C:N ratio was abnormal because N had no signal; the value was retained, since C% and isotopic values were very close to the replicate with all parameters within the acceptable range. In the case of #8687, the C:N ratio of replicate 2 was lower than the acceptable range with no evidence for instrumental error, and was therefore rejected for dietary reconstruction.

Even if distribution was not normal in most cases, as is likely with such a small sample sizes that come from taking each group separately, I tried to test some groups for correlation between the parameters of preservation (collagen yield and C:N ratio) and the isotopic values, with the expectation of finding weak or no relationship (Herrschera 2003:}
The test had to be performed group by group to avoid the detection of false relationships due to non-homogeneous groups. A generally weak relationship was found, with a few exceptions, which are likely due to random effects of the resulting small statistical populations. Table 16 shows the elements of the equations representing the best-fitting line (model) that describes the relationship between $\delta^{13}$C, $\delta^{15}$N on one side and collagen yield and C:N ratio on the other side, and between collagen % yield and C:N ratio.

Between $\delta^{13}$C and % yield, there is a weak but significant correlation at Scaba ‘e Arriu M, and a weak and barely significant correlation at Seddas de Daga (where one fourth of the variation is explained by the model). The relationship found between $\delta^{15}$N and % yield at Iscalitas is stronger ($r = 0.73$) and more significant. However, removing just one or two individuals (two replicates each) makes the relationship weak and non significant ($p$ above 0.05). In conclusion, as concerns both the human and faunal samples, the results that were retained can be considered reliable, and the values as mostly preserving the original isotopic signature that reflects the environment and dietary relations of the ecosystem where they were generated and incorporated in living tissues.

Table 16. Statistical correlations between preservation indicators

<table>
<thead>
<tr>
<th>Scaba ‘e Arriu A</th>
<th>Collagen yield</th>
<th>C:N ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td># Subs.</td>
<td>r</td>
</tr>
<tr>
<td>$\delta^{13}$C</td>
<td>28</td>
<td>0.04</td>
</tr>
<tr>
<td>$\delta^{15}$N</td>
<td>28</td>
<td>-0.06</td>
</tr>
<tr>
<td>C:N</td>
<td>28</td>
<td>-0.07</td>
</tr>
<tr>
<td>Scaba ‘e Arriu M</td>
<td>Collagen yield</td>
<td>C:N ratio</td>
</tr>
<tr>
<td></td>
<td># Subs.</td>
<td>r</td>
</tr>
<tr>
<td>$\delta^{13}$C</td>
<td>21</td>
<td>0.55</td>
</tr>
<tr>
<td>$\delta^{15}$N</td>
<td>21</td>
<td>0.25</td>
</tr>
<tr>
<td>C:N</td>
<td>21</td>
<td>-0.16</td>
</tr>
<tr>
<td>Iscalitas</td>
<td>Collagen yield</td>
<td>C:N ratio</td>
</tr>
<tr>
<td></td>
<td># Subs.</td>
<td>r</td>
</tr>
<tr>
<td>$\delta^{13}$C</td>
<td>18</td>
<td>0.18</td>
</tr>
<tr>
<td>$\delta^{15}$N</td>
<td>18</td>
<td>0.73</td>
</tr>
<tr>
<td>C:N</td>
<td>18</td>
<td>0.07</td>
</tr>
<tr>
<td>Seddas de Daga</td>
<td>Collagen yield</td>
<td>C:N ratio</td>
</tr>
<tr>
<td></td>
<td># Subs.</td>
<td>r</td>
</tr>
<tr>
<td>$\delta^{13}$C</td>
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<td>-0.54</td>
</tr>
<tr>
<td>$\delta^{15}$N</td>
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<td>0.25</td>
</tr>
<tr>
<td>C:N</td>
<td>14</td>
<td>-0.14</td>
</tr>
</tbody>
</table>

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7.1.2. Bone Apatite Preservation

As explained in the section on methods, apatite does not have clear cut-off points in preservation parameters for rejecting vs. retaining samples on the basis of risk of contamination. Here some of these parameters are examined. The most important is the yield of (assumed) biogenic carbonate. Since bone contains 65-70% mineral (the remainder being mainly collagen), what would be expected of well-preserved samples is a significant weight loss in the bleach, indicative of good preservation of the organic portion, and a small weight loss in the acetic acid bath, indicating a small quantity of non-biogenic carbonate carrying contamination to the isotopic signature. Higher weight loss is indication of severe alteration, with the associated likelihood that the signal is contaminated by heavy recrystallization, whether it be in the ground or in the buffered acetic acid solution.

The carbonate yield generally meets this expectation (Figure 67): in humans, values (Table 17) range from 43.4% (#8613, Iscalitas) to 82.2% (#6948, San Benedetto), and the averages per site range from 51.5 ± 5.1% (Concali Corongiu Acca II) to 73.1 ± 6.6 (San

![Figure 67. Box-and-whisker plot of bone carbonate yield as weighed after bath in acetic acid/acetate buffered solution for the different groups. Reference percentage in fresh bone is 65-70%. In italics are different contexts from Montessu and Is Aruttas, which are either uncertain or out of the chronological range of this study.](image)
Table 17. Means of bone apatite carbonate yield by group. (values in italics belong to groups outside the time range targeted by this study).

<table>
<thead>
<tr>
<th>groups</th>
<th>n</th>
<th>m</th>
<th>s.d.</th>
</tr>
</thead>
<tbody>
<tr>
<td>San Benedetto</td>
<td>16</td>
<td>73.1</td>
<td>6.6</td>
</tr>
<tr>
<td>Cannas di Sotto</td>
<td>6</td>
<td>61.8</td>
<td>4.9</td>
</tr>
<tr>
<td>Serra Cannigas</td>
<td>5</td>
<td>66.1</td>
<td>7.0</td>
</tr>
<tr>
<td>Santa Caterina di Pittinuri</td>
<td>10</td>
<td>68.8</td>
<td>7.9</td>
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<tr>
<td>Scaba ’e Arriu A</td>
<td>14</td>
<td>65.8</td>
<td>4.7</td>
</tr>
<tr>
<td>Scaba ’e Arriu M</td>
<td>13</td>
<td>61.6</td>
<td>6.5</td>
</tr>
<tr>
<td>Seddas de Daga</td>
<td>7</td>
<td>61.0</td>
<td>7.8</td>
</tr>
<tr>
<td>Su Stampu ’e Giuannicu Meli</td>
<td>9</td>
<td>63.5</td>
<td>6.3</td>
</tr>
<tr>
<td>Sa Duchessa</td>
<td>3</td>
<td>67.9</td>
<td>3.4</td>
</tr>
<tr>
<td>Mind’e Gureu</td>
<td>1</td>
<td>65.7</td>
<td>0</td>
</tr>
<tr>
<td>Padru Jossu M</td>
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<td>78.9</td>
<td>0</td>
</tr>
<tr>
<td>Padru Jossu A</td>
<td>18</td>
<td>62.3</td>
<td>7.0</td>
</tr>
<tr>
<td>Padru Jossu B</td>
<td>13</td>
<td>67.7</td>
<td>6.1</td>
</tr>
<tr>
<td>Iscalitas</td>
<td>29</td>
<td>64.9</td>
<td>6.7</td>
</tr>
<tr>
<td>Concali Corongiu Acca</td>
<td>5</td>
<td>51.5</td>
<td>5.1</td>
</tr>
<tr>
<td>Montessu t.10</td>
<td>1</td>
<td>58.8</td>
<td>0</td>
</tr>
<tr>
<td>Is Aruttas</td>
<td>11</td>
<td>67.1</td>
<td>4.2</td>
</tr>
<tr>
<td>Montessu t.33</td>
<td>3</td>
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<td>5.6</td>
</tr>
<tr>
<td>Montessu t.32</td>
<td>2</td>
<td>70.4</td>
<td>1.1</td>
</tr>
<tr>
<td>Montessu t.15</td>
<td>1</td>
<td>67.4</td>
<td>0</td>
</tr>
</tbody>
</table>

Benedetto), plus the single-individual group of Padru Jossu, Monte Claro phase (yield 78.9%). Part of the difference from the expected yield may be due to some loss inherent in the rinsing process. The only group that seems to have consistently lower yields than the expected average is Concali Corongiu Acca, which is also quite extreme in the isotopic values. I therefore suspect that the original signature of the carbonate might be altered. This is also suggested by its anomalously depleted $\delta^{13}C_{ap}$ values.

Overall, the results are to be considered fairly reliable. The faunal archaeological samples had average carbonate yields of 69.1 ± 4.3% (Scaba ’e Arriu A) and 62.9 ± 7.2% (Santa Caterina di Pittinuri), a pattern which follows the different preservation indicated by the collagen yields and by the calcareous concretions observed by the excavators in the latter burial (Buffa, et al. 1995).
An exploratory study has been done to ascertain the presence of relationships between preservation parameters in the human samples database, and between such parameters and the isotopic results. Such relationships may be indicative, although they need to be taken cautiously for the presence of possible non-homogeneous subgroups. The danger is that of casting doubts on results that are reliable but may show spurious relationships.

In all cases studied there is a linear relationship that is significant ($p$ values ranging from 0.00 to 0.05) but relatively weak, with $r \leq 0.34$ and percent explained by the model $r^2 \leq 11.50\%$ (Figure 68). Collagen yield and weight loss during the bleach bath are expected to be somewhat related, since both are a measure of the organic content of bone, and they do, significantly but in small proportion ($r^2$ is 9.13%, $p=0.00$). Uneven recovery from the vials obscuring such effect and some approximation in weighing may be responsible for the weak relationship, besides the expectedly irregular presence of humic acids and soil contaminants.

Figure 68. Scatterplots and best-fit lines of several parameters pertaining to bone apatite preservation: a) collagen yield vs. carbonate % weight lost in the bleach bath; b) carbonate % weight lost in the bleach bath vs. apatite $\delta^{13}C$; c) carbonate % weight lost in the acetic acid/acetate buffered solution bath vs. apatite $\delta^{13}C$; d) carbonate % weight after the bleach bath vs. apatite $\delta^{13}C$. 
Similarly, a weak but statistically significant relationship was found between sample weight % after bleach bath (or sample weight % lost in the bleach bath, which is complementary, and inversely the weight % lost in the acetic acid solution) and $\delta^{13}\text{C}$, which remains even if up to three selected groups are removed. This would seem to point to $\delta^{13}\text{C}$ values becoming slightly more enriched when the organic portion is less preserved. If so, isotopic values would be enriched by contamination in conditions of worse preservation, possibly due to limestone carbonate (important part of the rocky matrix at many sites) leaching and recrystallizing in the bone. However, even if specific soil tests are unavailable and for most sites impossible, this seems unlikely. The groups with burial environments rich in carbonate concretions, which if contaminated would have more enriched values like the limestone matrix (Santa Caterina di Pittinuri, Concali Corongiu Acca II, Su Stampu ’e Giannicu Meli), instead appear to spread across the range of $\delta^{13}\text{C}$ values. Similarly, those samples from individuals buried in pits, which if contaminated by soil with higher organic matter would show more depleted values, do not assume meaningful patterns.

In these cases, where no significant relationship is expected but as mentioned there is a weak but significant one, the $p$ value rises significantly if one or two of the groups is removed, often one of the larger ones. This seems to indicate the random effect of dishomogeneous groups rather than any real or important causal relationship. Therefore, considering such intrinsic danger of non-homogeneous groups, the range of variation within the expected values, and the absence of clear relationship with the burial environment, it appears likely that the relationship is spurious. The observed variation is largely to be attributed to the original biogenic signal.

Similar comment can be made for the statistically significant and moderate relationship between collagen yield and $\delta^{18}\text{O}$ ($r = 0.55$, $r^2 = 30.29\%$, $p = 0.00$). In this case, removing the groups of Is Aruttas and Iscalitas leaves $p < 0.01$, but the coefficients of correlation and determination drop ($r = 0.23$, $r^2 = 5.37\%$). Non-homogeneity of groups creates false relationships. Weak and scarcely significant were also the relationships between both the % weight lost in the acetic acid and the % weight lost in bleach solution as predictors and $\delta^{18}\text{O}$ as outcome (which are not presented here for brevity). This again indicates the isotopic values were not systematically related to preservation, and supports the reliability of the dataset as a whole.
Another indication that the bone apatite values preserve most of the original biogenic signal is provided by their comparison with the enamel apatite, which is considered very resistant to diagenesis and therefore reliable (Table 18). While the average interval is mostly within 1.1‰ for both $\delta^{13}$C and $\delta^{18}$O, supporting the reliability of bone apatite, there are a few cases of larger differences. In the case of Is Aruttas, cranium 2 (= #6879$_{\text{col}}$ = 6890$_{\text{apat}}$ = 7128$_{\text{enam}}$), such a discrepancy might lend support to the hypothesis of diagenetic alteration, and this could be investigated in the future with further testing; the single tooth is a first premolar, which should be $\delta^{18}$O-enriched, rather than depleted as compared to bone, due to its formation during pregnancy and breastfeeding. In the case of Padru Jossu, cranium 67 (= #6906$_{\text{col}}$ = 6929$_{\text{apat}}$ = 7130$_{\text{enam}}$), this is the only individual available from the earliest phase, and shows a distinct isotopic signature in comparison with all the later individuals. In this case, the $\delta^{13}$C enrichment in bone corresponds to a diet richer in isotopically heavier lipids, away from the depleted lipids of breast milk reflected in the sampled tooth, which is a first molar and corresponds more closely to breastfeeding age (Wright and Schwarcz 1998: 10-12). These comparisons must be considered loosely though, since there is remarkable variation in isotopes that is not fully understood. Such variation seems to be related to the different phases of growth and development, a factor that is intertwined with the dietary change during childhood and adolescence, so making interpretation particularly difficult.

Even if this does not guarantee that the situation is the same for all samples: it has been shown that depending on preservation, treatment can enhance or worsen the resistance

<table>
<thead>
<tr>
<th>Table 18. Means of bone apatite and tooth enamel isotopic values, and their difference.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<tr>
<td></td>
</tr>
<tr>
<td>San Benedetto</td>
</tr>
<tr>
<td>Scaba’e Arriu A</td>
</tr>
<tr>
<td>Scaba’e Arriu M</td>
</tr>
<tr>
<td>Padru Jossu M</td>
</tr>
<tr>
<td>Padru Jossu A</td>
</tr>
<tr>
<td>Padru Jossu B</td>
</tr>
<tr>
<td>Is Aruttas</td>
</tr>
</tbody>
</table>

243
of the original chemical signature (Nielsen-Marsh and Hedges 2000b showed that depending on preservation, treatment can enhance or worsen the resistance of the original chemical signature). However, at least an indirect proof that the procedure used was fairly successful in preserving the original isotopic signal is provided by the faunal bone apatite values for Scaba ’e Arriu A and particularly Santa Caterina di Pittinuri. The isotopic differences by species at these sites reflect the differential fractionation according to each species’ physiology: obligate drinkers and especially pigs are associated with enriched $\delta^{13}C$ and depleted $\delta^{18}O$, moderately drought-tolerant species such as sheep/goat with more depleted $\delta^{13}C$ and enriched $\delta^{18}O$, and rodents, the most drought-tolerant mammals in the ecosystem, showing depleted $\delta^{13}C$ and very enriched $\delta^{18}O$ (Figure 69).

Since there is no foolproof way of detecting contamination, however, the possibility that other groups of samples where such an indirect indication is missing are to some extent altered, cannot be ruled out. A distinction must also be made between $\delta^{13}C$ and $\delta^{18}O$. The former is much more resistant, and its signal will be intact even when the latter is already fully altered. The diagenetic model for the two has a well-established L-shaped pattern. When rainwater is the source of contamination, values tend to become depleted; therefore, if this was the source of contamination, as we could expect in soils and bedrocks that are non-calcareous, values that cluster too tightly on the lower end of both ratios could be taken with

![Figure 69. Scatterplots of $\delta^{13}C$ and $\delta^{18}O$ of faunal specimens from the two sites of Santa Caterina di Pittinuri and Scaba ’e Arriu (phase A). Values reflect the different positions of different species according to their different physiology, which implies the original biogenic signal is preserved.](image)
caution (Sharp 2007: 135-138). The groups of Concali Corongiu Acca II, Santa Caterina di Pittinuri and the single individual of Montessu, tomb 15, might follow this pattern. However, when the water in the ground contains also a high concentration of dissolved carbonate from the sedimentary bedrock, $\delta^{13}C$ tends to decrease (sedimentary limestones have $\delta^{13}C$ values broadly nearing 0‰), so the L-shaped diagenetic pattern will first deplete $\delta^{18}O$ and then enrich $\delta^{13}C$. The only group that could correspond to this pattern is Iscalitas. Is Aruttas bone apatite yielded very enriched $\delta^{18}O$ (-1.3‰ ± 0.8) that does not match with the only value from tooth enamel (-3.3‰). The possibility of it reflecting a change of residence between adolescence and adulthood is slim, since the tooth used is a third molar, and it would anyway be unlikely that the only sampled individual is among the presumably few who did change their residence.

7.1.3. Tooth Enamel Apatite Preservation

The procedure utilized to extract carbonate from tooth enamel is the same as that for bone. The only difference is, as explained in the section on principles and methods, that in the large majority of cases teeth preserve the original signal more faithfully. The proportion of mineral in fresh tooth enamel is over 96%, and its high crystallinity makes this material extremely resistant (among the studies comparing bone and enamel, see Wang and Cerling 1994; Wright and Schwarcz 1998); most of the specimens in this study had a carbonate yield between 70-90% weight of the powdered whole bone (Figure 70); most of the difference may be due to loss in the rinsing process. The good preservation is also indicated by the fact that the average isotopic values of the microsamples analyzed without preparation, removed after just a careful cleaning of the enamel surface, were close to the values of the bulk sample from the whole surface of the tooth.
Figure 70. Box-and-whisker plot of tooth enamel carbonate yield as weighed after bath in buffered acetic acid/acetate solution for the different groups. Reference percentage in fresh bone is >96%. In italics Is Aruttas, which is out of the chronological range of this study.

7.2. Stable Isotopic Values

7.2.1. Collagen Values

All isotopic values by group are in the Appendices, tables 29 through 44. Human collagen $\delta^{13}$C values from all sites (Figure 71) are between −21.3 and −18.2‰, with an average of $-19.2 \pm 0.4‰$, and $\delta^{15}$N values between 6.0 and 13.1‰, with an average of 10.3 ± 1.2‰. These values indicate that human groups were part of a fully C$_3$ food chain, with negligible amounts of marine resources and/or C$_4$ plants in the diet, with relatively little differentiation in this regard, as the small interval defined by the $\delta^{13}$C standard deviation shows. From $\delta^{15}$N, it is also possible to assess that animal products were generally an important part of the protein portion of the diet: values over 8-9‰ in Europe commonly indicate that most protein was derived from animals.

The linear relationship between $\delta^{13}$C and $\delta^{15}$N ($\delta^{15}$N = 36.25 + 1.35 * $\delta^{13}$C; $r^2 = 23.49\%$, $p = 0.00$) is expected, as both derive mostly from the same dietary protein (Figure 72) and are affected by the same environmental variation in the ecosystem. The slope, quite
Figure 71. Scatterplot of all collagen $\delta^{13}$C and $\delta^{15}$N values of all groups. One outlier from Seddas de Daga has been left out to allow better visibility of the main cloud of datapoints. Points are color-coded as follows: orange, Late Neolithic; red, Post-Ozieri Copper Age; blue, later (Monte Claro) Copper Age; green, Bell Beaker; black, Early Bronze Age; empty symbols, later sites.

Figure 72. Biplot of all collagen $\delta^{13}$C and $\delta^{15}$N values with the best-fit line.
steep with much more variation in $\delta^{15}N$ than in $\delta^{13}C$, and the shape more oval than linear of the data-points’ cloud, is a further indication that most of the dietary variation comes from differences in foods from different trophic levels, rather than from different ecosystems. If contribution of fish was substantial in the amount of variation observed, we would more likely find a less vertical and thinner spread of values toward enriched $\delta^{15}N$ and $\delta^{13}C$ (Honch, et al. 2006: 1498). If there was any archaeological indication of any consumption of freshwater fish, we could contemplate the possibility that high $\delta^{15}N$ could be due to it, but the overwhelming evidence for domesticates for the sites where the animal bones were analyzed, and the overall cross-cultural evidence, increases the confidence of the interpretation.

As concerns inter-site variation, which is one of the main concerns of this study, reading the data without any correction would indicate that most groups had largely overlapping diets along a continuum, except the Copper Age group of Seddas de Daga. The individuals buried at this site would appear to have relied on a much more plant-based diet, as suggested by its $\delta^{15}N$ over 2‰ lower than the averages at most other groups (only exception is the middle-bronze-age single individual from Montessu, t.10). However, as will be clear in the discussion, this does not account for synchronic climatic effects, and in dietary terms such differences in raw values may be highly misleading.

7.2.2. Apatite $\delta^{13}C$ and Spacing Collagen-Apatite $\delta^{13}C$

These parameters can be described together, since they are directly connected and have a strong linear relationship ($\delta^{13}C_{col-apa} = - 18.05 - 0.94 \times \delta^{13}C_{apa}$; $r^2 = 93.52\%$, $p = 0.00$). As has already been discussed (Hedges 2003), most of the variation in the spacing comes from $\delta^{13}C_{apa}$ rather than from $\delta^{13}C_{col}$ (Figure 73). The $\delta^{13}C_{apa}$ values range from -15.8‰ to -4.3‰, with an average of -12.2 ± 1.9‰, and $\delta^{13}C_{col-apa}$ values from -14.2‰ to -3.0‰, with an average of 7.2 ± 1.8‰ (Figure 74). Most values appear to spread across the range known for mammals, representing the span of human nutritional variation between mostly carnivorous to mostly herbivorous diets, through the majority of individuals that were omnivorous.
Figure 73. Biplots and best-fit lines of apatite δ¹³C vs. spacing δ¹³C_{col-apa} and collagen δ¹³C vs. δ¹³C_{col-apa}. The distributions and the best-fit lines show that most of the variation in δ¹³C_{col-apa} derives from δ¹³C_{apa} rather than δ¹³C_{col}.

Figure 74. Scatterplot of all collagen δ¹⁵N and apatite δ¹³C values of all groups. Three outliers, from Is Aruttas, Su Stampu ‘e Giannicu Meli and Scabà ‘e Arriu (phase A) have been left out to allow better visibility of the main cloud of datapoints. Points are color-coded as follows: orange, Late Neolithic; red, Post-Ozieri Copper Age; blue, later (Monte Claro) Copper Age; green, Bell Beaker; black, Early Bronze Age; empty symbols, later sites.
The $\delta^{13}C_{\text{col-apa}}$ spacing values (Figure 75) are generally comparable to those of Mediterranean prehistoric sites of different time periods: in Anatolia at Nevalı Çori (average spacing = 8.26‰, Lösch, et al. 2006), in Greece at Tharrounia, Theopetra and Kouveleiki (average spacing = 8.16‰, 7.53‰, 7.46‰ respectively, Papathanasiou 2003), in Russia in the Middle Neolithic and Early Bronze Age in the Angara region (average spacing = 7.3‰, 7.7‰ respectively, Katzenberg and Weber 1999) on the herbivorous end; again in Greece, at Franchthi and Kephala (average spacing = 5.73‰, 6.43 respectively, Papathanasiou 2003) and in Russia at several locations (Katzenberg and Weber 1999) on the more carnivorous end. A few groups, however, do show averages over 8‰, which would indicate a diet based almost exclusively on vegetal foods and/or porcine meat. More aspects of the dietary variation that bone isotopic values suggest are discussed in chapter 8, based on the dataset already corrected to allow inter-site comparability.

Figure 75. Scatterplot of all collagen $\delta^{15}N$ and $\delta^{13}C_{\text{col-apa}}$ values of all groups, clearly symmetrical and virtually equivalent to the chart where apatite $\delta^{13}C$ is plotted instead of $\delta^{13}C_{\text{col-apa}}$. Three outliers, from Is Aruttas, Su Stampu ‘e Giuannicu Meli and Scaba ‘e Arriu (phase A) have been left out to allow better visibility of the main cloud of datapoints. Points are color-coded as follows: orange, Late Neolithic; red, Post-Ozieri Copper Age; blue, later (Monte Claro) Copper Age; green, Bell Beaker; black, Early Bronze Age; empty symbols, later sites.
7.2.3. Apatite $\delta^{18}O$

The $\delta^{18}O_{\text{apa}}$ values (Figure 76) range from $-5.8\%e$ to $+0.2\%e$, with an average of $-3.7 \pm 1.0\%e$. When compared with the few previous studies reporting on $\delta^{18}O$ in the western Mediterranean, they are overall within the expected range. At locations in northern Italy, such as the Arene Candide cave and Spilamberto (D’Angela and Longinelli 1990, 1993), values measured on phosphate, when converted into carbonate (Iacumin, et al. 1996) overlap with the highest measured in this study (the highest single-site average being $-4.6 \pm 0.4\%e$ at Iscalitas) and higher, up to $-6.7\%e$. This is a few points per mil more depleted than Sardinia, as expected from areas with heavier rainfall, and approximately mirrors the clines measured in present-day rainwater $\delta^{18}O$ in Italy (Longinelli and Selmo 2003).

The average values by group for the subject period span from $-2.6 \pm 0.6\%e$ at Padru Jossu B, to $-4.6 \pm 0.4\%e$ at Iscalitas, although more groups cluster in the more depleted end. This might reflect a consistent average of climatic conditions with few anomalies, which however remain mostly within $-2\%e$. This indicates that climatic variation across sites and

![Figure 76. Scatterplot of all bone apatite $\delta^{18}O$ and $\delta^{13}C$ values of all groups. Three outliers, two from Is Aruttas, one from Su Stampu ’e Giuannicu Meli, have been left out to allow better visibility of the main cloud of datapoints. Points are color-coded as follows: orange, Late Neolithic; red, Post-Ozieri Copper Age; blue, later (Monte Claro) Copper Age; green, Bell Beaker; black, Early Bronze Age; empty symbols, later sites.](image)
periods has been possibly sensible, and precipitation may have varied within a 400 mm range, following the ~1‰/200 mm rainfall approximation in Bar-Matthews et al. (2003).

This variation can be effective in bringing about remarkable environmental change, and while δ¹⁸O does not need a correction in order to disentangle the variation due to diet, a correction is possible to account for geography and extract the broad climatic change over time by means of controlling the ‘space’ variable. Such correction is explained in detail in chapter 8. As a general description of the observed variation, three groups can be distinguished: one averaging -4‰ or less, which includes sites from the 4th through the early 3rd millennium cal BC, and the latest ones, Iscalitas and Concali Corongiu Acca II; such values possibly indicate rainfall over ~750 mm/year. The second group, with intermediate values between -4‰ and -3‰, indicating possibly rainfall between ~500 and ~750 mm/year, is associated with radiocarbon dates between the 29th and the 24th century cal BC. The third group is made up of Padru Jossu B alone, which has an average δ¹⁸O of 2.6 ± 0.6‰ and corresponds to an average annual rainfall of ~350 mm/year. The probable effects of these events and what they meant within the cultural and economic context are discussed below, based on corrected values.

7.2.4. Tooth Enamel δ¹³C and δ¹⁸O

7.2.4.1. Bulk Results

As reported above when discussing the preservation of the bone apatite isotopic signal, the measurements of tooth enamel carbonate yielded comparable results, with a few exceptions and some distinctions. The average interval is further reduced considering only the same individuals from which both bone and tooth have been sampled. The range for δ¹³C is from -13.9 to -8.6‰, the average -12.3 ± 1.1‰. The variation of averages per site goes from -13.5 to -11.6‰. For δ¹⁸O, the range is from -4.8 to -3.1‰, with an average of -3.9 ± 0.5‰ and variation between site averages from -4.8 to -3.3‰ (Tables 19 and 20).

A difference between tooth and bone is to be expected due to changing isotopic fractionation patterns in relation to growth. Breastfeeding has been shown to affect the isotopic signature of teeth according to the age of formation. Even if contrasting patterns have been documented (White, et al. 2004; Wright and Schwarcz 1998), δ¹⁸O values are
Table 19. Difference in isotopic values in bone apatite and enamel within same individuals.

<table>
<thead>
<tr>
<th></th>
<th>n</th>
<th>$\delta^{13}\text{C}_{\text{bone apatite}}$</th>
<th>$\delta^{18}\text{O}_{\text{bone apatite}}$</th>
<th>$\delta^{13}\text{C}_{\text{enamel}}$</th>
<th>$\delta^{18}\text{O}_{\text{enamel}}$</th>
<th>s.d. $\delta^{13}\text{C}_{\text{bone apatite}-\text{enamel}}$</th>
<th>s.d. $\delta^{18}\text{O}_{\text{bone apatite}-\text{enamel}}$</th>
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</thead>
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<td>-1.3</td>
<td>-11.6</td>
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<td>1.3</td>
<td>-0.1</td>
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<td>8</td>
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<td>-12.3</td>
<td>-4.4</td>
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<td>-0.2</td>
</tr>
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<td>Scab'e Arriu M</td>
<td>3</td>
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<td>-2.6</td>
<td>-11.7</td>
<td>-3.7</td>
<td>0.5</td>
<td>1.8</td>
</tr>
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<td>-13.5</td>
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</tr>
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<td>-4.3</td>
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<td>0.6</td>
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<td>-4.4</td>
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<td>0.0</td>
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</table>

generally heavier in deciduous teeth and become lighter in third molars, due to weaning with the end of input of enriched breast milk. Such depletion has also been observed between second and third molars to bone (White, et al. 2004: 243). Unfortunately, in the contexts of the few studies on the subject, the basic food resources at play in determining the change in isotopic values at weaning and adolescence are different from those of the western Mediterranean in prehistory, due to the absence of ruminant milk (in pre-contact Americas) or the presence of C₄ crops (Africa). General trends seem similar, and $\delta^{13}\text{C}$ enrichment observed in Mesoamerica has been suggested to be not as notable as in the case of progressive introduction of C₄ plant foods, but anyway visible, due to the introduction of lipids less isotopically depleted than breast milk (Wright and Schwarcz 1998: 10-12). Due to the small sample size by group, no statistical analyses were considered appropriate, and results (Figure 77) are described and commented on here.

Three out of the four individuals sampled from the Late Neolithic remains of San Benedetto (#7125, 7126, 9815) show lighter (more negative) $\delta^{13}\text{C}$ values in bone than in teeth, which is expected, while only one (#7127) shows the opposite. Likely, such a difference still reflects breastfeeding in teeth, with scarce supplementation of $\delta^{13}\text{C}$-enriched solid foods (they are two first molars and two premolars, that grow up to age 6), or supplementation of foods with depleted lipids, such as possibly ruminant milk (Copley, et al. 2003; Evershed, et al. 1999). This would make sense if these individuals had their most important source of lipids in sheep, goat or cow milk, with substantial introduction of plants and pork meat, and consequent reduction in depleted fats, during adulthood. Interestingly,
Table 20. Tooth enamel isotopic values (with bone values for comparison)

<table>
<thead>
<tr>
<th>USF#</th>
<th>tooth type</th>
<th>Site</th>
<th># ind.</th>
<th>Subgroups</th>
<th>collagen</th>
<th>apatite</th>
<th>enamel</th>
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<td></td>
<td></td>
<td></td>
<td>Sex</td>
<td>Age</td>
<td>δ¹³C</td>
<td>δ¹⁵N</td>
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<td>-3.3</td>
<td></td>
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<td>Ind Adu</td>
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<td>-3.8</td>
<td></td>
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<td>m1</td>
<td>Scab'e Arriu A</td>
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<td>Ind Adu</td>
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<td>-3.3</td>
<td></td>
</tr>
<tr>
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<td>m2</td>
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<td>4938</td>
<td>Ind Inf</td>
<td>-19.3</td>
<td>9.9</td>
<td>-11.5</td>
</tr>
<tr>
<td>7118</td>
<td>p2</td>
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<td>Ind Inf</td>
<td>-19.3</td>
<td>11.2</td>
<td>-11.2</td>
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<tr>
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<td>m1</td>
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<td>10.1</td>
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<td>-3.3</td>
<td></td>
</tr>
<tr>
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<td>m(1?)</td>
<td>Scab'e Arriu A</td>
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<tr>
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<tr>
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<td>-9.7</td>
</tr>
</tbody>
</table>

δ¹⁸O values for the three females are very similar, while in the only male (#9815) they are lighter in bone, as expected.

From Scaba`e Arriu A (Early Copper Age), three infants and one adult were sampled. As expected, the difference between enamel and bone is relatively small (only in one case is it over 1 ‰); δ¹³C values tend to be slightly heavier in bone, as generally expected. Specifically, the smallest interval is found in the infant whose sampled tooth is a
first molar (#7119). The two tissues were evidently synthesized during overlapping time spans. The two infants whose sampled teeth are a second molar and a premolar (#7117 and 7118) may have had supplementary solid foods by age 2, since the bone already has a slightly different signature, compatible with a new source of lipids other than breast milk. This was probably vegetal, otherwise there may have been a reduction of total lipids for the introduction of carbohydrates, such as processed cereal, which are also δ^{13}C -enriched compared to breast milk. Sample #7121, an adult, does not show any difference in δ^{13}C, and has bone δ^{18}O as expected lighter than its tooth (an undetermined molar). If this tooth was a second or third molar, this individual could have had solid foods from ages 6-12, similar to adulthood, whereas the δ^{18}O could indicate that breast milk or possibly ruminant milk was still part of the liquid component of the diet. Less likely, a climatic shift or a temporary change of residence could also account for the observed difference.

From Scaba’ é Arriu, Monte Claro phase (Late Copper Age), three individuals were sampled, and in this case we see a rather small difference bone-tooth as concerns δ^{18}O,
whereas all $\delta^{13}$C values in teeth are tight within 1‰, but their diets must have then diverged toward adulthood, because bone values span from -10.9 to -13.5‰. Again, different quantities of animal and vegetal foods can be the cause.

Just the opposite appears to be the case for the three individuals from Padru Jossu, phase A (Bell Beaker): the enamel $\delta^{13}$C values are more diverse than the bone, which is all within 0.5‰. In this case it is possible that the mothers’ diets were different, whereas as adults (and one juvenile) they had a very similar diet. This may be indirectly confirmed by the fact that, based on bone results, women from this group had particularly diverse diets as adults. Here again the expected $\delta^{18}$O trend of depletion over time from teeth to bone is reversed. One explanation could be mobility from a birthplace with isotopically lighter drinking water to a warmer, drier area. Another cause might be, as for $\delta^{13}$C values, a significant consumption of ruminant milk. Although there is to my knowledge no research on its effect on human isotopic values, sheep and goats, as moderately drought-tolerant, have enriched $^{18}/^{16}$O ratios as compared to humans and obligate drinkers in general (Bryant and Froelich 1995; Kohn 1996; Kohn and Cerling 2002: 464-470; see also the few measurements on sheep from Santa Caterina di Pittinuri and Scaba ’e Arriu A). A significant contribution of sheep/goat milk to the total ingested liquids after weaning could significantly raise the $\delta^{18}$O isotopic ratio in bone (sheep-goat isotopic ratios of samples in this study are ~1-3‰ less negative than humans). Alternatively, a climatic shift toward more arid conditions within the lifetime of the individuals, which is not implausible, could also have resulted in such a difference between teeth and bone.

The largest group sampled is from Padru Jossu, phase B. Whereas $\delta^{18}$O follows the same reversed pattern as Padru Jossu A, with more enriched values in bone than in tooth, $\delta^{13}$C as generally expected is enriched in bone compared to teeth in six cases vs. three. Here, since five teeth out of nine are post-weaning, the rest being one a first incisor (#7129), one a second premolar (#7132), and two undetermined molars (#7136, 7138), what is best recorded is the signature of solid and liquid diet in the years around age 10 and in adulthood. There is no apparent meaningful difference in the pattern for pre/peri-weaning teeth on one hand, and second and third molars on the other, as compared to bone. Without the control of the microsampling where the same $\delta^{18}$O trend is visible, we could be suspicious of undetected diagenesis for this anomalous phenomenon; but the four third molars do show similar lighter values in later phases, supporting the reliability of the measurements. There is a wide
variation in enamel $\delta^{13}$C values (over 4‰), much less in $\delta^{18}$O (~1‰), which points to some degree of dietary diversity in the proportion of different foods in the diet of children up to age ~11. However, all four third molars (#7131, 7134, 9816, 9817) have very similar $\delta^{18}$O values, suggesting that the source of dietary water was similar for these individuals around age 8-12. If there was any shift to high consumption of sheep milk as possibly indicated by enriched $\delta^{18}$O and discussed above, this started at a later age. However, one problem with the milk scenario is that $\delta^{13}$C from the same food (due to fat) would be more depleted: a possible answer could be a combination of a consumption of milk high enough to impact the $\delta^{18}$O, but coupled with a high quantity of dry plant foods such as cultivated grains, rich enough in carbohydrates to impact strongly the bone $\delta^{13}$C, making it heavier.

As mentioned in the section on general principles of stable isotopes, a physiological effect on hair $\delta^{15}$N has been observed in a study of living populations in Gambia, where the fall of breastfeeding-related enrichment continues during pre-adolescence/adolescence, to values that are lower than those at which it stabilizes in adulthood (O’Connell and Prentice forthcoming; see also Privat, et al. 2002: 785; White and Schwarcz 1994: 177). Therefore, since this is not variation related to diet, even if not demonstrated yet, it could be the case as well for $\delta^{13}$C and $\delta^{18}$O. This would account for the enrichment detected from third molars to bone.

Another possible explanation for the enriched $\delta^{18}$O in bone could be seasonal mobility from the locality where the individuals grew up to areas of lower elevation and/or rainfall. Such mobility, if started after age ~11-12 and involving several months in such areas where water had markedly higher $\delta^{18}$O, would result in a weighed average of the two locations, and a consequent rise in bone $\delta^{18}$O. The fact that the few pre/peri-weaning teeth are slightly higher in $\delta^{18}$O, coupled with these observations, might also suggest that the anomaly of not seeing depletion from breastfeeding age to post-weaning might just be due to random sampling. By having single teeth per individual, the shift that multiple teeth could document is missing. In fact, for this dissertation, teeth were sampled for a control of bone values rather than to infer dietary patterns between youth to adulthood, which can be the subject for a specific study with a larger population.

A single tooth each was sampled from Padru Jossu, Monte Claro phase, and Is Aruttas. The former shows a remarkable enrichment in both $\delta^{18}$O and $\delta^{13}$C from breastfeeding age to adulthood. For this, the same possible explanations as for Padru Jossu B
hold. The Is Aruttas sample has the same $\delta^{13}$C values in the premolar and bone, but very different $\delta^{18}$O, over 2‰, for which the reader can again refer to the same reflections above. These are not considered for dietary reconstruction because they turned out to be of later date than the subject period.

7.2.4.2. Tooth Microsampling Pilot Project Results

Crown formation in human third molars starts, according to recent studies, at about 8 years of age and lasts approximately 3 years (Reid and Dean 2006). Growth is faster in the first half of the total time, and slows down slightly in the second, so that more than half the length of the tooth from the apex is formed within one to one and a half years. The four individual teeth selected for pilot microsampling, whose results are presented in Table 21,

<table>
<thead>
<tr>
<th>Subsample #</th>
<th>$\delta^{13}$C‰</th>
<th>$\delta^{18}$O‰</th>
<th>Collection #, age, sex, pathologies</th>
</tr>
</thead>
<tbody>
<tr>
<td>7131f</td>
<td>-12.4</td>
<td>-3.8</td>
<td>Cranium 3, 25-35yy or older, male, heavy toothwear</td>
</tr>
<tr>
<td>7131e</td>
<td>-12.4</td>
<td>-3.9</td>
<td></td>
</tr>
<tr>
<td>7131d</td>
<td>-10.6</td>
<td>-4.8</td>
<td></td>
</tr>
<tr>
<td>7131c</td>
<td>-14.3</td>
<td>-4.7</td>
<td></td>
</tr>
<tr>
<td>7131b</td>
<td>-10.5</td>
<td>-3.5</td>
<td></td>
</tr>
<tr>
<td>7131a</td>
<td>-10.0</td>
<td>-2.8</td>
<td></td>
</tr>
<tr>
<td>7134g</td>
<td>-11.6</td>
<td>-4.0</td>
<td>Cranium 6, adult male, slight cribra orbitalia and cranii</td>
</tr>
<tr>
<td>7134f</td>
<td>-12.0</td>
<td>-4.1</td>
<td></td>
</tr>
<tr>
<td>7134e</td>
<td>-11.1</td>
<td>-4.1</td>
<td></td>
</tr>
<tr>
<td>7134d</td>
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<td></td>
</tr>
<tr>
<td>7134c</td>
<td>-10.7</td>
<td>-4.2</td>
<td></td>
</tr>
<tr>
<td>7134b</td>
<td>-9.4</td>
<td>-3.7</td>
<td></td>
</tr>
<tr>
<td>7134a</td>
<td>-9.6</td>
<td>-3.5</td>
<td></td>
</tr>
<tr>
<td>9816f</td>
<td>-13.1</td>
<td>-3.8</td>
<td>Cranium 19, 20-25yy female</td>
</tr>
<tr>
<td>9816e</td>
<td>-13.3</td>
<td>-4.0</td>
<td></td>
</tr>
<tr>
<td>9816d</td>
<td>-12.9</td>
<td>-3.8</td>
<td></td>
</tr>
<tr>
<td>9816c</td>
<td>-12.8</td>
<td>-3.9</td>
<td></td>
</tr>
<tr>
<td>9816b</td>
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<td></td>
</tr>
<tr>
<td>9816a</td>
<td>-12.3</td>
<td>-3.9</td>
<td></td>
</tr>
<tr>
<td>9817f</td>
<td>-11.2</td>
<td>-4.5</td>
<td>Cranium 35, young (&lt;20yy) possibly male</td>
</tr>
<tr>
<td>9817e</td>
<td>-12.0</td>
<td>-4.4</td>
<td></td>
</tr>
<tr>
<td>9817d</td>
<td>-12.0</td>
<td>-4.4</td>
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<td>-11.2</td>
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</tr>
<tr>
<td>9817b</td>
<td>-9.9</td>
<td>-4.2</td>
<td></td>
</tr>
<tr>
<td>9817a</td>
<td>-9.6</td>
<td>-3.6</td>
<td></td>
</tr>
</tbody>
</table>
were chosen from the same site, to try to address as well as possible with such a small number of individuals a problem of interest related to the broader goals of this study: the archaeological evidence, human groups may have been more mobile and less sedentary.

The largest range is found in #7131, where $\delta^{13}$C values span 4.3‰ and $\delta^{18}$O values 2.0‰, whereas the other three samples have much smaller ranges ($\delta^{13}$C = 2.4, 1.0 and 2.4‰; $\delta^{18}$O = 0.7, 0.3, 0.9 for #7134, 9816 and 9817 respectively). Seven sequences out of eight (exception is $\delta^{18}$O in #9816) start more depleted than they end (Figure 78), giving an indication of the general trend of diet and/or physiology in this group of prehistoric pre-teens.

Figure 78. Charts with all tooth enamel $\delta^{13}$C and $\delta^{18}$O values of the microsamples of the four third molars from Padru Jossu, phase B.
Although the small numbers must be taken cautiously, the males appear to show trends different from the female. The former, three individuals, with remarkable isotopic shifts during the ~3-4 years of formation, all end up enriched in both $\delta^{13}C$ and $\delta^{18}O$ as compared to the start, and all are visibly depleted in $\delta^{13}C$ later in life, as detectable from the corresponding bone apatite values. The only female instead shows much less general variation and nothing similar to the clear unmistakable trend of isotopic enrichment of the males.

A sharp difference in each subsample’s value is obliterated by the mixing of the portion removed, which averages possible differences within, in a way repeating at a finer scale the mechanism of bulk sampling of one tooth. Nevertheless, assuming the formation lasted about 3 years, we may be seeing a pale reflection of seasonal variation in the charted values of the sequences #7134-$\delta^{13}C$, #9816-$\delta^{13}C$ and #9816-$\delta^{18}O$, with the highs corresponding to summers and the lows to winters. The dietary change between the age ~8 to ~12 was significant for boys, and can be interpreted in several ways. One is a decrease in sheep milk (or less likely cow milk) consumption, which has very $\delta^{13}C$-depleted lipids; however $\delta^{18}O$, which in this case would probably get depleted, gets enriched, which might indicate the opposite. This could be coupled with an increase in plant foods (high percent of enriched carbohydrates). Alternatively, but less likely, such a pattern could be explained by a decrease in milk consumption and increase in pork meat (relatively enriched lipids), with similar contribution of plant foods. A combination of both is also possible. It seems probable in any case that milk was an important component in the juvenile’s diet, possibly replacing breastfeeding when solid foods were introduced and being progressively integrated with plant foods and various items. The young female #9816 was not involved in these profound changes: her diet as a 8-to-12 year-old girl was isotopically slightly enriched in $\delta^{13}C$ as much as during third molar cusp formation, but such variation was comparatively small.

Finally, comparing the last values of around age ~12 with bone apatite (Table 22), some individuals show $\delta^{13}C$ depletion (#7131 and 7134, the latter with a 1.0‰ depletion also in $\delta^{18}O$), which may be an indication of a generalized better access to meat – and its fat – in adulthood, which is not surprising. The young adult #9817 does not show this, possibly because higher consumption of meat had not started yet (the individual was younger than 20 at death), or the bone had not had enough turnover time for the isotopic ratio to be substantially different. The female experienced a remarkable enrichment in both $\delta^{13}C$ and
δ^{18}O, which mirrors the trend observed in pre-teen boys, only delayed to the time between adolescence and early 20s. It must be underlined that in females pregnancy and nursing can also determine enrichment, which has been documented for δ^{15}N in vivo (O’Connell and Prentice forthcoming). A similar effect of growth has been recorded even archaeologically, from the time span 7-12 years of age to adulthood (White and Schwarcz 1994). Consequently I suspect some similar mechanism in δ^{18}O fractionation, in which case the curve in values during age ~8-12 could reflect a fundamentally normal physiological trend, making the dietary hypotheses unnecessary.

7.3. Faunal and Botanical Control Samples

All isotopic values for faunal and botanical samples are in the Appendices, table 44. They include aquatic animals from different niches, one sample of wild boar from an 1800s’ dumpster in Iglesias, southwestern Sardinia, the Copper Age samples of both domesticated and wild species, and vegetal samples of both domesticated and wild plants common in present-day Sardinia. The marine ecosystem (Figure 79) has values that compare to those documented elsewhere in the Mediterranean and in the world (Pinnegar and Polunin 2000; Pinnegar, et al. 2003; Polunin, et al. 2001; Richards and Hedges 1999e). Lower δ^{15}N values are recorded in invertebrates (Aristeus a., Mytilus g.) and fish that feed in relatively shallow waters on the bottom of the sea, whereas higher values are associated with predators such as swordfish, eel and squid. The values of the brackish water fish (Mugil sp.) are also interesting in that they are enriched in δ^{13}C but not particularly enriched in δ^{15}N, probably reflecting the lagoon environment. Whereas such values are nevertheless within a marine range, one of the lagoon molluscs (Chamelea sp.) has typically freshwater values; this might be linked to the

<table>
<thead>
<tr>
<th>Individual (original #)</th>
<th>Youngest M3 subsample #</th>
<th>δ^{13}C‰ enamel</th>
<th>Bone apatite sample #</th>
<th>δ^{13}C‰ bone apatite</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cranium 3</td>
<td>7131a</td>
<td>-10.0</td>
<td>6930</td>
<td>-11.1</td>
</tr>
<tr>
<td>Cranium 6</td>
<td>7134a</td>
<td>-9.6</td>
<td>6933</td>
<td>-12.3</td>
</tr>
<tr>
<td>Cranium 19</td>
<td>9816a</td>
<td>-12.3</td>
<td>6924</td>
<td>-11.1</td>
</tr>
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<td>Cranium 35</td>
<td>9817a</td>
<td>-9.6</td>
<td>6938</td>
<td>-9.7</td>
</tr>
</tbody>
</table>
Figure 79. Scatterplot of all $\delta^{13}$C and $\delta^{15}$N values of flesh specimens of aquatic fauna. All species are marine, although the molluscs, Mugil and Anguilla also live in brackish waters.

differential mobility of the two species, which allows the fish to move seasonally between the lagoon and the open sea, so acquiring a signature from both ecosystems.

The terrestrial ecosystem’s species (Figure 80) are within the expected ranges, with plants depleted in both $\delta^{13}$C (range -30.1 to -23.7‰) and $\delta^{15}$N (range -0.8 to +3.7‰). It must be noted how, contrary to broad generalizations (DeNiro and Hastorf 1985), in this specific study there is no interval between N-fixers ($Vicia faba$) and non-fixers ($Triticum durum, Olea europaea, Avena sativa$). Factors besides physiology such as water supply, N supply or slope may have affected such values. $Olea$ as expected has particularly depleted $\delta^{13}$C, due to its high lipid content (lipids have usually more depleted values within any given organism). The isotopic distance of plants from the animal species appears remarkable, slightly higher than what would be expected for the trophic level effect (3-4‰), but since the two groups come from different contexts, they are not directly comparable. Average values for terrestrial mammals from the two archaeological sites of Santa Caterina di Pittinuri and Scaba ’e Arriu A are $\delta^{13}$C = -20.8‰ and $\delta^{15}$N = 5.1‰, and $\delta^{13}$C = -20.0‰ and $\delta^{15}$N = 8.2‰, although the single species have rather diverse values and general averages are not particularly
informative. In fact, the former site has a depleted average simply because of the smaller representation of pig specimens.

_Prolagus_ and the single deer specimen, with their depleted values, point to a forest environment (Heaton 1999; van der Merwe and Medina 1991), as does the one pig specimen. Ovicaprines, most pigs and cattle are isotopically closer to each other than they are to other species, due to a strong component of plant foods in their diet. Pigs are slightly more enriched in δ¹⁵N than ovicaprines because their diet incorporates a variety of items, which is what qualifies them as omnivores. Less straightforward is the position of Copper Age cattle, which show values clearly enriched as compared to those of sheep/goats, and closer to those of pigs and the single specimen of dog. The discussion of the practices and food chains that can be reconstructed for these two prehistoric communities is reserved for chapter 8.

Average apatite values for mammals at Santa Caterina di Pittinuri and Scaba ’e Arriu A are δ¹³C = -11.6‰ and δ¹⁸O = -3.1‰, and δ¹³C = -11.1‰ and δ¹⁸O = -2.5‰, although similar to collagen values, what matters are the isotopic ratios per species. As evident from the δ¹³C for the two groups, at Scaba ’e Arriu A pigs have values quite similar to those of
humans, while at Santa Caterina it is very distinct: this seems related to variation in the human diet rather than in the way of tending pigs. The patterning of Prolagus, ovicaprines and fox are consistent, pointing to a coherent interaction of diet and physiological factors. While we would expect enriched $\delta^{13}C$ in herbivores, pigs at Santa Caterina are actually more enriched than sheep/goats, and the $\delta^{13}C_{col-apal}$ spacing is similarly in the same range. The deer unexpectedly shows values similar to those of pigs, which is likely related to a similar forest ecosystem, while foxes have the most carnivorous spacing of the sampled species.

$\delta^{18}O$ values, as already pointed out as evidence of preservation of the isotopic signal, follow the general expectation according to drinking needs. Obligate drinkers such as pigs and humans show depleted values; on the other hand, moderately drought-tolerant animals such as sheep/goats, and rodents, have more enriched values.

### 7.4. AMS Dating

All AMS raw radiocarbon dates relative to the studied collections are presented in table 23, with calibrated dates, also plotted in the chronological sequence of the intercept (Figure 81). Calibration was performed with the software Oxcal 4.0. available online, which is one of the several programs that have been tested and found to be virtually equivalent (Weninger, et al. 2005).

One date (#AA64832) is to be rejected, since it was processed and analyzed by mass spectrometry despite a low carbon yield. In fact, isotopic analyses of collagen on the same sample were also impossible due to its complete disappearance. Two dates (#AA64836 and AA64834) are to be taken cautiously for relatively low carbon yields. One of them matched the expected date based on cultural materials, the Sardinian Middle Bronze Age, dated ~1900-1600 BC. The other, from skeletal materials thought to pertain to the Early Bronze Age (~2200-1900 BC) turned out to date much later, in the centuries around ~AD 1000. The sample from Is Aruttas (#AA64824), believed to be Late Neolithic, also yielded a much later date, during the Late-Final Bronze Age (in Sardinia ~1600-1000 BC: Perra 1997; Tykot 1994). This date deprived this study of the only possibility of investigating the diet of a coastal Late Neolithic site. No large collections are preserved besides San Benedetto, which is inland. As explained in chapter 4, Late Neolithic remains were mixed and probably for the most part completely degraded (except possibly teeth?) during the long utilization of the new
Table 23. All the AMS radiocarbon dates of the collections analyzed for stable isotopes

<table>
<thead>
<tr>
<th>Site</th>
<th>Sample Lab #</th>
<th>Intercept</th>
<th>Error 1σ</th>
<th>Error 2σ</th>
</tr>
</thead>
<tbody>
<tr>
<td>sa Duchessa</td>
<td>AA64832**</td>
<td>4990</td>
<td>530</td>
<td>1.00</td>
</tr>
<tr>
<td>cal BC</td>
<td>4357-3093</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>San Benedetto</td>
<td>Beta-72233</td>
<td>4920</td>
<td>70</td>
<td>1.00</td>
</tr>
<tr>
<td>S. Caterina di Pittinuri 1</td>
<td>AA72148</td>
<td>4496</td>
<td>46</td>
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<td>cal BC</td>
<td>3333-3213</td>
<td>3188-3155</td>
<td>3131-3092</td>
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<td>Cannas di Sotto</td>
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<tr>
<td>Serra Cannigas A</td>
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Table 23 (continued). All the AMS radiocarbon dates of the collections analyzed for stable isotopes:

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</table>

* Dates available before this study are shaded. All others were obtained within this project.

** Unreliable date, carbon content too low.

*** Dates to be taken with caution, carbon content not optimal.
burial sites by their descendants, up to the mid-3rd millennium BC. The collections of Santa Caterina di Pittinuri and Iscalitas were re-dated, to confirm the chronology with more accurate measurements. In previous determinations (Beta-72235 and Beta-107558) the error was ± 140 and ± 70, respectively, whereas the dates in this study (#AA72148 and AA72149) have ± 46 and ± 42, respectively. While the date of the latter was virtually confirmed, the
date for the former was much earlier and not overlapping with the one previously available, providing fresh evidence of the long use of these burial chambers by the local community for at least five centuries. Overall, the purpose of AMS dating, that is providing good time control over the remains analyzed for stable isotopes, was substantially achieved, both by confirming chronological pertinence and by adding accuracy to several groups.
Chapter 8. Discussion

8.1. Transformation of Values and Corrected Results

8.1.1. Premise: the Aim of Value Transformation

An isotopic signature, as clear from the section on fundamentals and principles in chapter 6, is the combined reflection of several factors, where dietary information has to be assessed after ‘weeding out’ other possible substantial sources of error, due to ecosystem-wide variation. One way of doing this is to have a good frame of reference values from lower levels of the food chain, namely animals and plants that were likely to be consumed by humans. Unfortunately, this is not always possible. At many burials there are no animal offerings or bone tools, nor plant remains. Especially in older excavations, these remain may sometimes be in different locations with differential access and curation.

All this has pushed research towards single-site, in-depth isotopic analyses, which aims to reconstruct a single economic and ecological system. Furthermore, single-site analyses allow a larger sampling and consequently a better insight into social patterns as revealed by dietary variation between subgroups defined based on age, sex, health and class (e.g. Ambrose, et al. 2003; Privat, et al. 2002). While this generates detailed knowledge of diet in circumscribed contexts in space and/or time, only a long-lasting effort in the field of stable isotopic analyses with a focus on addressing specific problems can yields results that are relevant for longer periods of time and to trace wide variation patterns.

Additionally, there is a risk that, because of changing methods of sample preparation and analysis over time, and due to synchronic differences in such methods between different labs and researchers, results may not be completely comparable. Since this dissertation precisely aims at detecting dietary and climatic variation over a ~2000-year time period,
comparisons between different human groups situated in different time and space have to be carried out with caution. One element, middle-scale geographic variation, is accounted for by the relatively limited area the study covers: less than 15,000 km$^2$. Altitude itself is also to some extent accounted for by the low elevation of all sites considered.

However, there are microclimatic factors that have been recognized to be linearly related with isotopic values: temperature, sunlight, precipitation, all to a certain extent related with each other besides with isotopic values. This, as is clear from the section on Mediterranean isotopic studies, is particularly important in the absence of elements carrying strongly distinctive signatures, such as seafood or C$_4$ plants. Following the general global equations developed in previous studies (van Klinken, et al. 1994, Schwarcz, et al. 1999 for collagen values, various equations for single steps of correction for apatite $\delta^{18}$O), it is possible to disentangle partially these factors to isolate values that can virtually have two origins: either cultural variation (including food and drink, animal and landscape management practices, stress linked to specific practices) or natural variation, in terms of climate change not directly related to human agency. This, based on some surveys of isotopic values, is apparently far lower than broad-scale geographic and human-induced variation (van Klinken, et al. 2000; 1994).

### 8.1.2. Transformation Procedure

#### 8.1.2.1. Transformation of Collagen $\delta^{15}$N Values

For $\delta^{15}$N values, Schwarcz et al. (1999) used a global database to come up with a linear regression equation linking them with mean annual precipitation, which has a strong $r^2$ (0.84%):

$$
\delta^{15}\text{N} = (16.37 \pm 1.23) + (-0.01108 \pm 0.0011) \times \text{mean precipitation (mm/year)}
$$

This equation allowed the calculation of predicted values for the sites considered, retrieving the precipitation values from a map that averages the data collected between 1921 and 1960 (Pracchi and Terrosu Asole 1971, map # 21), with rounding to the closest 50 mm interval. The difference was then calculated between predicted value and measured value, and such difference added to an arbitrary constant value that was chosen as the average of all predicted values that are being considered. This leaves the numbers within the range of the observed
values, preserving the overall signal that contains dietary and broad-scale climatic information, but is so-to-speak ‘cleaned’ of error due to latitude, altitude, hill slope, direction of local valleys, and mountain ranges affecting the direction of rains in a way that is assumed here to be to some extent consistent.

8.1.2.2. Transformation of Collagen $\delta^{13}C$ Values

A similar procedure was followed for $\delta^{13}C_{\text{col}}$, using one of the equations obtained by van Klinken and colleagues (van Klinken, et al. 2000; 1994):

$$\delta^{13}C = a + (-0.181 \pm 0.039) \times \text{average annual } T^\circ C$$

Parameters such as temperature, rainfall, sunshine and humidity were all found to be strongly correlated, with $p < 0.001$, for a dataset including a wide area from Northwest Europe to Israel and Libya, with the exception of May temperature, possibly because in Mediterranean climates rains in spring and summer are just very scarce, therefore whichever curve has already met the zero line.

Since no geographically detailed database on Sardinia was available for July temperature, which was found to be highly correlated with isotopic values, the mean annual temperature was used instead, which is broadly similar, probably with variation slightly reduced since it may average out the peaks. Considering the strong linear statistical relationship that most climatic parameters have with $\delta^{13}C_{\text{col}}$, this is anyway a safe approximation. These climatic data were also taken from a thematic atlas of Sardinia (Pracchi and Terrosu Asole 1971, map # 11).

Since the slope for animal bone should be similar, it can be used for our purpose (van Klinken, et al. 2000 even use the slope for wood): its coefficient of determination for July temperature is strong ($r^2 = 0.78\%$). The intercept is not relevant because I used the average of all values, predicted by using the intercept itself, as a basis to calculate the corrected value by adding the difference $\Delta\delta^{13}C_{\text{pred}} - \text{observed values}$.

8.1.2.2. Transformation of Apatite $\delta^{18}O$ Values

Correcting apatite $\delta^{13}C$ has not been attempted nor is it likely to be. Its composition derives from too many dietary components that contribute each a very different signature, so
that a climatic effect would be obscured or anyway harder to pull apart from much wider ranges of variation due to food consumption. Since the $\delta^{13}C_{col-apa}$ spacing has a strong linear relationship with $\delta^{13}C_{apa}$ ($r^2 = 93.52\%, p = 0.00$ in this study’s dataset), and as a mathematical abstraction is not directly dependent on actual isotopic values, it is possible to extract dietary information from it instead of $\delta^{13}C_{apa}$.

$\delta^{18}O$ values do not depend, in obligate-drinker large mammals, on solid food intake, but on the drinking-water signature, which in turn depends on the rainwater signature among other interrelated factors. Such a signature, as already discussed, has been demonstrated to be correlated with a set of climatic parameters. When dealing with several human groups spread in time and space, in order to assess whether the isotopic variation derives from geographic patterns assumed to be comparable to the present day or to large-scale climate change over time, a way to control for such small-scale isotopic variation is needed. Such variation in some cases can be remarkable and therefore obscure the long-term trends. This does not generate a prediction on any factual phenomenon, since geography and global trends are always interacting at the local scale, but rather eliminates the variation due to small-scale geographic features, leaving values that should be closer to broad-scale climate change. The procedure, done on a Microsoft Excel spreadsheet, involves the following steps:

1. Calculating $\delta^{18}O_{water-(SMOW)}$ from local mean annual precipitation in mm/year (Bar-Matthews, et al. 2003: 3186):

   $\delta^{18}O_{water (SMOW)} = -3.25 - 0.0050842 \times \text{mm/year rainfall}$

2. Calculating predicted $\delta^{18}O_{bone phosphate (SMOW)}$ from $\delta^{18}O_{water (SMOW)}$ (Longinelli 1984: 386):

   $\delta^{18}O_{bone phosphate (SMOW)} = 0.64 \times \delta^{18}O_{water (SMOW)} + 22.37$

3. Calculating predicted $\delta^{18}O_{bone carbonate (SMOW)}$ from $\delta^{18}O_{bone phosphate (SMOW)}$ (Iacumin, et al. 1996: 3):

   $\delta^{18}O_{bone carbonate (SMOW)} = (\delta^{18}O_{bone phosphate-(SMOW)} + 8.5) / 0.98$
4. Converting $\delta^{18}$O$_{\text{bone carbonate (SMOW)}}$ into $\delta^{18}$O$_{\text{bone carbonate (PDB)}}$, which is the notation used for bone apatites, in order to make predicted and observed values comparable;

5. Calculating the difference between observed $\delta^{18}$O$_{\text{bone carbonate}}$ values and predicted $\delta^{18}$O$_{\text{bone carbonate}}$ values;

6. Adding such difference to an arbitrary number (as in van Klinken, et al. 2000, for carbon), which was chosen to be the average of all predicted values.

This procedure eliminates variation due to local geography and limits the variation to anomalous broad climatic variation, as if all sites were placed in the same geographic location. Although the procedure certainly leaves some error due to the effect of other climatic parameters, different patterns of geographic variation in the past and changing circulation of air masses, considering the relatively small area of this study, the variation that is left can reasonably be assumed to be caused by climate change.

The arbitrary number that was chosen is the average of all predicted values in order to keep the values realistically close to the observed ones, and also to be more easily readable due to its similarity to the uncorrected range. This procedure also provides a means of assessing any covariation between $\delta^{18}$O, $\delta^{13}$C$_{\text{col}}$, $\delta^{15}$N$_{\text{col}}$, and $\delta^{13}$C$_{\text{apa}}$ which can be due to climate change rather than small-scale geographic variation or diet. The first predicted $\delta^{18}$O$_{\text{water}}$ was calculated from mean annual rainfall because there is no fine-grained database for $\delta^{18}$O$_{\text{water}}$ in Sardinia: only two measurements have been published (Longinelli and Selmo 2003), which appear within the range expected from the average rainfall, so supporting the outcome of these predictions. The same equations were used the inverse way to calculate a measure of possible reconstructed rainfall variation over the whole studied area based on the corrected $\delta^{18}$O values.

One limitation of this way of trying to get close to detecting climate change is the underlying assumption that people were fully sedentary. If an individual moves within a decade or so to a location that has a different $\delta^{18}$O$_{\text{water}}$ signature, or if the individual commutes seasonally between two or more locations, then the values may be a mix of both. This has been considered unlikely during this period (Lewthwaite 1981), but may however have been the case for some communities or at least for parts of them. This possibility, introduced in the background chapters 4 and 5, is discussed below.
8.1.3. Quantitative Analysis of Corrected Results

The high correlation between corrected $\delta^{13}C$ and $\delta^{15}N$ should have decreased with correction, since the geographic variation has been eliminated. What is left should be due to climate change and diet. In fact (Figure 82), the $r$ coefficient drops, with correction, from 0.48 to -0.08, $r^2$ from 23.50% to 0.57%, and $p$ increases from 0.00 to 0.36. After correction, the stronger the relationship between corrected $\delta^{13}C_{\text{col}}$ and $\delta^{15}N_{\text{col}}$ values on one hand, and $\delta^{18}O$ on the other, the more their remaining variation should be due to broad-scale climate change; the weaker the relationship, the more the remaining variation in $\delta^{13}C_{\text{col}}$ and $\delta^{15}N_{\text{col}}$ should be due to cultural factors in the form of diet. For $\delta^{13}C_{\text{col}}$, from raw to corrected data (Figure 83), the coefficient of correlation with $\delta^{18}O$ drops (from $r = 0.39$ to $r = 0.01$), the percent of variation explained by the linear model ($r^2$) shrinks, from 14.89% to 0.01%, and $p$ increases from 0.00 to 0.90. Such a weak and scarcely significant relationship ensures that climatic variation, which is assumed to be best reflected in $\delta^{18}O$, is not strongly related, nor responsible for the variation found in the corrected $\delta^{13}C_{\text{col}}$ data. It is therefore possible to be reasonably confident that most of it, at this point, reflects differences in diet.

As concerns the relationship between $\delta^{15}N_{\text{col}}$ and $\delta^{18}O$ (Figure 84), it is significant but weak using raw data ($p = 0.02$, $r = 0.19$, $r^2 = 3.68\%$), and as expected both significance and amount of variation explained by the model decrease further when data are analyzed after

![Figure 82. Comparison of biplots with best-fit lines for collagen $\delta^{13}C$ vs. $\delta^{15}N$, raw and corrected. The plot of corrected values shows that the linear relationship due to geography/microclimate has been removed.](image)
Figure 83. Comparison of biplots with best-fit lines for collagen δ¹³C vs. δ¹⁸O, raw and corrected. The corrected δ¹³C values do not have any strong correlation with δ¹⁸O, indicating that diet, not climate change, is responsible for the remaining variation.

Figure 84. Comparison of biplots with best-fit lines for collagen δ¹⁵N vs. δ¹⁸O, raw and corrected. The corrected δ¹⁵N values do not have any strong relationship with δ¹⁸O, indicating that diet, not climatic variation, is responsible for the remaining variation.

correction ($p = 0.09$, $r = 0.14$, $r^2 = 1.97\%$). In such absence of any strong or significant linear relationship with corrected δ¹⁸O, we can again reasonably infer that the remaining variation is largely due to diet.

After discussing the evidence that after correction there is no relationship between δ¹⁸O as a climatic indicator and δ¹⁵N_{col} and δ¹³C_{col} as dietary indicators, which implies that climate change is not a major source of variation in the transformed diet-related values, there is also evidence coming from a quantitative relationship that becomes stronger. This is
provided by the comparison of the indicators of linear relationship between $\delta^{15}\text{N}_{\text{col}}$ and the spacing $\delta^{13}\text{C}_{\text{col-apa}}$ before and after correction. As discussed in chapter 6, based on theoretical modelling and increasing evidence, these two sets of values should be related. The former is the most sensible indicator of trophic level, in other words of the amount of animal protein in the diet; the latter reflects heavily the quantity of fats, which commonly are of animal origin (Hedges 2003; Lee-Thorp, et al. 1989). Therefore, a large portion of their variation should derive from the same source. If correction of the data is effective, this relationship is expected to become stronger, since the effect of environmental variation would be removed, leaving a proportionally larger amount of variation due to diet. In fact (Figure 85), the effect of transforming the Sardinian data supports this: both the coefficient of correlation and the amount of variation the model accounts for rise remarkably after data correction ($r = 0.02$ to $0.50$, $r^2 = 0.04\%$ to $24.94\%$). Also, the $p$ value decreases remarkably, indicating that the significance of the relationship is much higher ($p = 0.82$ to $0.00$). Essentially, the data transformation increases the amount of variation explained by the linear model from nearly zero up to almost one fourth: the relationship between $\delta^{15}\text{N}_{\text{col}}$ and $\delta^{13}\text{C}_{\text{col-apa}}$ expected based on physiology becomes visible after removing the climatic “noise”.

**Figure 85.** Comparison of the biplots with best-fit lines of collagen $\delta^{15}\text{N}$, raw and corrected, vs. the spacing $\delta^{13}\text{C}_{\text{col-apa}}$. The raw $\delta^{15}\text{N}$ values do not have a significant or strong linear relationship with the spacing, as would be expected according to current knowledge as both reflect the degree of carnivory in the diet. When corrected, their relationship becomes strong and significant, and the model accounts for almost one fourth of variation. This confirms the effectiveness of the data transformation to get closer to the dietary variation of the examined human groups.
8.1.4. Comparison of Raw and Corrected Results

The section above leads me to conclude that the data, as they are after correction, are suitable to be used to extract meaningful information about dietary variation across the human groups that are the subject of this study. From a methodological perspective, a specific consideration of the discrepancy between a comparison of raw data versus corrected data seems useful, in order to illustrate how misleading a simplistic traditional interpretation can be, and on the flipside how deep insights can be gained in the variation over the longue durée.

Looking at the scatterplots of the collagen $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ values represented as the means and standard deviation (Figure 86) in the attempt to get a feel of the overall dietary trends during the two thousand years under examination, quite different interpretations come out of the two charts. A traditional reading of raw data would tell us that, within a common framework of mixed diet, the Late Neolithic community of San Benedetto was one of the

![Figure 86. Scatterplots of the means and standard deviation of collagen $\delta^{15}\text{N}$ vs. $\delta^{13}\text{C}$, raw on the left and corrected on the right. The linear correlation visible in the raw values is shown by correction to be an effect of microclimatic variation, not of dietary variation.](image)

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most reliant on plant foods; the Copper Age groups would have a diet with more animal proteins, except Seddas de Daga which appears radically different and heavily reliant on plant foods. The Bell Beaker group would have consumption of animal products at levels similar to the high end of the Copper Age groups, and the Early Bronze Age groups would have a similar diet, except Concali Corongiu Acca, which is the one relying the most on animal products. The corrected data tell a different story: a Late Neolithic group showing high consumption of animal proteins, Copper Age and Bell Beaker sites largely overlapping but showing a slightly lesser amount of animal protein, and Early Bronze Age groups much more reliant on plants, still with the exception of Concali Corongiu Acca. The anomaly of Seddas de Daga disappears after correction for microclimatic variation. In sum, the general direction from the Neolithic to the Early Bronze Age changes, relative to animal protein, from a -/+/- pattern to a +/-/-.

### 8.2. Discussion of the Corrected Results

#### 8.2.1. Variation in the Protein Component of Prehistoric Diets

The protein component of the diet is reflected, as explained in chapter 6, mainly in collagen values (Figure 87). While a strong linear relationship was found between $\delta^{13}C$ and $\delta^{15}N$ when analyzing raw measurements, which was due to environmental effects, such a relationship, as expected, is absent from the corrected data (Table 24). The scatterplot of the means and standard deviations (Figure 88) helps discern overall patterns in the values (groups out of the time range of interest are not shaded). There is a large overlap of values among all sites excluding Concali Corongiu Acca, which appears to be the one with the highest consumption of proteins of animal origin. The range of $\delta^{15}N$ values between 8‰ and 12‰ represents approximately one trophic level, meaning that highest values would represent substantially carnivorous diets, whereas the lowest would represent substantially vegetarian diets. $\delta^{13}C$ values are within ~1.5‰, which is a fairly small interval, and probably do not yield much information compared to $\delta^{15}N$. 

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Figure 87. Scatterplot of corrected collagen $\delta^{15}N$ vs. corrected collagen $\delta^{13}C$. This graph represents mostly real dietary values, and can be used to assess variation in protein source between groups. Points are color-coded as follows: orange, Late Neolithic; red, Post-Ozieri Copper Age; blue, later (Monte Claro) Copper Age; green, Bell Beaker; black, Early Bronze Age; empty symbols, later sites.

Once it has been established that most proteins came from animals and plants within a C$_3$ ecosystem, the differences between groups can be tentatively read. As concerns the contribution of seafood, the data confirm that at all sites and phases it was negligible or none. If there was any seafood, yet very limited, the single individual from the Monte Claro phase at Padru Jossu is the best candidate to represent it, with its values slightly more enriched in both $\delta^{15}N$ and $\delta^{13}C$. A very limited amount of freshwater fish could be responsible for slightly depleted $\delta^{13}C$ in groups that also show enriched $\delta^{15}N$: Cannas di Sotto and Su Stampu. On the other hand, a small consumption of C$_4$ plants would possibly account for values that are relatively depleted in $^{15}N$ and enriched in $^{13}C$. This might be the case for the Early Bronze Age groups of Padru Jossu B and Iscalitas, and the Copper Age group of Serra Cannigas, with the addition of the later group of Is Aruttas, which is close to brackish water lagoons and high-salinity environments (this would be quite fitting, since C$_4$ plants are well adapted to dry and saline ecosystems). Of course, while the data could reflect both different
Table 24. Means of all corrected isotopic results by group*.

<table>
<thead>
<tr>
<th>Sites</th>
<th>n</th>
<th>corrected δ¹³C‰ Mean</th>
<th>s.d.</th>
<th>corrected δ¹⁵N‰ Mean</th>
<th>s.d.</th>
<th>corrected δ¹⁸O‰ Mean</th>
<th>s.d.</th>
</tr>
</thead>
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<tr>
<td>San Benedetto</td>
<td>16</td>
<td>-19.1</td>
<td>0.3</td>
<td>11.3</td>
<td>0.5</td>
<td>-4.0</td>
<td>0.3</td>
</tr>
<tr>
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<td>0.3</td>
<td>10.5</td>
<td>0.3</td>
<td>-4.5</td>
<td>0.4</td>
</tr>
<tr>
<td>Serra Cannigas</td>
<td>2</td>
<td>-18.9</td>
<td>0.1</td>
<td>10.1</td>
<td>1.6</td>
<td>-5.1</td>
<td>0.6</td>
</tr>
<tr>
<td>Santa Caterina di Pittinuri</td>
<td>5</td>
<td>-19.4</td>
<td>0.4</td>
<td>10.9</td>
<td>0.5</td>
<td>-4.2</td>
<td>0.3</td>
</tr>
<tr>
<td>Scaba ’e Arriu A</td>
<td>14</td>
<td>-19.3</td>
<td>0.2</td>
<td>10.8</td>
<td>0.8</td>
<td>-3.5</td>
<td>0.6</td>
</tr>
<tr>
<td>Scaba ’e Arriu M</td>
<td>12</td>
<td>-19.2</td>
<td>0.2</td>
<td>11.2</td>
<td>0.8</td>
<td>-4.1</td>
<td>0.3</td>
</tr>
<tr>
<td>Seddas de Daga</td>
<td>7</td>
<td>-19.6</td>
<td>0.6</td>
<td>10.3</td>
<td>1.7</td>
<td>-3.7</td>
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</tr>
<tr>
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<td>-19.8</td>
<td>0.6</td>
<td>10.5</td>
<td>0.7</td>
<td>-3.5</td>
<td>0.7</td>
</tr>
<tr>
<td>Sa Duchessa</td>
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<td>14.5</td>
<td>0.0</td>
<td>-4.3</td>
<td>0.0</td>
</tr>
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<td>0.0</td>
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<td>0.0</td>
<td>-3.6</td>
<td>0.0</td>
</tr>
<tr>
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<td>0.2</td>
<td>10.1</td>
<td>0.9</td>
<td>-3.8</td>
<td>0.8</td>
</tr>
<tr>
<td>Padru Jossu A</td>
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<td>0.5</td>
<td>9.4</td>
<td>1.1</td>
<td>-3.2</td>
<td>0.6</td>
</tr>
<tr>
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<td>0.3</td>
<td>9.0</td>
<td>0.9</td>
<td>-5.3</td>
<td>0.4</td>
</tr>
<tr>
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<td>13.3</td>
<td>0.8</td>
<td>-4.0</td>
<td>0.5</td>
</tr>
<tr>
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<td>9.9</td>
<td>0.0</td>
<td>-4.2</td>
<td>0.0</td>
</tr>
<tr>
<td>Montessu t.10</td>
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<td>-18.6</td>
<td>0.3</td>
<td>9.0</td>
<td>0.9</td>
<td>-2.0</td>
<td>0.8</td>
</tr>
<tr>
<td>Montessu t.33</td>
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<td>-19.6</td>
<td>0.2</td>
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<td>0.6</td>
<td>-3.4</td>
<td>0.2</td>
</tr>
<tr>
<td>Montessu t.32</td>
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<td>0.0</td>
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<td>0.0</td>
<td>-3.9</td>
<td>0.8</td>
</tr>
<tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Italics indicates groups analyzed but out of the chronological target of this study.

Secondary sources of protein with very distinct signatures (fish), and different sources of lipids contributing to the isotopic signature, it just seems more reasonable to imagine readily available food sources such as pigs. In fact, pigs have on their side an overwhelming evidence from historical sources and faunal remains, whereas foods such as aquatic resources seem to not have been as important in Mediterranean diets, whether we consider prehistoric remains or medieval through modern times. The trend recorded isotopically throughout the later prehistory of the Mediterranean is substantially supported by this finding.

Another source of variation could be due to the trophic level of the protein source. A diet based on lamb and beef should result in lower δ¹⁵N than a diet based on pork, since pigs, being omnivorous, would have values about half a trophic level higher than herbivores (~2‰). In this case, assuming most variation derives from differences in the kind of animal proteins, we could infer that at Concali Corongiu Acca pigs were nutritionally important,
Figure 88. Scatterplot of the means corrected collagen $\delta^{15}N$ vs. corrected collagen $\delta^{13}C$. This graph represents mostly real dietary values, and can be used to assess variation in protein source between groups. Points are color-coded as follows: orange, Late Neolithic; red, Post-Ozieri Copper Age; blue, later (Monte Claro) Copper Age; green, Bell Beaker; black, Early Bronze Age; empty symbols, later sites.

Ruminants were more important in correspondence with the middle values, and plant proteins were more important in the low $\delta^{15}N$ end.

A further factor to consider, which may have affected the patterns I try to explain, is the variation in legume consumption. Legumes, as N-fixers, have $\delta^{15}N$ values considerably lower than do non-N-fixing plants, and $\delta^{13}C$ values comparatively similar. The percent of protein per weight unit is 25-35%, similar to that of milk, although sensibly lower than that of meat. Thus, the isotopic signature recorded at the Early Bronze Age sites of Padru Jossu B and Iscalitas could also be accounted for by a considerable variation in the level of reliance on legumes. It must be underlined that legumes are documented as part of the Neolithic package (peas, lentils, chickpeas, faba beans), and were a staple in traditional Mediterranean rural economies until the 20th century.

An aspect that is probably more theoretical than practical, because of its very limited variation in collagen, is the understanding of $\delta^{13}C$ differences. Such limited variation makes its reliability for dietary interpretation not optimal: most of it is contained within ~1‰, and considering that even the precision of the measurement is ~0.2‰, it is definitely impossible to extract refined dietary information from collagen $\delta^{13}C$. For this, the integration of collagen
δ^{15}N and the spacing δ^{13}C_{col-apa} is best (below). Nevertheless, reading collagen δ^{13}C variation can be an example of methodological problems and potentials. Its interpretation benefits from the consideration that a lesser portion of the proteins that enter the synthesis of collagen can come from nutrients other than ingested protein, especially if the overall quantity of protein is small (Schwarcz 2000) and according to the quantity of N and C of any given food (Phillips and Koch 2002). Consequently, the expected variation due to lipids and carbohydrates should increase with a decreasing amount of protein, which is likely to correspond to a decreasing amount of animal products, in turn reflected in δ^{15}N values. In other words, enriched δ^{15}N should correspond to less variation because most of the proteins would come from N-rich animals, whereas more δ^{13}C variation should correspond to lower intake of animal proteins, reflected in depleted δ^{15}N values, since the whole diet – more likely to be more differentiated – would be more and more represented. The distribution of values might actually fit this model. If this is the case, then some degree of δ^{13}C variation could be due to carbohydrates and lipids and their sources. While carbohydrates' sources do not differ radically in δ^{13}C, lipids of different origin do (Copley, et al. 2003; Evershed, et al. 1999). The human groups with more depleted values would then reflect more ruminant adipose fats and milk, whereas the more δ^{13}C-enriched would reflect more pig fats. It must be considered that pork would also slightly enrich δ^{15}N values: therefore, if this is actually the case, equal δ^{15}N values would not correspond to similar quantities of protein; since pork is commonly enriched as compared to ruminants, the same δ^{15}N ratio would correspond to lower amounts of pork meat than it would to amounts of ruminant meat/milk. For instance, the protein quantity eaten by the Serra Cannigas individuals would be considerably lower than the small δ^{15}N difference from the δ^{13}C-depleted sites would indicate. Theoretically, vegetal fats should be added to the range of options: olives, whether wild or cultivated, and lentisk, could have been exploited. However, it is unlikely that their quantitative contribution to the diet would be so high as to affect noticeably the isotopic values (especially of collagen). As a conclusion to this attempt to interpret collagen δ^{13}C variation, it must again be underlined and emphasized that this is not a reliable indicator of whole diet, a role that is best fulfilled by apatite δ^{13}C and the δ^{13}C_{col-apa} spacing (Jim, et al. 2004).

Under the multiple interpretive lenses discussed above, the development of diet could be read as one of decreasing overall protein supply from the Neolithic to the Early Bronze Age. After ruling out any major role of marine food, the major question posed in the first
chapters concerns the amount of animal versus vegetal proteins within a terrestrial C\textsubscript{3} ecosystem, that is, the emphasis on farming versus animal husbandry. The traditional view of an agricultural Neolithic opposed to a pastoral Copper Age is not supported by the evidence. The Late Neolithic group of San Benedetto shows a diet largely similar to, and on average slightly richer in animal protein than that of all the Copper Age groups. The comparison is not the most efficacious possible, since San Benedetto is a site in a hilly region with steep slopes, probably more appropriate for herding at all times, but the lack of alternative Late Neolithic skeletal collections coming from alluvial lowlands prevents a full comparability. Therefore, the possibility that future discoveries might yield different results cannot rule out.

The evidence presented here definitely suggests a quite similar diet, on average more reliant on plant foods in the Copper Age sample than in the Late Neolithic.

As concerns internal differences within the Copper Age, there is again a large overlap, and no great variation. The four human groups of Post-Ozieri tradition and the three Monte Claro had a fairly similar diet. Based on the hypothesis that small variation may be due to fats, it would seem that at Cannas di Sotto, Su Stampu and Seddas de Daga there was more consumption of milk and/or ruminant meats, whereas at Serra Cannigas there might have been higher consumption of pig fat. The remaining three groups are very close in their isotopic values, pointing to a protein component of the diet substantially similar. The identified pattern underlines the fact that geographic variation was more important than chronological variation, and that there were no linear shifts in subsistence. Also, the wide variation in $\delta^{13}$C compared to the small variation in $\delta^{15}$N tells us that whereas the trophic level of protein sources was overall similar throughout the Copper Age, the differentiation is more likely to be in the type of source, which is revealed by the effect of fats. Following the argument discussed above, depleted $\delta^{13}$C implies more ruminant lipids and enriched $\delta^{13}$C more swine.

The values of the Bell Beaker and two larger Early Bronze Age groups, Padru Jossu B and Iscalitas, are still largely overlapping but clearly lower than the Copper Age and Late Neolithic ones. They are about 2‰ more depleted, which could be about half a trophic level. This does point to overall reliance on plant foods heavier than that of most Copper Age groups, and distinctly higher than that of the Late Neolithic San Benedetto. Concali Corongiu Acca, instead, is definitely different, in that its extreme values and the remarkable distance from the lowest averages point to a diet where most proteins came from animals.
Excluding Concali Corongiu Acca there is a slow shift to lower values, which means to more plant consumption, from the Late Neolithic to the Early Bronze Age. The Bell Beaker phase at Padru Jossu represents intermediate values between the Copper Age sites and the Early Bronze Age groups.

The two single-individual groups of Mind’e Gureu and Padru Jossu, Monte Claro have quite distinct values. The former’s high $\delta^{15}N$ indicates very high consumption of animal protein, whereas the latter’s could reflect a small consumption of C$_4$ plants, or seafood. However, the presence of values such as for Mind’e Gureu and Concali Corongiu Acca, which are ~6‰ higher than the lower end of values, suggests a diet mainly based on pork meat, possibly pigs fed meat and high-trophic level scraps, or else additional phenomena might be at work, such as meat of animals feeding in fields fertilized with manure (Bogaard, et al. 2007). Alternatively, some kind of severe stress, of which a symptom may be identified in the severe diploic thickening of the Concali Corongiu Acca individuals, suggesting some kind of chronic anemia, could be responsible for the abnormally high values. Consequently, such values are to be considered cautiously in evaluating daily diets in comparison with the other groups.

In sum, proteins came from a combination of animal and plant foods. If a shift in nutritional terms actually happened towards increased reliance on dairy and meat, it may have been already in progress in the Late Neolithic site of San Benedetto, parallel to trends outlined for peninsular Italy, and continued, possibly slightly reversed, in the Copper Age. No clear nutritional trends can be identified within the Copper Age, and not along its two main cultural traditions. The idea of the Bell Beaker and Early Bronze Age communities as pastoral and permeated by warrior ethics, sober and essential (Lilliu 1988a: 358-359) is not confirmed by dietary evidence, as shown for the two groups of Iscalitas and Padru Jossu B. These groups relied on plant foods more than the Copper Age people. This lends instead some support to the interpretation given by Perra (1997) of societies tied to cereal cultivation rather than animal husbandry. On the other hand, Concali Corongiu Acca, the third Early Bronze Age site, is the one with the highest $\delta^{15}N$, pointing to a heavy consumption of animal protein. The hypothesis of intensification of animal husbandry as a characterizing element for the Early Bronze Age, as suggested by Lewthwaite (1986), and Lilliu (1988a), is therefore not confirmed: pastoralism may possibly have been an identity, a trait of identity related to maleness, rather than an economic reality.
A very important point is that inter-site variation seems in the Copper Age (and in the 
Early Bronze Age if including the group of Concalì Corongiu Acca, probably chronically ill) 
higher than differences between broad periods. In this situation, key witnesses become the 
multi-layered sites where we can follow the development of isotopic values at one point in 
space: the two sequences of Scaba ’e Arriu and Padru Jossu (Figure 89), also conveniently 
located in the same area (less than 20 km distance) and in hilly lowlands, cover together almost a millennium. At Scaba ’e Arriu, protein consumption did not change perceptibly 
between the Post-Ozieri and the Monte Claro phase: $\delta^{13}$C values differ just 0.1‰, $\delta^{15}$N 
values only 0.4‰; at Padru Jossu, the only available Monte Claro individual shows very 
enriched values, indicating the highest consumption of animal products (possibly even small 
amounts of seafood?). The following Bell Beaker and Bonnanaro A phases are definitely 
more depleted in $\delta^{15}$N: the Bell Beaker group’s average is 0.7‰ lower than the Scaba ’e 
Arriu A group (corrected values). The distance between averages of Scaba ’e Arriu Monte 
Claro and of Padru Jossu B is 1.8‰, about half a trophic level, which indicates a substantial

Figure 89. Plot of the means and standard deviation of corrected collagen $\delta^{15}$N in the different phases of 
Scaba ’e Arriu and Padru Jossu. Points are color-coded as follows: red, early (Post-Ozieri) Copper Age; 
blue, later (Monte Claro) Copper Age; green, Bell Beaker; black, Early Bronze Age.
gap in animal protein consumption, with about half the protein mass from a source lower in the food chain. This confirms at a more localized scale the trend recognized from the comprehensive scatterplot.

### 8.2.2. Overall Composition of prehistoric diets

As explained above, apatite is a more comprehensive dietary indicator, since it derives its isotopic signature from all three macronutrients, as opposed to mainly one like collagen. The spacing of collagen $\delta^{13}C$ and apatite $\delta^{13}C$ (Figure 90), which has a much stronger correlation with apatite values, is considered therefore the best evidence for whole diets. It has also been discussed how a correlation was found between collagen $\delta^{15}N$ and such spacing, as expected since both have some degree of correlation with the overall proportion of animal versus plant foods. Considering that most C$_3$ plant foods have similar $\delta^{13}C$ values (legumes are rather different in $\delta^{15}N$), fats probably play an important role in apatite $\delta^{13}C$ variation in the prehistoric Mediterranean.

An effective way of visualizing the spacing values is by plotting it with $\delta^{15}N$ (Figure 91), which as discussed provides the best indication of protein sources and quantity. The spacing integrates this information and completes it, together with the knowledge of available food options that comes from biotic remains. The majority of all $\delta^{13}C_{col-apa}$ spacing values lie between ~-10 and ~-4‰. The following interpretation is based on two main points. One is that generally a smaller spacing should correspond to more carnivorous diets, due to the effect of depleted lipids, which cause apatite $\delta^{13}C$ to be closer to collagen $\delta^{13}C$ (Hedges 2003; Lee-Thorp, et al. 1989). The spacing tends to have a linear negative relationship with $\delta^{15}N$, since higher amounts of protein are generally associated with whole diets rich in animal products and consequently lipids. This linear relationship should correspond to a line in the biplot, a line which is actually visible after collagen $\delta^{15}N$ correction, as had been quantitatively described and discussed above. The second point is the assumption, already justified ethnographically and ethnohistorically, that most fats were likely to be of animal origin. This limits the main effects on spacing to two factors: quantity of plant carbohydrates versus protein and quality of fats (ruminant fats, whether adipose or milk fat, and porcine fats). High $\delta^{15}N$ coupled with small spacing should correspond to high-animal protein diets with substantial contribution of sheep/goat/cattle fats. Low $\delta^{15}N$ coupled with large spacing
Figure 90. Scatterplot of the means of corrected collagen $\delta^{15}$N vs. the spacing $\delta^{13}$C<sub>coll-apo</sub>. The chart contains all the dietary information necessary to an overall assessment of diet. Points are color-coded as follows: orange, Late Neolithic; red, Post-Ozieri Copper Age; blue, later (Monte Claro) Copper Age; green, Bell Beaker; black, Early Bronze Age; empty symbols, later sites.
should correspond to protein-poor or plant-protein-rich diets, with substantial reliance on cereal grains, possibly with the addition of legumes. High $\delta^{15}N$ coupled with large spacing should correspond to high-animal protein diets with substantial consumption of enriched fats.
which are likely to be derived from pig, and possibly, less likely and in smaller quantities, from plants.

Along these lines, the diet of the few individuals from Concali Corongiu Acca would be extremely rich in protein of ruminant origin, although as discussed above the spacing is abnormally small, and there might be some effect related to the remarkable hyperostosis recorded in those individuals. As a whole, the trend over time detected in the collagen of a reduced protein intake is confirmed: most Copper Age groups (except Santa Caterina di Pittinuri) have larger spacings, indicating lower consumption of animal products. The Copper Age groups also show a wide variation that does not align along the two main material culture traditions. The two Early Bronze Age groups have among the largest spacings, over 7.5‰, suggesting diets more vegetarian than that of most Copper Age groups. The Bell Beaker group at Padru Jossu appears substantially overlapping with the Copper Age sites Cannas di Sotto, Seddas de Daga and Serra Cannigas: while there was a slight reduction of the animal proteins, values suggest no sharp change. Two Copper Age groups, Scaba ’e Arriu A and Su Stampu, show a large spacing, comparable to the Early Bronze Age groups of Iscalitas and Padru Jossu B, although their higher δ⁵¹⁵N points to a higher consumption of porcine fats rather than a diet mostly based on plants. It is also to be noted that the three sites that yielded 4th-millennium AMS dates cluster more on the higher-protein and ruminant fat area, whereas Copper Age sites dating from ~2900 BC to ~2400 BC are more diverse in their whole diet while maintaining a fairly good amount of animal protein. This seems to indicate an increasing differentiation from mostly ovicaprine herding to a diversification at different locations, involving an emphasis on either ovicaprine (Scaba ’e Arriu Monte Claro, Seddas de Daga, Serra Cannigas) or swine (Su Stampu, Scaba ’e Arriu A, the single individual at Padru Jossu, Monte Claro phase). This reading is partially supported by the tentative generalizations drawn from the variation in faunal data (chapter 5), and would make sense in a society with intensified circulation of goods, which might encourage a certain degree of specialization.

Looking at the two multi-layered sequences of Scaba ’e Arriu and Padru Jossu (Figure 92), the trend seems to be from more porcine to more ruminant fats, which points to an increase in herding, possibly mobile, with no radical difference in the quantity of ingested foods.
Figure 92. Plot of the means and standard deviation of the spacing $\delta^{13}C_{col-apa}$ in the different phases of Scaba ‘e Arriu and Padru Jossu. Points are color-coded as follows: red, early (Post-Ozieri) Copper Age; blue, later (Monte Claro) Copper Age; green, Bell Beaker; black, Early Bronze Age.

animal protein ($\delta^{15}N$). The single individual from the Monte Claro phase of Padru Jossu has values compatible with high porcine meat consumption, whereas the diet of the Bell Beaker group of Padru Jossu A is more rich in ruminant than porcine fats; however, the overall quantity of animal protein ($^{15}N$) is lower. Finally, the Early Bronze Age phase of Padru Jossu B is characterized by lower consumption of animal products in general. As concerns Padru Jossu, this picture agrees with the faunal evidence (Sorrentino 1982), where ovicaprines are almost exclusive in phase A, while a more balanced presence of the different domesticates is associated with phase B. Unfortunately, no plant remains were recovered, and they may not even have been as culturally appropriate as animal offerings.

The few individuals of Santa Caterina di Pittinuri yielded values more compatible with ovicaprine (ruminant) fats than with porcine fats; this apparently contrasts with the abundant pig remains found as offerings at the entrance area of the tomb, along with signs of food processing, drinking and deer antler (Cocco and Usai 1988; Fonzo, personal communication). This could indicate that rather than offerings of common foods, the pig mandibles might have represented, as the deer antler, special items for ritualized social
settings. If this is compared with the more positive correspondence of faunal and isotopic data at Padru Jossu, we might be identifying the material traces of a phenomenon already suggested based on ethnographic analogy and other kinds of evidence: the transition between specialized, non-convertible prestige and power towards a more generalized prestige based on wealth and maleness (Robb 1994a, 1999). In other words, while in the earlier Copper Age community the rituals related to the ancestors required extra-ordinary goods, and probably specialized foods and professional figures, in the later Bell Beaker and Bronze Age there was a more individualistic and generalized offering of owned animals, where bare presence or quantity was more important than intrinsic quality, and prestige and authority were reflected and constructed through common and convertible material means: the livestock available in the herd.

In conclusion, the data do not support a shift to pastoralism during the Copper Age. They do not, first because there is isotopic evidence for heavy reliance on animals already in the Late Neolithic site of San Benedetto, and in the other 4th-millennium sites, and moreover because there is no evidence for less, but for slightly more plants in the diet. A higher diversification in the type of tended animals (swine and ovicaprines) could be identified in post-2900 BC Copper Age sites, regardless of their material culture affiliation to Post-Ozieri or Monte Claro. No higher reliance on animal husbandry coincided with the Bell Beaker period at the site of Padru Jossu, nor did it with the Early Bronze Age: both large groups considered reliable show a sensibly heavier reliance on plant foods (likely cereals and legumes).

8.2.3. Dietary Variation by Age

The difference in diet between different age groups can provide insights in social perceptions and power relations within a community. It has been suggested for the Neolithic of peninsular Italy that there may have been a rigid class system based on age, as is found in several East African societies permeated by livestock as the most important economic and symbolic capital. Access to livestock would have been also, among other aspects, necessary for the acquisition of wives (Cámara Serrano and Spanedda 2002; Robb 2007: 145-146). On the other hand, following Robb’s suggestion (1999) of a more generalized concept of prestige due to convertible wealth, we could imagine that dietary differences in the Copper Age and
Early Bronze Age societies were less based on age. Subadults have generally wide variation in isotopic values due to the physiology during growth. This, coupled with an age assessment not very accurate, can be misleading. So, only mature/senile and adult values have been compared, with special reference to $\delta^{15}N$ and the spacing $\delta^{13}C_{col-apa}$, which as discussed above are the best dietary indicators (Figure 93). The data for Su Stampu are not reliable due to the scarce number of individuals, only two adults and one senile; moreover, one of the adults has a very abnormal spacing, over 13‰, deriving from an apatite $\delta^{13}C$ which is hard to explain. Leaving this aside, and besides a fair amount of variation, the Bell Beaker-Early Bronze Age groups show a consistent trend of higher $\delta^{15}N$ and smaller spacing for seniles as compared to adults. This seems likely to be due to higher consumption of meat, which is likely mostly ovine/caprine, since pork would likely affect the spacing making it larger. Such a clear trend is not visible, or not as notable, in the Late Neolithic and Early Copper Age groups available. At San Benedetto, the slightly larger spacing for the elderly could be due to higher amounts of pig fat, whereas at Scaba 'e Arriu A it seems that adults have more animal protein, or protein from higher-trophic level animals as pigs. This, however, is unlikely because we should find it reflected in a larger spacing.

*Figure 93. Barcharts of the variation in $\delta^{15}N$ and in the spacing $\delta^{13}C_{col-apa}$ by age, expressed as the difference between the mean of all adults and the mean of all senile/mature values. Values lower than zero indicate higher $\delta^{15}N$ and smaller spacing in senile/mature individuals. The numbers next to each barchart are the observations of adults:senile/mature.*
These phenomena, identifiable only tentatively due to the limited number of samples per subgroup, could lend support to a higher differentiation based on age in Bell Beaker and Early Bronze Age groups. In turn, this is compatible with generalized increasing differentiation, if honoring the elders could be functional to incipient, or attempted, trans-generational transfer of authority in Big-Man societies.

8.2.4. Dietary Variation by Sex

As age and possibly even more, sex, used as a necessary approximation for gender, is a very important factor evaluating differences in diet related to social and power relations. As underlined in chapter 4, gender studies in Sardinian prehistory are moving their first steps. Stable isotopes can be powerful tools to gain clues of the gender differences within a given community. As for age, differences between males and females in $\delta^{15}$N and the spacing $\delta^{13}$C_{col-apa} have been visualized in barcharts (Figure 94). Similarly, though present in the chart for the sake of completeness, groups of two or three individuals (Cannas di Sotto, Su Stampu ‘e Giuannicu Meli, Concali Corongiu Acca) are not considered for extracting social information.

$\delta^{15}$N values show a relatively persistent higher trophic level of protein sources in males, at most sites; exceptions are San Benedetto (Late Neolithic) and Padru Jossu B (Early Bronze Age), where average ratios for males and females are fairly similar, and especially Seddas de Daga, which shows an inverse ratio with $^{15}$N-enriched protein sources for females. San Benedetto shows similar $\delta^{15}$N and smaller $\delta^{13}$C spacing in males. Since we would expect also $\delta^{15}$N to be high if actual protein quantity was much different, it can be tentatively suggested that the kind of products was the point differentiating diet in the two sexes: males would be consuming more meat and/or milk of ruminant origin, whereas females would be eating mostly pork meat. Females would also be consuming an overall lesser quantity of animal products, since pork, being omnivorous, would generally cause $\delta^{15}$N values to be higher than lamb, beef or milk would.

The largest difference in $\delta^{15}$N is found at Scaba ‘e Arriu A, where the large $\delta^{13}$C_{col-apa} spacing for males points to a substantially higher quantity of pork meat as compared to females (ruminant lipids would tend to reduce the spacing). In the following phase Monte
Claro at the same site, such a gap is much reduced, and the difference in spacing virtually none. The abnormal situation among the individuals from Seddas de Daga, where much higher $\delta^{15}$N in the female average is strongly influenced by individual GA 36, which is sharply different from the group and might be an outsider coming from more arid lowlands.

The Bell Beaker group from Padru Jossu (A) show consistent values indicating that males had a fairly higher intake of ruminant proteins and fats, which points to the importance of milk and fits well the possible indication of differential mobility identifiable in the $\delta^{18}$O values. Besides this group, the following phase at Padru Jossu (B) and the other Early Bronze Age group of Iscalitas have spacings compatible with a slight male prevalence in protein consumption, but much reduced (in fact, Padru Jossu B shows negligible $\delta^{15}$N difference). It would seem, in sum, that intra-site variation based on sex was, from the Bell Beaker onwards, mostly due to ovicaprices (milk/meat).

Figure 94. Charts of the variation in $\delta^{15}$N and in the spacing $\delta^{13}$C_col-apa by sex, expressed as the difference between the mean of all males' and the mean of all females' values. Values lower than zero indicate higher $\delta^{15}$N and smaller spacing in male individuals, and vice versa. The numbers next to each barchart are the observations of females:males.
8.2.5. Bone Apatite δ¹⁸O: Climatic Variation

In order to investigate climate change and disentangle what is due to geographic variation and what to change over time, the δ¹⁸O values corrected based on local precipitation are used. Tooth enamel values have not been considered due to the small number of groups, and of teeth per group, and of same type of tooth per group, which makes any reliable reconstruction impossible. The bone apatite values have been plotted with the median of the 2σ range of the AMS date(s) available for each group (Figure 95). The plot indicates both variation over time and within groups. The groups already identified on the raw values are somewhat confirmed, with some differences. Considering broad cross-cultural patterns and consistent ethnohistoric evidence in the Mediterranean, females are more likely to have been more sedentary when there is a substantial difference in values according to sex. Under this assumption, considering female values only, the differences along the time span of interest appear enhanced (Figure 96). This is likely due to the effect of mobility towards cooler/rainier areas.

![Figure 95](image_url)

*Figure 95. Plot of corrected apatite δ¹⁸O vs. radiocarbon years cal BC, as an indication of climate change in southern-central Sardinia between ~4000 and ~1900 BC.*

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in drier phases, which would tend to homogenize values in males. No alternative explanations, such as a prescribed separation of water sources for men and women, seem likely; physiological causes would work in all groups, whereas some do not show any clear difference by sex.

The results of corrected $\delta^{18}O$ visually matched the overall division in climatic phases autonomously derived from the literature review on climate change in the Western Mediterranean. The same phases identified by synthesizing qualitatively the previous evidence (chapter 3) were slightly adjusted in their chronology according to the isotopic results (Table 25). Based on these groups, ANOVA was performed to assess the significance.
of the differences between these groups. The test of statistical significance of the difference between groups indicated it was 30.16 times (F-ratio) larger than the difference within groups, at the 95.0% confidence level ($p = 0.00$). This indicates that despite the fact that each period is represented by a few groups, such periods defined based on previous literature and slightly modified according to the new chronological data are highly unlikely to be random “artifacts”. Multiple range tests also showed that the periods 2850-2600 cal BC and 2350-2200 cal BC, the identified dry phases, are statistically, not only visually, similar.

In Table 25, besides the details of the chronological adjustments to the periods identified, there are the averages of corrected $\delta^{18}$O for each period, and the reconstructed rainfall. The reconstructed rainfall per period, since it is calculated using the $\delta^{18}$O average of all sites, is to be considered as an average of the rainfall variation at all the sites considered.

The quantification in climatic terms chosen here, in terms of annual average precipitation, is based on the consideration, already discussed in chapter 6, that even though rainfall generally correlates better with $\delta^{18}$O values in tropical areas, a linear relationship has been measured in the Eastern Mediterranean, which has a similar, highly seasonal pattern of precipitation (Bar-Matthews, et al. 2003; Koch 1998; Rozanski, et al. 1992). The rainfall variation is therefore a rough approximation, since temperature did have some effect that cannot be quantified as of yet.

The data presented here are relevant in supporting and adding evidence to the previous data. They are particularly valuable for a number of reasons: the large majority of the data coming from pollen analyses always have the problem of reflecting environmental changes that can be largely human-made and independent from broad climatic patterns; on the contrary, $\delta^{18}$O variation can be affected by human modifications of the environment (intense or special land uses, erosion etc.), but in the large majority of cases reflects fairly well the meteoric water. This can be considered true especially in Sardinia, where there are no long and perennial rivers (as the long rivers fed by Alpine glaciers, or the Nile: D'Angela and Longinelli 1990, 1993; White, et al. 2004). For the most part streams are short and seasonal, and most of the drinking water comes from local water tables and springs, all unlikely to have $\delta^{18}$O values radically different from the ground source.

Thanks to the several AMS dates, the periods identified in Sardinia have relevance in that they build a centennial-scale climatic framework of interaction with human practices in the shaping of a cultural environment and landscape. This overcomes a chronic problem
Table 25. Comparison of the climatic periods hypothesized based on previous literature and climatic periods identified based on δ¹⁸O from Sardinian samples. In the columns on the left: mean corrected δ¹⁸O values and average annual rainfall for southern-central Sardinia, calculated with the equations in Iacumin et al. 1996, Longinelli 1984, and Bar-Matthews et al. 2003 (see text).

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stemming from the archaeological use of paleoclimatological and paleoenvironmental data that aim at geological time frames rather than to the times of humans (Bintliff 2002; Dincauze 2000: 23-27), which are related to lives, generations, and the stretch of lived and living memory. The confirmation of the existence of climatic phases likely to have involved sizable changes in precipitation legitimizes the call for more consideration of climatic change in the understanding of cultural and economic change in Western Mediterranean later prehistory. Far from meaningless climatic determinism, the atmospheric conditions must be taken into account as factors putting constraints on human actions and affecting randomly the
ever-changing anthropic landscapes. The point is therefore not to find out whether environmental change was due to climate or to human impact, but to disentangle the interaction of the two, within cultural environmental contexts. The depth of analysis of human agency and experiences in mutual interaction with an environment in continuous evolution that these climatic data allow is also more likely to have a bearing in the applied anthropological significance of understanding patterns of sustainability and resilience in the past, in order to inform policy for the future (Crumley 1994; van der Leeuw and Redman 2002).

One limitation of this dataset is that the climatic periods are in fact represented by a few sites each, and they are likely to reflect mostly the Campidano lowlands, Marmilla and the Southwest, where the bulk of samples were collected. Taking a closer look at what the data involve in terms of change of precipitation over time (Figure 97), males’ $\delta^{18}$O values turned out to be often more depleted than females’, with corresponding reconstructed rainfall

![Figure 97](image_url)

*Figure 97. Comparison of the possible reconstructed rainfall change in southern-central Sardinia as calculated from corrected $\delta^{18}$O, based on values measured on males (blue) females (red), and the average of all individuals (dashed line).*
levels higher, for most of the 3rd-millennium BC groups. This fits the model of seasonal movements with the flocks if a scenario is maintained, suggested based on archaeological evidence and ethnohistoric generalizations, that males were more mobile than females. This discrepancy is especially remarkable in the 2350-2200 BC period, identified as drier, covering the two phases at Padru Jossu, which points to a longer period of time that most males would spend away from the village or camp, or a location further away that bears a very different isotopic signal, something similar to long-distance transhumance of modern Sardinia and Italy.

The average rainfall variation detected pinpoints the importance of the two dry phases documented 2850-2600 BC and 2350-2200 BC. The first had been suggested based on soil morphology and pollen studies in central Italy (Drysdale, et al. 2006; Magri and Sadori 1995), Tunisia (Zielhofer, et al. 2004) and possibly also in Israel (Bar-Matthews, et al. 1997), and through hydrology in France (Magny 1993); it is here further defined chronologically to the 29th-26th centuries BC, lasting approximately 350-250 years. The second dry spell, that has been brought to the attention of the scientific community for its claimed disastrous effects on the complex states of Southwest Asia (Dalfes, et al. 1997; Weiss, et al. 1993; Weiss 1997), recognized also in the West in central Italy, Tunisia and Catalonia (Drysdale, et al. 2006; see also references in table 2, ch. 3), appears to find one more independent trace in the Sardinian data. Its tentative duration from the present dataset seems to span the period 2350-2200 BC, possibly about 150 years.

As opposed to an average precipitation in other periods 4000-1900 BC between ~800 and above 1000 mm/year or more, the rainfall reconstructed for these two periods is slightly lower than 650 mm/year (average of all sampled individuals). Considering the average values calculated only on females (Figure 96), more likely to reflect faithfully local values not contaminated by drinking water from other areas, the values would have dropped lower than 500 mm/year. Such a difference within a few centuries is likely to require significant adjustments in the way of making a living, and to have significant effects on the environment, particularly if human-made disturbance of some kind (fires, soil overuse, overgrazing, mining) had already rendered the ecosystem more fragile.

While other Western Mediterranean areas have been investigated (among others Carcailllet 1998; Carrión, et al. 2003; Maggi 1998; Quilès, et al. 2002; Reille, et al. 1999b; Terral and Mengüal 1999), there is nothing comparable to such evidence coming directly
from Sardinia. Some projects are currently under way that should provide new environmental
data from Lake Baratz (Tanda, personal communication) and the Cabras Lagoon (A. Usai,
personal communication). However, at the moment it is only possible to infer for Sardinia
those same mechanisms that have been detected in many other areas. Among these
phenomena is the progressive spread in the 4\textsuperscript{th} and increasingly in the 3\textsuperscript{rd} millennium BC of
evergreen oak, well adapted to fires, and probably of olive tree and Mediterranean scrub
species, and the substantial erosion in occasion of particularly arid events such as those
identified, with the consequent massive infilling of the stream beds and the coastal lagoons.
This was caused by the exposure of topsoil, likely due to clearance through fire and grazing.
Mining also involves deforestation, since it may require cracking and removing large
quantities of rock to reach or extract the ores, which is achieved by heating. A likely
consequence of erosion would have been that previously rich estuarine basins would have
become shallow, stagnant brackish water lagoons, with both positive and negative side
effects, and the productivity of the land in general would have become severely diminished.

\textbf{8.2.6. Note on the Chronology of Prehistoric Sardinia 4000-1900 BC}

As stated already in the section on materials and methods of the isotopic project, the
first goal of AMS dating of the remains is that of providing a reliable chronological
framework for the dietary and climatic reconstruction. In this regard I emphasizing how the
key site of Is Aruttas, previously dated through association of cultural materials but no
reliable stratigraphy, turned out to be of a much later date. This outcome incidentally
furnished the first isotopic evidence on Nuragic diet around the Middle to Final Bronze Age,
but made the data irrelevant for the purpose of this study. This loss is particularly important
in that it makes it impossible to compare the inland site of San Benedetto with another Late
Neolithic site, to assess the possible variation due to seafood. The same holds for Montessu,
where the individuals supposed to pertain to the Early Bronze Age were dated to the Middle
Ages, showing a case of late reuse of the tomb, and the single individual supposed to be Late
Neolithic was so altered that it did not have any collagen left.

Broader contributions, however, stem from the new dates for the chronology of
Sardinian prehistory in the 4\textsuperscript{th}, 3\textsuperscript{rd} and initial 2\textsuperscript{nd} millennia BC. In fact, the last work of
critical synthesis (Tykot 1994), while providing a frame of reference that is still valid today,
left open a few questions, particularly regarding the Copper Age, for which only one date was then available, with the addition of six determinations from Monte d’Accoddi that could be only inserted in an endnote because it was published after the article was written (Tiné 1992b).

To my knowledge, the total number of available radiocarbon dates for the period of interest Late Neolithic through Early Bronze Age (Figure 98), increased surprisingly little, from 23 up to the mid-1990s to 39 prior to the present study (Figure 99), which added 15 (without including the determinations that yielded later dates, AA-64836, AA-64824, AA-64834, from the Middle Bronze Age to the Middle Ages, and one that was processed by mistake, and yielded an unreliable raw date with an error of over 500 years, AA-64832). Some of the new dates come from the efforts of the Department of Experimental Biology, Anthropology section, of the University of Cagliari, on the collections curated at their facilities, either published (Manunza 1998; Marini, et al. 1997a; Sanna, et al. 1999) or courteously made available by Dr. Rosalba Floris. Among the previously available dates, some (I-14,774 from Duos Nuraghes and Gif-243 from Bruncu Maduli o Madugui) have such large errors that their information potential is nowadays minimal when compared with the new determinations.

The chronology of Monte d’Accoddi is important for the understanding of cultural developments on the whole island, although definitely outside the southern area that the present stable isotopic study focuses on. While two determinations (UTC-1464, UZ-2475/ETH-4716) agree with the Early Copper Age chronology of the second half of the 4th millennium BC, four dates are from layers that follow the construction of the first platform and temple. The overwhelming prevalence of typical Ozieri pottery reported in the layers earlier than the building, and the presence of Filigosa and Abealzu pottery in layers above the building, has led for a while to divergent attribution of the construction itself: Tiné and Traverso (Tiné 1992b; Tiné and Traverso 1992a) held firmly the opinion that the first monument post-dates Ozieri, and has been later suggested to be Sub-Ozieri (Tiné 1997); Lo Schiavo (1992), instead, read the evidence and especially the radiocarbon dates to conclude that the temple of phase I was actually built in Ozieri times, although she includes Ozieri dipinto, painted ware, which is today considered Sub-Ozieri. The retrieval of Sub-Ozieri pottery underneath the partial collapse of the phase-I red temple does place a terminus post
Figure 98. Map of Sardinia showing the location of sites for which radiocarbon dates are available for the period 4000-1900 BC. Map by the author, based on cartographic material from S.A.R. Sardegna consortium, with kind permission.
Figure 99. Plotted radiocarbon dates available for Sardinian prehistory 4000-1900 BC, including previous determinations and those presented in this dissertation.
quem for this event (Tiné 1997), but does not necessarily mean that the construction and use of the temple itself, or of the platform, is associated with Sub-Ozieri: the building may have been erected in Ozieri times, which the radiocarbon dates refer to, and used during the transformations of pottery style into Sub-Ozieri.

These issues have profound implications, besides the surprisingly early date for the monument itself; if Tiné, the excavator, is correct regarding the stratigraphy of the dated samples, this would imply a much earlier date for the end of the Ozieri style than all previous evidence supports. In fact, all previous dates for classic Ozieri pottery, coming from Sa ’Ucca ’e su Tintirriolu, Grotta su Guanu, Filiestru (Tykot 1994) and San Benedetto (Sanna, et al. 1999) cluster in the first half of the 4th millennium cal BC, with one slightly earlier at the end of the 5th millennium (Q-3027) and one slightly later around the very middle of the 4th millennium (R-1785), although the stratigraphy of the latter is not clear. Such an early beginning for Post-Ozieri mostly undecorated pottery does not fit the current reconstruction, especially from the dates added by this study, which fall well in the second half of the 4th millennium cal BC (AA-72148, Santa Caterina di Pittinuri, AA-64825, Cannas di Sotto) and up to around the mid-3rd (AA-64826, Mind’e Gureu). This can be explained if:

a) the radiocarbon dates from the layer of occupation after Monte d’Accoddi phase I, from wood in deposits around the building, are actually Ozieri, possibly from old wood used later in Sub-Ozieri or Filigosa times, or from wood fragments picked up with soil and potsherds and for some reason ended up in such a location; this seems unlikely due to the high consistency of the four dates;

b) the Post-Ozieri, undecorated style, in its earliest aspect of Sub-Ozieri, started much earlier at this site and was adopted slowly in the rest of the island, after remaining relatively confined to the northwestern tip of Sardinia, since the contemporary dates at Sa ’Ucca, Filiestru and Grotta su Guanu appear to pertain to more ‘classic’ Ozieri style; this alternative is, if possible, more disconcerting as the first;

c) the layers conclusively labeled as Sub-Ozieri/Filigosa could be closer to Ozieri than clear-cut classifications can express. As already observed by Tanda (1992c), in the early report Tiné states, regarding the supposed Post-Ozieri layer III, that “ceramic materials, from this layer up to layer V, do not show significant differences and are characterized by a
consistent presence of sherds decorated in the classic Ozieri style, and by many others deprived of decoration, but with brown or rosé surfaces, well polished”, and corrects this first impression in a side note (Tiné 1992a: vi). Therefore, it seems more likely that the dates refer to occupation and use of the first platform while Ozieri, or some initial Sub-Ozieri pottery, was still used (Lo Schiavo 1992), placing it no later than ~3550 cal BC. Unfortunately, no Harris matrix has been published where a clear relationship between the platform’s walls and the soil layers is clear.

In addition to the dates from the known cave sites (Sa ’Ucca, Filiestru, Su Guanu), from Contraguda (Boschian, et al. 2002), and from San Benedetto (Beta-72233, Sanna, et al. 1999), the new dates add information for a more accurate dating of the end of the Ozieri ‘culture’, or of the use of Ozieri pottery: none of all these dates’ 2σ range is later than 3366 cal BC, whereas the earliest end of the Post-Ozieri range is 3518 cal BC. This places the likely shift in pottery style closer to ~3450-3400 cal BC, refining the tentative date ~3200 cal BC suggested by Tykot (1994) with a question mark, on the basis of the scarce evidence available in the mid-1990s.

The following ceramic styles, defined by the main Sardinian prehistorians as Sub-Ozieri or Final Ozieri, Filigosa and Abealzu, all part of a gradual change with no breaks (Melis 2000d) which are referred to as Post-Ozieri, were placed in an overall chronological sequence through their stratigraphic relationship with preceding and following styles, to between a tentative 3200 cal BC and another tentative 2700 cal BC (Tykot 1994). No dates reliably associated with these styles were available until the two later dates from Monte d’Accoddi (UTC-1464 and UZ-2475/ETH-4716), one from Santa Caterina di Pittinuri (Beta-72235), and those from Ispiluncas and su Coddu-Canelles (R-2772 the former, LTL-295A, LTL-404A, LTL-1104A, and LTL-1105A the latter site: Melis, et al. 2007). This dissertation research added one date from Santa Caterina, room C (AA-72148), earlier and non-overlapping with the one available, whose context is unfortunately unclear. More Post-Ozieri dates were obtained from Cannas di Sotto (AA-64825), Serra Cannigas, tomb A (AA-72151), Scaba ’e Arriu (AA-72793 and AA-64828) and Mind’e Gureu (AA-64826). Based on this pool of reliable dates, the time during which Post-Ozieri styles (Sub-Ozieri, Filigosa and Abealzu) were in use spans, in 2σ ranges, from 3518 cal BC through 2210 cal BC, with the first dates from Monte d’Accoddi, after the phase-II platform was built, and the last one from su Coddu-Canelles. Such a date is considered suspiciously late by Melis (2007), but it is not
too much later than the one from Mind’e Gureu, which comes from a burial that has been attributed to the Abealzu style by the publishers (Fonzo and Usai 1997) and to Melis’ phase C. This, tentatively defined Filigosa II, is the last well-represented phase of her ceramic sequence, since phases D and E were represented by comparatively few assemblages. The tentative span, in synthesis, seems to be longer than previously anticipated, from ~3450-3400 cal BC to somewhere between 2500 and 2300 cal BC.

Concerning the sequence of phases within the Post-Ozieri tradition, compared with Melis’ reconstruction, I think the reliable dates from su Coddu-Canelles pin down the chronology of the Sub-Ozieri aspect to the second half of the 4th millennium BC. This supports the attribution of the earliest dates from Monte d’Accoddi to the classic Ozieri ceramic aspect rather than the Sub-Ozieri, in line with the latest date from Contraguda, with the dates from Sa ’Ucca de su Tintirriolu, and especially parallel to the one from San Benedetto. Therefore, the beginning of the Sub-Ozieri style can be placed in the mid-4th millennium BC. Furthermore, the new dates help outline roughly the chronology of the following aspects, as defined by Melis (2000d). The dated assemblages evaluated as most homogeneous are Scaba ’e Arriu and Mind’e Gureu, both attributed to phase C, hypothetically defined by the author as “Filigosa II”: the dates point to the period 2800-2400 cal BC. Consequently, an earlier aspect, possibly Melis’ “Filigosa I”, can be placed before 2800 cal BC and after the two earlier dates from Canelles, which mark assemblages substantially Sub-Ozieri, at approximately 3200-3100 cal BC. This period would correspond to the lower layers at Santa Caterina di Pittinuri. As anticipated in chapter 4, it seems that the phase defined Abealzu, long established in the literature, is represented by no more than few assemblages and a few diagnostic types, and does not deserve a distinct identity. The chronology seems to fit this reconstruction.

The Monte Claro style was as well only tentatively placed between 2700 and 2200 cal BC, with no radiometric proof, since only one radiocarbon date was available, from the Grotta di Acquacadda, or Acqua Calda (R-677), which was suspiciously late, but still judged not impossible (Tykot 1994). The present project added three dates, from the Monte Claro depositions at Scaba ’e Arriu (AA-64829), the cave II of Seddas de Daga (AA-64830) and from the basal layer at Padru Jossu (AA-72790). These dates give a comprehensive potential 2σ-based span between 2866 and 2235 cal BC, which is clearly largely overlapping with Post-Ozieri. The series of radiometric measurements presented here therefore document
beyond doubt the reconstruction already suggested by Contu (1989), of a contemporaneous existence of the two styles on the island. The beginning of the Monte Claro style can be placed around 2800-2600 cal BC, confirming Tykot’s informed assessment (~2700), and its end possibly slightly earlier, at ~2350 cal BC, at least in the South, as documented at Padru Jossu. The three dates coincide remarkably with the dates for the Fontbouïsse style of Southern France (Centre de datation par la radiocarbone UMR 5138: Archéométrie et Archéologie: Origine 2007), with which the Monte Claro has long been compared, providing support to the hypothesis of a direct connection with movement of groups and styles between the two areas.

Furthermore, a few points can be made regarding the geographic evolution of the distribution of the two traditions. While dates are needed from the North, especially the large excavated villages such as Biriai and Monte Baranta, in the South all three dates are earlier than the Post-Ozieri date from Mind’e Gureu. The dates from Padru Jossu and Scaba ’e Arriu are particularly significant, since they are relatively close to each other and close chronologically. This helps defining the changing distribution of Monte Claro pottery widening from the Southern plains to the interior, possibly beginning in the 28th-27th century cal BC, until around 2500-2400 cal BC it had reached the southern Marmilla region, where the Monte Claro burials of Scaba ’e Arriu were at a distance of less than 20 km from communities who still used Post-Ozieri pottery and further inland erected in great numbers the complex statue-menhirs and the megalithic burials at Pranu Muttedu. This area is also characterized by intense Monte Claro presence, which through these dates we can infer must have been settled after the mid-3rd millennium cal BC and occupied for a relatively short time. Hypothesizing that the adoption (or importation) of Monte Claro pottery in the highlands occurred from two different routes, the first directly from the southern lowlands and the second from the Western lowlands up to the Tirso valley and then east and south, we could then justify the distribution of the sub-styles: a southern one, and another that covers the West and the Nuoro area (Depalmas 1989; Ferrarese Ceruti 1989: 57-59; Lilliu 1988a: 166-177). A sort of borderline could have been identified near Orroli (Sanges 1989).

The dating of the Bell Beaker in Sardinia was based up to now only on stratigraphy and correspondence with the European mainland, and had been hypothesized by Contu (1989) to start in the 29th century cal BC, and by Tykot (1994: 125, 129) tentatively at ~2700 cal BC, parallel to the Monte Claro ‘culture’. The two dates from Padru Jossu phase A (AA-
72152, AA-72153) suggest, at least for this site and area, a later chronology, 2463-2201 cal BC (2σ range for the two dates combined). Since there are tight dates from the preceding Monte Claro layer and from the following Bonnanaro A (called undecorated Bell Beaker by Ugas 1998), the time of use of the burial by classic Bell Beaker users can be safely limited to a few generations, probably within the 24th century cal BC. How much this can be applied to the rest of the island is to be ascertained through as many radiocarbon determinations as possible from different locations, with associated ceramic phases. Judging from the style, which is considered to be already mature, since in Sardinia the aspects considered early and middle Bell Beaker are present only sporadically (Atzeni 1996a), it seems that Padru Jossu A represents a later aspect of this style that connects Sardinia with central Europe via central Italy, characterized by the frequent presence of handles, of polypod vessels, and the substantial number of undecorated ceramics (Ferrarese Ceruti 1981a: lvii-lviii; Ugas 1998). Therefore, the chronology is strictly valid for this specific stylistic aspect. I expect that more radiocarbon dates in the future may pin down as well the timing of the so-called “maritime” Beaker style, which is found at several sites, particularly on the West coast, from Alghero down to the Sulcis-Iglesiente area, and of the aspects typical of the Southwest, which are likely to be later. We can therefore place this phase in the 24th century cal BC, and the previous phases possibly within a few centuries earlier, so that an overall estimate of the duration of the classic Bell Beaker style in Sardinia can be between ~2500 cal BC and ~2250.

The dating of the Early Bronze Age style Bonnanaro A (or Corona Moltana) was assessed up to the 1990s through comparison with the Polada contexts of Northern Italy and directly through two radiocarbon dates, from Filistru and Sisaia (Tykot 1994: 125). Five more dates are now available, one from Concali Corongiu Acca, II (AA-72150), two from Iscalitas or Is Calitas (Beta-107558 and AA-72149), and two from Padru Jossu, phase B (AA-72791 and AA-72792). The comprehensive 2σ-calibrated range is between 2548 and 1899 cal BC. The earliest limit, in reality is probably due to the large error in the raw date from Sisaia (±100): in fact, the dates from Padru Jossu B, which are constrained by the previous phase, suggest the end of Beaker decorated pottery – at least in the central-southern lowlands - more around 2350-2250 cal BC, with the beginning of assemblages that resemble more the typical Bonnanaro A, although gradually and with no sharp breaks. A somewhat later phase is that of Iscalitas and Concali Corongiu Acca, with 2σ range between 2287 and 1899 cal BC, pointing to a duration of classic Bonnanaro A style centered around the last two
centuries of the 3rd millennium cal BC. The transition to the Middle Bronze Age Sa Turricula style seems to have occurred from the beginning of the 2nd millennium, as shown by the available dates (e.g., Q-3031 from Filiestru, R-963α from Sa Turricula, unknown lab # from Cannisoni and Gastea near Seulo, AA-64836 from Montessu, tomb 10), spanning from 1939 to 1441 cal BC (2σ range), overlapping with some dates already Nuragic.

In light of this new evidence, the date from Acquacadda or Acqua Calda (R-677), associated with Monte Claro pottery, fits perfectly the chronology for Bonnanaro A, while it does not match the dates for Monte Claro, which are no later than ~2300 cal BC at Padru Jossu, where the date is constrained by the following phase Beaker A. Therefore the cave, similarly to several others in the Southwest (e.g. Baieddus de sa Sedderenciu near Tani: Ferrarese Ceruti and Fonzo 1995), must have been used for burial in both periods, and possibly the absence of stratigraphic reliability led to the misattribution. Radiocarbon date Q-3029 from Filiestru is fully compatible with the chronological range of the Post-Ozieri cultural aspects, rather than Monte Claro, which starts later.

The site of Noeddos deserves a separate discussion. The material culture from this site was clearly indicated by the excavator as being outside common classifications, and this needs consideration together with the chronometric evidence. The earliest radiocarbon date (Q-3069) finds its best fit in the Monte Claro chronology. Since the remaining two dates from phase I (Q-3071 and Q-3168) are much later, with a 2σ-calibrated range between 2194 and 1698 cal BC which point to a final phase of the Early Bronze Age or even initial Middle Bronze Age, they do not seem to be compatible despite their being all associated with phase I. The first date relative to phase II (Q-3167) is instead very close to them. The dates from phase III (Q-3070) and IV (Q-3169) follow, identified as pertaining to the Middle Bronze Age phases Sa Turricula and Nuragic, in turn followed by the remaining date from phase II (Q-3868). Some elements could actually point to a Monte Claro identification for phase I: in fact, the excavator states that “reddish ware [dominant in phase I] was better represented in Monte Claro”, but rules out the option due to the absence of fluted and grooved ware (Trump 1990: 15). The element that leads him to assimilate this phase to Bonnanaro A is the elbow/angled handles, although they are said to be typical of phase II (Trump 1990: 11). Also, despite highlighting how the tripod, the dominant type in phase I, does not correspond to the Ozieri, nor to the Bonnanaro A shape, he does not mention the possibility of Monte Claro tripods. These, and other sherds, seem actually comparable to specimens from several
excavated Monte Claro sites (Castaldi 1999: 270, Table XXXII, n. 3; Locci 1988: 66, figure 2, n. 8, 9, 10; Moravetti 2002: 158, figure 118, n. 10). Finally, the location of the site corresponds to a typical preference for elevated and hilltop sites documented for the Monte Claro period, and the unexplained rectangular buildings (Webster 1994) do not seem to occur in Sardinia after the Copper Age until possibly the 1st millennium BC.

I believe that the occupation of the area during the Monte Claro phase, relative to at least some of the rectilinear structures, may have been followed by abandonment or sporadic use during most of the Early Bronze Age. At the end of this phase or the beginning of the Middle Bronze Age, some 500 years later, the site may have been reoccupied, the nuraghe was built, and some rectilinear buildings cleaned of the sherds and dirt (which possibly filled the adjacent trench in square Gb, the main repository of phase I materials). They were probably only reutilized, not built, in the later Middle Bronze Age. The radiocarbon dates, if this was the case, would date the occupation, not the construction, of the rectilinear structures, which conform fully to the tradition of Monte Claro-pottery users and some of the final Post-Ozieri. A deeper examination of both the ceramic assemblages and the site-formation processes could clarify the situation and verify the plausibility of this hypothesis, although the details of the stratigraphy contextual to the radiocarbon dated specimens are not provided.

In conclusion, the integration of the new dates allowed a refinement (Table 26) of the current chronological models for Sardinian prehistory, as drawn by Tykot (1994) and Contu (1998) in the early to mid-1990s and still generally valid. Among the important points:

1. the Ozieri style seems to have ended considerably earlier than previously assessed;
2. the Post-Ozieri tradition, rather than a short transitional phase of a few centuries, appears to have a millennium-long duration;
3. the chronological correspondence of Monte Claro style with similar well-dated Fountbouïsse aspects documented in southern France is for the first time supported by radiometric measurements, and so is its being partially contemporary with the last phase of the Post-Ozieri tradition;
4. the Bell Beaker style has been dated for the first time in Sardinia;
5. the duration of the Early Bronze Age has been further refined; and
6. the new evidence, finally, enabled the reconsideration of the chronological sequences of two key sites, Monte d’Accoddi and Noeddos.
Table 26. Proposed chronological sequence for Sardinian prehistory 4000-1900 BC, updated with the new dates including those obtained within the present dissertation project.

<table>
<thead>
<tr>
<th>Calibrated years BC (after Tyson 1994 with modifications)</th>
<th>Chrono-cultural phase</th>
<th>Culture (ceramic style) Northern Sardinia</th>
<th>Culture (ceramic style) Southern Sardinia</th>
<th>Period covered by this study</th>
</tr>
</thead>
<tbody>
<tr>
<td>4200</td>
<td>Middle Neolithic</td>
<td>Bonu Ighinu</td>
<td>Bonu Ighinu</td>
<td></td>
</tr>
<tr>
<td>4100</td>
<td>Late Neolithic</td>
<td>Ozieri</td>
<td>Ozieri</td>
<td></td>
</tr>
<tr>
<td>3900</td>
<td>Early Copper Age</td>
<td>Sub-Ozieri</td>
<td>Sub-Ozieri</td>
<td></td>
</tr>
<tr>
<td>3800</td>
<td></td>
<td>Filigosa</td>
<td>Filigosa</td>
<td></td>
</tr>
<tr>
<td>3700</td>
<td></td>
<td>Abealzu</td>
<td>Monte Claro</td>
<td></td>
</tr>
<tr>
<td>3600</td>
<td>Late Copper Age</td>
<td>Beaker</td>
<td>Beaker</td>
<td></td>
</tr>
<tr>
<td>3500</td>
<td>Early Bronze Age</td>
<td>Bonnanaro A</td>
<td>Bonnanaro A</td>
<td></td>
</tr>
<tr>
<td>3400</td>
<td>Middle Bronze Age</td>
<td>S. Rosti</td>
<td>S. Rosti</td>
<td></td>
</tr>
</tbody>
</table>

8.2.7. A Closer Look into Sample Groups

8.2.7.1. San Benedetto

Internal patterning within the sample of the San Benedetto community allows us to gain tentative insights into differentiation in dietary and mobility practices by subgroups. The only clear, meaningful cluster in the scatterplot of $\delta^{15}$N vs. the spacing $\delta^{13}$C_{col-apa} (Figure 100) appears to be that of adult males: they have consistently the smallest spacings, whereas $\delta^{15}$N
values are at the center of the range for the whole group. This can reflect a diet higher in ruminants. These could be cattle, more likely sheep and goat, and might also reflect milk consumption. The fact that $\delta^{15}$N values are not the highest, however, seems to indicate that meat consumption in general was not necessarily prevalent in males. In fact, several females probably consumed more pork, reflected in somewhat larger spacings and higher $\delta^{15}$N.

The graph of apatite $\delta^{13}$C vs. $\delta^{18}$O (Figure 101) replicates the dietary difference depending on ruminant-derived products (more depleted $\delta^{13}$C in males). More interestingly, all senile and infant $\delta^{18}$O values, independently from their diet, align around -4‰, whereas most adults show more depleted values; this is compatible with a group that moves seasonally to higher elevations, identifiable in some of the adults, whereas the elderly and the kids remained in the village. This is a strong indication for transhumance, although it is impossible to measure the range of such movements. They were likely fairly small, since relatively high mountains are close by, due to the steepness of the slopes. It is interesting that although males show a distinct diet, to be attributed to distinct kind of animal product,

![Figure 100. San Benedetto (Late Neolithic) Scatterplot of collagen $\delta^{15}$N vs. the spacing $\delta^{13}$C_{col-apa} by sex and age groups.](image)

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females moved with men, as indicated by similar $\delta^{18}O$ values; this in turn could either lend credit to the hypothesis of a transhumance requiring certain nuclear families to move together keeping their division of labor in the summer pastures, or simply that women were herding stock with men.

8.2.7.2. Santa Caterina di Pittinuri

Due to the scarce number of human individuals accessible, further decreased for collagen due to the poor preservation of some of them, not much can be detected regarding internal patterns in the community. The presence of faunal samples, on the other hand, even if also few in number due to preservation, makes a few tentatively inferences possible (Figure 102). The red deer, as expected from a forest feeder, has low $\delta^{15}N$; the swine, showing comparable values, likely lived in a similar environment, which means that either it was a wild boar, or it was a partially controlled pig fed in the forest. This practice is documented in Sardinia at least from the Middle Ages up to now, and fits the inference made by Albarella et
al. (2006) based on morphometry, that Sardinian prehistoric pigs were not kept under strict control in the village, as for instance in Neolithic Greece (Halstead 2006: 45), but left semi-wild, probably as today, allowed to interbreed with the wild boars. Within the expected range are also the fox, showing an omnivorous diet between humans and herbivores, and the Prolagus specimens, which probably reflect a mixture between the open-pasture, grass-eating of sheep and the depleted forest litter.

As concerns the origin of proteins and the overall human diet, the general reading based on the comparison of corrected values for all sites indicated a ruminant-based protein. Reading the chart with both humans and fauna, this is only partially confirmed: while there are no cattle to compare, the pig is only one, and the sheep-goats only two, the trophic level shift, which is commonly about 3-4‰, seems to reflect a mid-point between ovicaprine (Δ = ~2.5‰) and swine (Δ = ~5‰), as the most likely origin of protein. Alternatively, a combination of ovicaprine products and a fair amount of legumes could account for similar values. The greater number of apatite samples analyzed for δ¹³C and δ¹⁸O (Figure 103) cluster tightly, indicating a diet less differentiated internally compared to what is observed at
San Benedetto and several other sites. From the few samples available, it would also seem that women were spending, or spent at some point in their life, part of the time at higher elevations. This might indicate, contrary to what would be commonly expected based on gender roles as hypothesized for the prehistoric Western Mediterranean, and also generally supported by isotopic values, that women were tending the flocks instead of men. Alternatively, their origin could be from areas farther from the coast than where the site is located. If confirmed by a larger number of samples, such data could provide indications in marriage patterns, which in this case would be patrilocal.

The infant collagen δ¹⁵N values, consistently higher than the adults’, are difficult to interpret due to the wide age range estimated (6 year-span); they could still reflect bone tissues synthesized up to a few years of age while breastfeeding, and/or the substitution of maternal milk with sheep milk during their pre-teens. In this case, however, δ¹⁸O values again show children to have enriched values similar to some of the adults, but not higher,
which suggest differential residence for at least part of the year. In the case of breastfeeding
infants, we would expect values enriched also in comparison to those of adults, which is not
the case.

8.2.7.3. Scaba ’e Arriu

Scaba ’e Arriu is one of the key sites for understanding change over time, since its
depositions span two chronologically and culturally distinct phases, the earlier (A), of Post-
Ozieri tradition, centered around the 29th-27th centuries BC, the later (M), Monte Claro,
centered around the 26th-25th centuries BC. Additionally, the presence of faunal remains in
stratigraphic association with the phase A enables a more reliable interpretation of the
connections between trophic levels within the ecosystem, and of the diet.

Wild fauna yielded values within the expected range (Figure 104); the fox has values
somewhat similar to the one at Santa Caterina di Pittinuri, although in this case there is a
clear divergence from human values: while the trophic level is apparently similar, the
difference could be due to swine products, whose fat, enriched relative to ruminant fat, makes

![Figure 104. Scaba ’e Arriu A (Early Copper Age). Scatterplot of collagen δ¹⁵N vs. the spacing δ¹³Ccol-apa by sex and age groups, with the inclusion of faunal values.](image)
human apatite $\delta^{13}$C heavier and the spacing larger. The Prolagus’ diet is as well similar to that detected at Santa Caterina di Pittinuri, probably due to a mix of different plants both in open pasture and more forested environment. In this case we can compare the fox with a domestic canid, the dog; the latter shows values more similar to humans, revealing their sharing of the same foods. Among the domesticates with a dietary significance, sheep/goats have the lowest $\delta^{15}$N values (~7‰), reflecting their fully herbivorous diet, whereas pigs are situated, as expected, about half a trophic level higher (~8.5-9‰), and their variation in spacing reflects the range of foods that could have been consumed, from forest roots, plants and fruits, to refuse of meat, plant, and even dairy foods, depending on their being wild, penned, kept freely roaming in the forest or in and near the household.

Cattle samples’ $\delta^{15}$N values are surprisingly within the range of pigs’ rather than ovicaprines’. Since any contribution of animal products to the diet can be excluded, possible alternatives can be evaluated. Manuring has been shown to have the potential of enriching isotopically cereal grains, which could account for high $\delta^{15}$N values in humans (Bogaard, et al. 2007). These authors also consider unlikely that such an effect could sensibly affect values in herbivores due to the small quantity of N in grains, although if all nitrogen is from grains this might be the case. Even if no experimental testing confirms it, if this is the case for cereals, we could still take into account other possibilities. One relates to a topographic difference in pasture location for ovicaprines and cattle, with the latter feeding on bottom valley, possibly closer to the village, and the sheep/goats on ridges and slopes: it has been shown that higher nitrogen concentration as in rich, fertile soils can inhibit the atmospheric N-fixing, leading to enriched values, whereas N-poor vegetal communities would uptake lighter N from the air (Garten 1993). This applies as well to cultivated fields, especially if manured (Amundson, et al. 2003). Alternatively, even fire has been suggested as an ambiguous potential factor in enriching $\delta^{15}$N values (Cook 2001; Saito, et al. 2007), at least in case of fires mobilizing large amounts of N compared to the demand for regrowth. In other words, a fire in a high-biomass primary forest would enrich $\delta^{15}$N values of the young new plants, whereas frequent fires in shrubby, dry vegetal communities would increase the need for bacterial N-fixing, causing lower values. The problem of explaining such enriched values for the cattle at Scaba’ e Arriu remains therefore uncertain: the most reasonable explanation
seems, however, to be found in their being kept in richer, cultivated, possibly manured fields near the village whereas sheep/goats were grazing more freely in non-cultivated, non-manured, more distant lands with poorer soils. Such a dichotomy is also historically and ethnohistorically documented in Sardinia from the Medieval rural organization, where the tamed cattle were kept close to the village, near the gardens and groves (Le Lannou 1941: 117); the outer area was divided in two or three, and alternatively cultivated with cereal (vidazzone, 'idassoni or other variants) or left fallow (paberile). The farthest and less productive land (saltus or sartu) was the permanent pasture of small stock sheep and goats.

The protein component of the human diet is difficult to reconstruct due to the wide overlap of swine and bovine values and the potential mix of several sources. Based on the large \( \delta^{13}C_{\text{col-apa}} \) spacing, a fair share is likely to have come from plants (legumes and cereal). The consumption of ruminant products was definitely limited, whereas some consumption of pork is more likely (porcine fat would enrich apatite \( \delta^{13}C \) values and widen the spacing with collagen \( \delta^{13}C \)). The overall diet seems to have been more dependent on plant foods than animal products. A gender difference appears in the fact that males consumed more animal protein than females. The difference in the spacing is negligible if we exclude the outlier and likely outsider n. 5949 (see below).

Since the \( \delta^{18}O \) values of the sampled group (Figure 105) seem not to split along sex lines as at other sites, it seems that herding of ovicaprines (and possibly cattle) was probably not associated with seasonal mobility, and the livestock were kept near the village, where there are no sharp elevation gaps. One female individual (n. 5950) in particular had a diet isotopically similar to that of a swine, indicating a high contribution of plant foods to her protein needs, possibly even a small amount of \( C_4 \) plants. Her uniqueness is also in her \( \delta^{18}O \) values, which are clearly enriched when compared to those of the rest of the group. She likely was an outsider, possibly coming either from the west coast near the Oristano Gulf where closeness of the sea may result in enriched \( \delta^{18}O \) ratios, or from somewhere to the South (near Cagliari Gulf or southwest Sardinia), where enhanced aridity could have also resulted in similar values, and the presence of highly saline environments makes the likelihood of \( C_4 \) plant consumption higher.

What seems only possible for individual n. 5950 is instead very probable for the outlier n. 5949: his values indicate origin from a coastal, possibly arid area, and some
consumption of C₄ plants. The option that brackish water fish could account for the enriched apatite δ¹³C (the sample of *Mugil*, #9572, coming from the Cabras Lagoon in the Western lowlands, is remarkably enriched) is ruled out by the consideration that a consumption of protein- and N-rich fish so high as to affect sensibly the apatite δ¹³C values would affect even more radically δ¹⁵N values, which is not observed. Alternatively, unknown effects due to differential turnover of collagen vs. apatite could be found, in future studies, to be significant, but we have no data regarding this aspect.

The second phase represented at the burial site is Monte Claro, for which there are no associated faunal remains. The isotopic values (Figure 106) appear extremely compact and very homogeneous within the framework of a generally higher reliance on animal products than in the previous phase, supporting the inference of a limited intra-group dietary variation. Therefore, a highly egalitarian social organization can be suggested, unless even temporary social differentiation was marked by symbols with the exclusion of diet. A difference between sexes is present, although smaller than in phase A, indicating somewhat higher
consumption of animal products by males. The two elderly females show the lowest $\delta^{15}$N values of the group, so it would seem that the relative proportion of plant foods increased with age. Needless to say, identifying a trend based on such a small number of observations is almost speculative; moreover, three of the four elderly suffered pre-mortem tooth loss, which may have limited their dietary options. On a speculative plane, assuming some correlation between tooth loss and diet, a slight reduction of animal products that entail relevant masticatory action could more likely be identified in meat than in milk and dairy; this could lead to the indirect, tentative inference that dairy products were generally not as quantitatively important as meat. The child, age less than 6, might still reflect in its high $\delta^{15}$N values the enrichment due to breastfeeding, which decreases up to age 10-12 before rising slightly.

There is no substantial variation in $\delta^{18}$O values (Figure 107) from the perspective of sex. Whereas at San Benedetto juveniles and elderly aligned with women, in contrast to adult men, making it plausible that the former represented the village's drinking water values and the latter the higher elevations of summer pastures, such a clear pattern is not visible here.
Three females and the infant have the most enriched values, and the four males are more depleted; however, another three females, two of which are senile, are also depleted. If we take the first group to be the sedentary portion of the community, we would have to conclude tentatively that all the elderly (males and females) had resided for some time at possibly higher elevations. This may seem unusual, but might possibly signify that the longer the movement was carried out through life, the stronger the different δ¹⁸O signature would become. Alternatively, if a lower oscillation in rainwater δ¹⁸O, which could indicate a rainier period, was in place during childhood for the senile-at-death, then at least part of the variation would also be explained. Again, the small number of samples makes these interpretations highly tentative, and in need to be evaluated with further testing.

Finally, the δ¹⁸O values measured in the juvenile individual affected by *cribra orbitalia* (cranium 5) are much more depleted than in the rest of the group; this could be an indication of anemia, as can be inferred from experimental evidence on living subjects (Epstein and Zeiri 1988). If such anemia was of nutritional origin, the apatite δ¹³C values,
considerably more enriched than the rest of the group, could also be justified. They are compatible with a type of diet comparatively poor in animal products. Alternatively, if the presence of *cribra* is not functional to the $\delta^{18}$O and $\delta^{13}$C values, it is still possible that the youth moved in from higher elevations; however, it seems less plausible that the connection between symptoms and causal factors be a pure coincidence.

A comparison of the two phases can be done keeping in mind the limitations. One is the relatively small sample population size. The second is the different quality of additional information available for the two phases: faunal samples from the same site, but preferential sampling based on sex (pelvic bones), for Scaba ’e Arriu A; no faunal samples, but more data on the individuals sampled (cranial specimens) for Scaba ’e Arriu M. Independent from these intra-site patterns, it is definitely recognizable through visual comparison (Figure 108), that the two communities had a clearly different diet. The Early Copper Age Post-Ozieri group relied much more on plant foods than the Monte Claro did, with a possible limited integration of pork meat. The homogeneity of diet increases in the Monte Claro phase, pointing to a more standardized diet, possibly stemming from more egalitarian food-sharing habits or simply a less varied cuisine, which nonetheless had a good balance of vegetal and animal foods. It must also be considered, however, that with decreasing protein consumption, carbohydrates and lipids affect proportionally more the apatite values (Schwarcz 2000), and therefore the $\delta^{13}$C_{col-apa} spacing. This implies that a slight difference in carbohydrates’ and

![Figure 108. Scaba ’e Arriu, comparison of the two phases Post-Ozieri and Monte Claro. Scatterplots of collagen $\delta^{15}$N vs. the spacing $\delta^{13}$C_{col-apa} and apatite $\delta^{13}$C vs. $\delta^{18}$O.](image)
lipids’ relative proportion, and in their origin, is likely to result in larger differences than it would in case of high protein consumption. The two communities do not show remarkable dietary differences based on sex, and this is consistent in both groups. The higher amount of animal products – both protein and lipids – in the Monte Claro group does not involve unequivocally any seasonal mobility, so both groups appear to be virtually sedentary.

8.2.7.4. Padru Jossu

Of the three phases represented at this burial site, the first, Monte Claro, associated by the excavator with the actual digging/carving of the tomb (Ugas 1982b), was represented by a few pottery and bone fragments in the thin bottom layer, and only one individual could be sampled. This individual (cranium 67), considered male by the first examiner (Germanà 1987), is most probably a female. This population, in fact, appears to have sexual dimorphism in the secondary sexual traits weaker than average, which makes it necessary that identifications are made after considering the specific traits of the local population (Beckett 2004, personal communication). The values are high in $\delta^{15}$N but the $\delta^{13}$C$_{col-apa}$ spacing is quite large. Coupling this with the high $\delta^{18}$O, indicative of conditions probably drier than average, and by consequence with the likelihood that the $\delta^{15}$N values would appear enriched, it can safely be assessed that this person’s diet was mostly based on plant foods, with some possible intake of pork.

The two phases better represented are A and B, Bell Beaker (Final Copper Age) and Bonnanaro A (Early Bronze Age). Within phase A, the isotopic range is very broad: over 3‰ for $\delta^{15}$N, ~4.5‰ for the $\delta^{13}$C$_{col-apa}$ spacing (Figure 109). This indicates very diverse combinations of foods in terms of both quantity/origin of protein and general diet, ranging from almost fully vegetarian to one that includes fairly good amounts of animal products. The number of males and females that it was possible to sample is very uneven, so that a reconstruction of dietary differences by sex must remain tentative. The average spacing conforms to the pattern of more animal proteins consumed by males, in fact the range varies from 5.5-7.7‰ for females to 4.7-7.3‰ for males. However, it seems that what best characterizes female’s diet is diversity: two out of four individuals (crania 52 and 43) have values in the low range of males’, one (cranium 56-bis) shows very enriched $\delta^{15}$N but large spacing, which can be due to high consumption of plant foods coupled with aridity effect on
or some consumption of pork meat, another one (cranium 54) shows low $\delta^{15}N$ and large spacing, which translates into a substantially vegetarian diet.

As concerns age differences, although subadults are not assigned to very accurate age sets, and due to the fast bone turnover and growth effects the isotopic ratio can be only tentatively interpreted, it would seem that older males (3 observations) tend to have higher $\delta^{15}N$ and smaller spacing, lending support to the view of a social organization where age might have been a social discriminant. A fairly substantial number of individuals in the community, including a few women and men, besides some of the elderly, shared in a substantial consumption of animal-derived products, which are likely to be ovicaprine, based on both the faunal remains (Sorrentino 1982) and the relatively small spacing.

Still with the caveat of the limited number of samples per each subgroup, the scatterplot of apatite $\delta^{13}C$ and $\delta^{18}O$ (Figure 110) shows, in a context of remarkable overall variation, a potentially important pattern related to sex: the four females all have $\delta^{18}O \geq -3.2‰$, whereas seven out of eight males are between -3.3‰ and -4.4‰. This seems to
Figure 110. Padru Jossu A (Late Copper to Early Bronze Age). Scatterplot of apatite $\delta^{13}$C vs. $\delta^{18}$O by sex and age groups.

indicate that generally females and males were drinking water from different sources; male values are compatible with what we would expect from groups that practice seasonal mobility to more elevated areas. Three mature males are in the depleted end of the range, indicating their participation in these periodical movements, as already tentatively observed in the phase Monte Claro at Scaba 'e Arriu: their longer-term activities in highland locations may explain an increasing accumulation of a depleted signature in the bone tissue. However, it must be underlined that the mature individuals at Padru Jossu are barely over 35 years of age; it is unlikely to be coincidental that the maximum age-at-death is considerably lower than, for instance, Scaba 'e Arriu M, where several individuals were over 50 and 60 years when they died; it is utterly unfortunate that systematic, comprehensive analyses of these remains have not been undertaken yet.
A plot of the values according to the identified pathologies (Figure 111) suggests again a likely nutritional etiology for the condition whose symptom on the bone is cribriform orbitalia. In fact, the three affected individuals all belong to the lower-$\delta^{15}$N end of the range. Furthermore, they are also characterized by enriched $\delta^{18}$O, which is likely also correlated, as depleted $\delta^{18}$O of respired air has been found to correlate with anemic conditions in experiments in vivo (Epstein and Zeiri 1988). In turn, these can be prompted or worsened by vitamin deficiency.

Isotopic values in phase B are as well very broad: over 4‰ for $\delta^{15}$N, ~3‰ for the $\delta^{13}$C$_{\text{col-apa}}$ spacing (Figure 112). Therefore, as compared to Padru Jossu A the variation is increased in the protein quantity/source but decreased as concerns the general diet. Since the trophic level indicator, $\delta^{15}$N, also decreases between the two phases, it seems likely that the quality of protein rather than the quantity is responsible for this internal variation, and this can be attributed to ruminant- vs. pork-derived products. The smaller overall amount allows protein not to affect much the spacing, which is likely dominated by the carbohydrate component. Let us not overlook that since $\delta^{18}$O values indicate relative aridity, $\delta^{15}$N values are also likely to be enriched because of this environmental factor rather than diet, so the overall consumption of animal products was considerably lower than in the phase A, as suggested also by the larger spacing (Padru Jossu B = 7.7‰ vs. Padru Jossu A = 6.4‰). Probably, judging from both stable isotopes and faunal analyses (Sorrentino 1982), there was a substantial reduction of the ovicaprine contribution to the diet, which induced smaller

![Figure 111. Padru Jossu A (Late Copper to Early Bronze Age). Scatterplot of collagen $\delta^{15}$N vs. the spacing $\delta^{13}$C$_{\text{col-apa}}$ and of apatite $\delta^{13}$C vs. $\delta^{18}$O by pathology.](image-url)
overall variation giving more dominance to plant foods in the synthesis of apatite, while emphasizing the difference in trophic level between pork and lamb/mutton/goat in collagen.

The sex-related difference in animal products consumption is in this group virtually absent: males and females have similar average values. Again, what must be underlined is instead the impression of higher diversity in female than in male diets. Their $\delta^{15}N$ range varies from 8.7-11.5‰ for females to 8.9-10.9‰ for males, and the $\delta^{13}C_{\text{col-apa}}$ spacing from 6.6-8.9‰ for females to 6.6-8.2‰ for males. In societies where the range of foods was far smaller than in our post-industrial, global-market societies, one likely explanation for this is to infer less strict normative dietary practices in females than in males. An alternative explanation, in situations of hardship due to famine, could be found in food insecurity, which tends to strike the weaker groups within a given society (Shipton 1990: 362). These two groups at the same burial site are by far those with the greatest intra-site spread in isotopic measurements, which makes their diets the least homogeneous of all those analyzed.
like A, appears to have a short lifetime average: even if there are no comprehensive analyses, only one individual among those sampled could be recognized as being ~35 years old.

The $\delta^{18}$O values (Figure 113) indicate, as already recognized at San Benedetto and in phase A at the same site, a somewhat different clustering between males and females, again readable as deriving from seasonal mobility, since males do have values compatible with permanence on more elevated, cooler/rainier areas for a portion of their lives. Variation independent of sex is likely added by decadal and centennial scale climate change, which is clearly recorded for these centuries.

The juvenile and infant values, for which no more accurate age estimates are available, are difficult to interpret for the rapid changes related to breastfeeding, weaning, and growth, as discussed in chapter 7 regarding tooth enamel values. The juvenile has the lowest $\delta^{15}$N and largest spacing of the whole group, which might be due to its age, if he/she were in the post-weaning, pre-teen low isotopic peak at the time of death.

A brief note on stable isotopes and pathology: the individual pointed out for his heavy toothwear (cranium 3) has values comparable to the rest of the group; more interesting

![Figure 113. Padru Jossu B (Early Bronze Age). Scatterplot of apatite $\delta^{13}$C vs. $\delta^{18}$O by sex and age groups.](image)

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is the adult male cranium 6, affected by *cribra orbitalia* and *cranii*, who shows a comparatively low $\delta^{15}N$, but small spacing, and low $\delta^{18}O$. It would seem that the amount of protein in his diet was low and/or likely from low-trophic level animals, such as herbivores rather than swine; this is supported by the relatively small spacing: the source is likely to be ovicaprine. The depleted $\delta^{18}O$ would indicate he was part of the mobile group of herders, which fits his diet. In this case, rather than anemia, the *cribra* could be rather due to vitamin deficiency, if the milk and cereal intake was not supplemented by fruits or other sources; milk and grains, in fact, lack vitamin C, and scurvy has been shown to result in *cribra* (Melikian and Waldron 2003; Ortner, et al. 1999; Salis, et al. 2005). Besides lack of fruits, also intense cooking, especially in copper containers, favors the loss of vitamin C.

The dietary information coming from teeth is also, for Padru Jossu, significant and deserves a brief discussion. What emerged from the results is that the three individuals from phase A showed $\delta^{18}O$ enrichment from tooth to bone, and no clear trend in $\delta^{13}C$, with values tighter in adulthood than in childhood. Phase B showed a similar overall pattern of $\delta^{18}O$ enrichment from teeth to bone and either enrichment or depletion in $\delta^{13}C$, with no evident differentiation between such trends in pre- and peri-weaning teeth vs. post-weaning teeth.

The tentative explanatory options were a) movement from a childhood in the highlands down to the lowlands where the burial is; b) a climatic shift during their short lifetimes from more humid to drier conditions; c) a substantial increase in contribution of ovicaprine milk (which should be $\delta^{18}O$-enriched) to the total drinking water needs; or d) no dietary variation underlying the values, but rather a physiological pattern not yet investigated in $\delta^{18}O$ but documented in $\delta^{15}N$ (O’Connell and Prentice forthcoming; White and Schwarcz 1994), whereby the lowest values in life are reached around age 7-12 before stabilizing to adult levels.

Mobility seems unlikely: I would rather think of the opposite pattern, with the children showing higher $\delta^{18}O$ values like females. Mothers would be the group more likely to be sedentary and in the lowlands, rather than mobile. The potential for climate change would normally be considered unlikely, because it would imply that all individuals lived during the same years; whereas in normal conditions of a collective tomb used for hundreds of years this coincidence would be tough to believe, the AMS dates suggest a concentrated and short utilization of the burial, so that this cannot be ruled out. The last two options seem more likely.
The microsampling on four third molars indicated that while one female (#9816) showed little variation, two males (#7131, 7134) had an overall enrichment in both $\delta^{18}O$ and $\delta^{13}C$ in the few years around age ~10, with subsequent depletion in $\delta^{13}C$ from age ~12 to adult age, when they died between their twenties and early thirties. The young female, instead, shows from age ~12 to adulthood the same strong enrichment in both $\delta^{18}O$ and $\delta^{13}C$ that the two boys experienced as pre-teens. While the slight $\delta^{13}C$ enrichment in all four individuals could be compatible with an increase in grains in the diet, the $\delta^{18}O$ values would instead indicate more milk in the drinking water supply. However, the apparent contradiction in a hypothetical large consumption of milk that does not affect the enamel $\delta^{13}C$ remains unexplained, so that in conclusion it seems likely that what is recorded is physiological variation that needs further investigation. The likelihood of dietary phenomena behind the tooth-bone isotopic difference should be less prone to pure physiological effects, and in the different pattern recorded in the two males and in the female there is an increasing gender divergence between the former consuming progressively more meat and/or milk ($\delta^{13}C$ depletion) vs. the latter consuming more cereal-based foods ($\delta^{13}C$ enrichment). While showing the potential for deeper understandings of physiological effects and dietary change in prehistoric children, these uncertainties and ambiguities clearly highlight the need for more research, both toward modeling and toward more sampling.

In synthesis, the two phases at Padru Jossu are, unlike those at Scaba ’e Arriu, part of a continuous development of the same community: the isotopic ratios have a large area of overlap in dietary and climatic indicators (Figure 114). It was possible to identify a substantial shift from a more mixed diet in the Bell Beaker phase, when there was a fair amount of ovicaprine products in the food resources, to one mostly reliant on plant foods in the Early Bronze Age. Both phases, probably characterized by low life expectancy, had on the bone traces of chronic illnesses that, if considered in combination with isotopic values, can be suggested to stem from anemia, in some cases, and in some or all from vitamin deficiency, while leaving open other possibilities such as parasites or genetic anemias. On a broad level, the worsening of health conditions specifically at the end of the Copper Age and especially during the Bronze Age makes this last option unlikely, since the genetic type would probably develop over a long period of time of sustained natural selection of traits (e.g. the effects of malaria).
The diet seems to have experienced a shift, probably within a few generations, between some consumption of meat to a very slim amount of animal products. The lapse of time is suggested by the AMS dates, which have largely overlapping ranges and indicate that the depositions that can be documented are probably concentrated within 150 years or less, and each of the two main phases A and B could even represent two or three generations of 25-35 years. The general climatic profile (see section above) derived by corrected $\delta^{18}O$ values generally supports the remarkable dry spell already detected by several studies at exactly this time period, ~2300-2250 BC, which must have generated widespread disturbance in the environment, determining a strain in the economy and practices of the local communities and interfering with daily social and individual decision making. Diet seems to have maintained some difference along gender lines in phase A, with males consuming more animal protein, whereas such a difference, possibly for the occurring general scarcity of animal products, virtually disappears in phase B. Also, in phase A the more mature males maintain better access to animal products.

Related to diet is mobility, suggested by the different clustering of males and females according to $\delta^{18}O$ values. Seasonal mobility was apparently practiced mainly by adult men, who would spend part of the year at higher elevations with the flocks, mostly sheep. It is possible that they were striving to keep these flocks intact during the bad years of phase A. This is a practice widely documented for cattle as a way of preserving social, symbolic and

Figure 114. Padru Jossu. Scatterplots of collagen $\delta^{15}N$ vs. the spacing $\delta^{13}C_{\text{col-apa}}$ and of apatite $\delta^{13}C$ vs. $\delta^{18}O$ in the two main phases (A and B).
economic assets, counter to the relatively simplistic view that was assumed at the beginning of this research. On the other hand, sheep may indeed have been favored precisely because of their better resistance to drought, which is a risk-buffering mechanism documented in relation to the first stages of famine (Shipton 1990: 363-364). The number of animals was probably drastically reduced by phase B, when there is a lower consumption of high-trophic level products, and plants are the main basis of the diet. Average life span was probably reduced, and disease related to malnutrition was common during a time that seems to have been critical: another strategy for coping with food insecurity is that of emphasizing high-carbohydrate, starchier foods over less-satiating but more nutrient foods (Shipton 1990: 364).

However, the maintenance of mobility indicates that the fabric of society was not ripped, there were still assets to keep in hope of better times, and animals were still offered or consumed in funerary rituals (Sorrentino 1982). Gender differences in diet were loosely maintained for a while, but abandoned in phase B, and probably women suffered more from food insecurity as possibly reflected in their broader range of isotopic values.

8.2.7.5. Iscalitas (Early Bronze Age)

Dietary variation within the sampled community of Iscalitas does not show sharp differences, but some variation by sex and age in the averages of collagen $\delta^{15}N$ vs. the spacing $\delta^{13}C_{\text{col-apa}}$ (Figure 115) does indicate that males had an overall slightly better access to animal protein, and that older individuals had better access than younger adults (see also Figure 93). The four mature males (above 35 years of age) all have $\delta^{15}N$ values over 10.5‰, indicating that within the context of a mainly plant-based diet, they had slightly better access to the scarce meat, possibly pork, which with its enriched adipose fat would keep the $\delta^{13}C_{\text{col-apa}}$ spacing large. However, the gap in values according to sex are smaller if compared with those recorded in both phases of Copper Age Scaba ’e Arriu and with Padru Jossu A, indicating milder gender differentiation in consumption patterns. Differences according to age are in line with San Benedetto and Padru Jossu A and B, although somewhat diminished compared with the latter site (Scaba ’e Arriu, Monte Claro phase shows a reversed pattern, with better access to animal protein in adults than in the elderly). The values of the four children are generally compatible with the $\delta^{15}N$ curve expected in an average life, with values
depleted relative to adulthood in the age range ~4-20, and especially ~5-13 (O’Connell and Prentice forthcoming; see also a compatible archaeological study: White and Schwarcz 1994); this is more likely than dietary change through life, since the spacing does not show a similarly clear corresponding pattern, which would be that of lower (smaller $\delta^{13}C_{\text{col-apa}}$ difference) values in more mature individuals, mirroring the higher intake of animal products.

The distribution of $\delta^{18}O$ values by subgroups (Figure 116) is as well not particularly revealing of any differentiation in mobility patterns. The general homogeneity of values is higher ($1\sigma = 0.4\%e$, vs. 0.8 and 0.6%e at Padru Jossu), and the range where most values belong is lower than 1%e. This could indicate some degree of isotopic difference in drinking water, but it does not seem related to any specific portion of the community, and does not therefore suggest gender or age as a factor for a sustained practice of mobility. A speculative hypothesis is that the family unit, or household, might have affected food availability or choices more than symbolic codes and practices shared at the community level. DNA analyses would help in gaining insights for this purpose. The breaking up and simplification of social organization into single households practicing farming with reduced emphasis on domesticated animals has been suggested for the Early Bronze Age by Perra (1997), and the...
scanty evidence of the only excavated habitation site seems to support this (Usai 1994). The observed isotopic patterning could be a further, tentative support.

No clear link was found between the few detected pathologies and isotopic data, while a possible trend can be recognized by looking at the isotopic data integrated with the grave goods associated with specific individuals. This site is the only one where detailed documentation and the active collaboration of the excavator, Dott.ssa M.R. Manunza, enabled an optimization of the knowledge that can be produced from the isotopic data in social terms. Considering the scatterplot of collagen $\delta^{15}N$ vs. the spacing $\delta^{13}C_{col-apa}$ for adults only (Figure 117), many individuals with grave goods cluster tightly in an area comparatively low in $\delta^{15}N$ and high in the spacing that indicates lower consumption of animal protein and of animal products in general. Values reflecting protein are particularly distinct, with five out of eight individuals provided with grave goods that are within the seven out of twenty-two lowest-trophic level data points. This trend, that seems unlikely to be a random effect, might suggest that some dietary practice was connected with somewhat higher social standing. In a
context where, as indicated by overall values, the diet was mainly based on plant foods, we would expect somewhat distinct individuals to have better access to meat or other less ordinary dishes. To the contrary, a higher proportional consumption of grains appears to mark the social status of the deceased in life as materials deposited in the tomb do in death. It is suggested that this item was likely to be have been some beverage, probably alcohol brewed from cereal. The best candidate is of course barley, particularly considering the shift from naked to hulled barley over wide areas of the western Mediterranean around the Copper Age and before the Middle Bronze Age, a shift that in some Mediterranean areas consisted in full replacement (Bakels 2002). Hulled barley is commonly considered the best malting/brewing variety. It may not be coincidental also that the individual whose cranium was laid into a tripod vessel with a brassard, the archer’s wrist-guard, shows comparatively high $\delta^{15}$N values and small spacing: somewhat more meat seems appropriate for someone who is buried with an element of the hunting/war paraphernalia of the time.
Two factors are to be considered limitations to the integrated interpretation of the previous proxies for economic practices and the isotopic data presented in this study. One is the number of sampled individuals, which is not as high considering the subgroups by phase, especially for phases represented by one group only (the Late Neolithic by San Benedetto and the Bell Beaker phase by Padru Jossu A). The second as concerns the Late Neolithic is the site location, which is not typical of Late Neolithic sites and does not compare well with most lowland sites, which make up the majority of the total population of this study. With this premise, I can attempt to make a few points, combining the different types of data now available, and following the synthetic prospectus of the main kinds of data discussed (Table 27). The picture of a Copper Age where there is some diversification in the animal husbandry is confirmed by stable isotopes: there are sites that appear to have relied mostly on ruminants, which from the faunal data can with confidence be identified as sheep (and probably to a lesser extent to goats, considering the sites are not in rugged and highland regions). Among these are the groups of Santa Caterina di Pittinuri and Scaba ‘e Arriu M. Other groups that may have relied more on swine products are Scaba ‘e Arriu A and Su Stampu, while still others that are in between are Seddas de Daga, Cannas di Sotto and Serra Cannigas. It must be considered likely, however, that the high $\delta^{15}N$ values of Scaba ‘e Arriu A and Su Stampu are due to some extent to the effect of aridity suggested by the enriched $\delta^{18}O$ values: therefore, these sites can be attributed an overall diet more based on plant foods and less on animal products.

Such a possible dichotomy has been identified very convincingly in Southern France through detailed studies of age-at-death and seasonality, with a statistical comparison between open-air sites and cave sites. Helmer et al. (2005) have documented and defined a persistent integration between cave-shelters and open-air sites, the former mostly dedicated to ovicaprine penning and the latter more generalized. The relationship between such types would have been similar since the Early Neolithic, and radicalized in the Final Neolithic-Copper Age, when caves experience reduced human presence and higher proportions of ovicaprine bones. Such a scheme is perfectly appropriate to describe the history of Filiestru Cave as reconstructed above (chapter 5). What is important to underline is that the French
Table 27. Comparison of $\delta^{15}$N and the spacing $\delta^{13}$C$_{col-apa}$ with other indicators of subsistence and diet from previous works: biotic remains, landscape archaeology, material culture, and osteology.

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<tr>
<td>LN (Ozieri) 4000-3200 BC</td>
<td>- cattle</td>
<td>?</td>
<td>alluvial lowlands, coasts</td>
<td>bowls + cooking tripods</td>
<td>microliths decline</td>
<td>11.3 ± 0.3 [16]</td>
<td>-5.7 ± 0.4 [16]</td>
<td>-</td>
<td>+</td>
<td>-?</td>
<td>+</td>
<td>-</td>
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<tr>
<td>ECA (Post-Ozieri) 3200-2500 BC</td>
<td>+ ovicaprids?</td>
<td>+ acorn?</td>
<td>continuity (S) + highlands (N)</td>
<td>+ jugs, bottles, beakers, strainers - cooking tripods</td>
<td>+ grinding stones + hoe-weights + loom weights</td>
<td>10.9 ± 0.2 [26]</td>
<td>-7.0 ± 0.3 [26]</td>
<td>+</td>
<td>-</td>
<td>+?</td>
<td>+</td>
<td>-</td>
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<tr>
<td>LCA (Monte Claro) 2700-2300 BC</td>
<td>? (locally + pig?)</td>
<td>+ olive cultivation?</td>
<td>hills &amp; lowlands no coastal; hilltops</td>
<td>+ large jars + cooking tripods</td>
<td>+ grinding stones + hoe-weights + loom weights</td>
<td>10.8 ± 0.2 [26]</td>
<td>-7.0 ± 0.3 [25]</td>
<td>+</td>
<td>-</td>
<td>+?</td>
<td>+</td>
<td>-</td>
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<tr>
<td>Beaker 2400-2200 BC</td>
<td>+ ovicaprids?</td>
<td>occupation break, Mostly lowlands</td>
<td>+ beakers, + serving tripods</td>
<td>+ arrowheads</td>
<td>10.1 ± 0.3 [18]</td>
<td>-6.4 ± 0.4 [17]</td>
<td>?</td>
<td>?</td>
<td>-?</td>
<td>-</td>
<td>+</td>
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<tr>
<td>EBA 2200-1900 BC</td>
<td>(locally + pig?)</td>
<td>+ hulled barley?</td>
<td>lowlands, + highlands</td>
<td>beakers, + serving/drinking tripods/cups</td>
<td>9.5 ± 0.2 [48]</td>
<td>-7.9 ± 0.2 [47]</td>
<td>-</td>
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evidence and the Sardinian isotopic data contribute to depict a model of Neolithic animal husbandry that seems rather different from the one documented for Neolithic Greece, where Halstead (2006) concludes that animal husbandry was tightly connected to cereal fields, small-scale and intensive rather than extensive. Conversely, for Mediterranean France a picture of specialized niches since the inception of Neolithic life has been outlined, and even a case of dairy production for exchange, beyond household consumption, in the Final Neolithic (Helmer, et al. 2005: 178). This is the system I believe may apply to Sardinia from Ozieri or Post-Ozieri times, a system that might derive from the different trajectories of Neolithic package adoption (the Aegean that continued overland through the Balkans vs. maritime, towards Southern Italy and the Western Mediterranean).

An additional factor involved in raising sheep could have been the production of wool; this could be reflected in the high numbers and sophistication of loom weights (Melis 1993). At the only multi-layered site spanning the two main traditions of the Copper Age, Scaba ’e Arriu, there is an increase in animal products consumption in the Monte Claro phase, which can be interpreted as higher reliance on meat and milk; this could be a symptom of a further step in the intensification of exploitation of secondary products, but could also reflect a localized, specific development which based on current data, cannot be extended to the whole island.

The heavier reliance on plant foods as compared with the only Late Neolithic group is consistent with the general increase in frequency of hoe weights and of grinding implements recorded for the Copper Age in Sardinia (Contu 1997: 205, 344-345; Lilliu 1988a: 122, 140), and with the flaked adzes identified in settlements in the Western lowlands (Lugliè 1999); these two phenomena combined fit a picture of agricultural intensification and of specialization. The latter in turn fits general trends observed for the Copper Age, with clues of more intense contacts and possibly exchange of goods, represented by metal items and by the clear similarities to pottery shapes of mainland Italy (Basoli and Foschi Nieddu 1993).

The decline in the presence of obsidian microliths in the Late Neolithic and Early Copper Age, which represented a long-lasting tradition since the Early Neolithic, could be related to two factors: the better standardization and distribution mechanisms of long obsidian blades, which could be made in large numbers and with no need of retouch (Cappai,
et al. 2004; Lugliè 2000b), and, increasingly during the Copper Age, the potential use of metal implements for harvest. With the emergence of a new ideology of maleness and the status symbols more related to hunting, adumbrated by the contemporary decline in hardstone axes and increase in arrowheads inside tombs, it is not surprising that no metal tools that could have been used for farming were recovered, since they could have been sharpened for decades and finally re-melted. These possible new technologies, rather than a widespread use of the plow, for which there is currently no evidence, could also feed into a heavier reliance on agricultural products.

Another factor to take into account is the change in social practices reflected in the parallel increase in containers of liquids and small vessels for individual consumption (Cocco and Usai 1988; Melis 2000d: 49-55). Such an increase in drinking, which is likely connected to either sweet or alcoholic beverages, could have had profound implications in land-use practices. The decline of communal, Neolithic forms of consumption indicated by the middle-sized bowls might also be an indication of the use of drier solid foods, following Trump’s (1990: 41-42) interpretation of tripods as porridge heaters. Baking would require more processing of the grains through reduction into flour, its refinement and preparation into dough. Finally, the increase in large jars might be connected to the storage of beverages or processed cereal versus grains, which can be stored in sacks or baskets.

Besides an intensification of herding, the accentuated interest for highland locations could be related to higher demand of cereal cultivation if this was to be used not only for more processed grains for daily needs, but also for malting (Dineley 2006). The interest for areas with high cereal-yielding potential is clear in the choice of settling the low hills of Marmilla and Trexenta in Monte Claro times (Dessì 1989; Lilliu 1985; Puxeddu 1962), whereas the reduced presence at several sites in the alluvial lowlands (Atzeni 1962; Locci 1988) could be caused by increased aridity and lowered water table during the first of the two arid events suggested based on previous data and confirmed by $\delta^{18}O$ isotopes, around the 29th-28th centuries BC.

In this picture, the few, rather impressionistic data from osteology and dental health might be significant to help our understanding of dietary practices beyond simple proportions of foods, into nutritional details and beyond. In fact, if we put together the increase in drinking with the increase in querns, and the choice of land good for cereal-growing, it is not surprising to find in Copper Age teeth higher caries, and lower toothwear frequency, than
both in the Neolithic and the Early Bronze Age (Coppa unpublished; Germanà 1999). The consumption of higher proportions of highly processed starch, and particularly of sugar drinks from malting cereal, seems a likely cause for such a combination.

The following centuries, marked by a remarkable occupational break at most of the island’s sites, seem also marked by a clear dietary shift. The Bell Beaker and Bonnanaro A groups analyzed have yielded isotopic results indicating a heavier reliance on plant foods than ever before. A correspondence with faunal remains data, which are partial and not unequivocal, is less visible than for the Copper Age. The main piece of evidence comes from the site of Padru Jossu, where the shift from high animal protein consumption giving way to more plant foods parallels the faunal data that show strong prevalence of ovicaprines in the Bell Beaker phase and more balanced presence of cattle and pig remains in the Early Bronze Age layers (Sorrentino 1982; Fonzo, personal communication).

As concerns the connection with material culture of food processing and consumption, similarly to the rest of the Bell Beaker realm in mainland Europe, there is an increase in polypod (multi-footed) vessels and beakers for individual consumption. Whereas tripods of Monte Claro times were tall, following the Neolithic tradition, and work well to heat up and cook foodstuffs, many of them from this period are low, and seem to be platters for serving rather than cooking. The advent of a social practice of drinking and possibly eating following different rules of etiquette seems to have been brought successfully to the island. The difference is that such table sets are mostly found in caves that may once again have become dwellings, and no evidence for open-air settlements has been found (only two sherds within Monte Claro villages: Ferrarese Ceruti 1981a): all Monte Claro stone-built villages were abandoned at the same time that the eponymous pottery was.

What is lacking for both Bell Beaker and Bonnanaro A phases is any substantial evidence for settlements, or for food-processing implements in reliable stratigraphic contexts. It is clear that there is continuity between the two phases, both in site occupation and material culture repertoires, although they do not say much about food preparation. The possible introduction or intensification of hulled barley cultivation by this period, based on broader trends and its presence in the later Bronze Age of Sardinia (Bakels 2002), could fit the emphasis on drinking vessels, and could mark a different processing of grains. Judging from the limited data on dental health, if the Copper Age was the age of sugar drinks, the Early Bronze Age might have coincided with a more intense diffusion of alcohol. A full
fermentation allows the conversion of sugars into alcohols (Jennings, et al. 2005), so the drop in the occurrence of caries could be associated to this shift in tastes and habits.

Apparently discordant are the data between preferences in the location in the landscape and the stable isotopic values at Padru Jossu A, but there are Bell Beaker sites also in the highlands (e.g. Fadda 1989b), and Padru Jossu is the only site analyzed. Moreover, as for Scaba ’e Arriu A and Su Stampu, also Padru Jossu might show $\delta^{15}$N values enriched due to aridity, so that the diet might be in both phases (A and B) more plant-based than the comparison with the remaining groups shows. The general increase in cribra orbitalia in connection with a more plant-based diet could point to nutritional anemia, and some limited evidence in support of this view comes from stable isotopes (see above). Especially in an environmental crisis such as the one triggered by climate change around 2300 BC on a heavily transformed landscape, a scenario of reduced milk and meat consumption seems to make sense, and so does a diet poorer in micronutrients that are disconnected from the perception of hunger (e.g. vitamin C, contained in fresh fruits and vegetables).

The higher occurrence of tooth wear remains disconnected from other indicators. The traditional explanation, that of lithic grit in the food due to grinding of grains into flour with stone implements, goes counter to the documented trend that caries is generally associated with cereal-based agricultural economies, whereas toothwear is inversely proportional to caries (Molleson and Jones 1991; Molleson, et al. 1993). However, a wide range of possible causes exists (Molnar 1972), and there is not much evidence for a change in processing implements to justify such a variation based on nutrient proportions in the diet, nor is there much evidence for processing implements at all. A more integrated explanation is related to bruxism. This is more commonly known as grinding teeth, usually associated with stress, anxiety, and one study found a positive correlation with tooth wear, besides documenting prevalence in males and a weak but significant relationship with unemployment (Bernhardt, et al. 2004). This already leads, however, to more complex interactions of factors other than diet, which is the subject of the next section.

8.4. Cross-Comparison and Integration of Domains: Explaining Change?

In this last section an attempt was made to assess, interpret and organize in a series of causal relationships the information that was available and has been summarized and the new
data, addressing the different components that interact to generate change. The visual
reference model in chapter 2 (Figure 4) is meant to clarify how this large mass of information
is organized. Different ways could be equally correct, nevertheless this seems a reasonable
simplified way of organizing the different causal links between broad interacting domains.
This does not imply that these domains are considered truly and intrinsically separate, which
is clearly not the case (Robb 1998), but only a way of structuring a discussion that concerns
them. Humans are part of the environment, rather than a separate entity that interacts with it;
they are simply the environmental element we as anthropologists are more interested in, and
their world is, as ours, deeply symbolic.

This study has confirmed previous evidence from several sites across the
Mediterranean, against common skepticism, that important climatic changes did indeed occur
in the period of interest. The direct effect of such climatic changes on environment, with
particular reference to vegetal communities, soil deposition/erosion histories and the like, is
currently impossible to determine for Sardinia, due to the lack of any relevant pollen studies
or well dated soil profiles. The argument that there was indeed an impact of climate on the
environment can however be made: the level of variation that has been reconstructed, even
considering some degree of error in both values and interpretation, seems to have been
relevant for contributing to substantial changes in plant communities, human livelihoods and
what is related to them. A rainfall variation over 500 mm, as suggested by corrected δ18O
values, can impact severely the equilibrium among species and the outputs of food
production, particularly if the change occurs fast enough to make human adjustments more
difficult. This seems to have been the case for the dry period between 2850 and 2600 cal BC
and particularly the one between 2350 and 2200 cal BC.

Such climatic events, occurring within two centuries or less (the first apparently in
the 29th, the second in the 24th century cal BC), seem to have unfolded within relatively few
generations, so that their effects must have been felt and must have been perceived as severe
problems to face for the maintenance of the lifestyles that the involved communities were
accustomed to. The effects can be tentatively traced by drawing parallels with better-
documented areas of the western Mediterranean: competition between forest species was
impacted by favoring plants well adapted to long droughts, like olive trees (both wild and
cultivated), juniper, evergreen arboreal species in general and in particular oak (Carrión, et al.
2001; Magri 1997; Reille, et al. 1999b; Yll, et al. 1997); conversely, black pines and high-
altitude species, still present in the Middle Neolithic (Castelletti 1980), may have disappeared completely from their post-glacial *refugia* on the Gennargentu massif. The vegetation changes documented in Corsica, certainly fueled by human practices and particularly fires, may have had an acceleration due to these dry events: the areas covered by deciduous oak, *Arbutus unedo* and *Erica*, probably widespread before heavy anthropization started, were more and more limited by grassland and scrubland with higher frequency of *Pistacia* and evergreen oaks. Plants requiring some degree of humidity such as hazel or alder must have become rarer, causing some loss in biodiversity. On the other hand, it is possible that Mediterranean coastlines were modified by marine regression during the Copper Age (Kayan 1997; Lambeck, et al. 2004), and that this, coupled with increased erosion due to grazing and farming, and enhanced by aridity, determined the infilling of estuaries and the formation of coastal lagoons and marshes, with a potential increase in biodiversity.

A separate, circumstantial rather than compelling argument is that of the correspondence between change in material culture and climate change. This could be, to a certain extent, an artifact of our approximation in categorizing and defining periods in both domains. However, from the data presented in this work, it appears that the whole island shows aspects of the same Ozieri/Post-Ozieri tradition up to the first dry event, when the Monte Claro culture begins; its material culture spreads over the whole island by the 23rd century cal BC, when a second, sharp dry event is recorded. At this point, occupational continuity is clearly broken before Early Bronze Age material culture and sites appear, and similar occupational breaks are registered at the same time in several Western Mediterranean regions (Colomer, et al. 1990; Di Maio, et al. 2003; Webster 1996: 62). It is argued, therefore, that climate change must be considered at least as an important co-factor in any explanatory model for this segment of Mediterranean prehistory.

Causal links between environment and human practices are more complex and definitely bidirectional. Environmental change related to climate can affect the choices available to human groups in several ways: a loss of biodiversity can reduce the ease of acquisition and the density of certain species, including plant foods such as hazelnuts and strawberry tree fruits, and game such as Prolagus. Conversely, new resources could have become more available: possibly mollusks, migratory birds and natural salt in lagoons and marshes, and fruits and plants well adapted to drier conditions, such as acorns, olives, lentisk berries. Besides wild resources availability, severe constraints can be set by environmental
variation on food production: soils thinned by aridity are more prone to erosion and progressively lower outputs, lower water tables can negatively affect both agriculture and inhabitability of specific locations, forcing human groups to abandon alluvial soils and relocate near freshwater springs, as has been documented in the Post-Ozieri contexts (Melis 2000d: 93-108). A flip side of the potentially new resources of marshes and lagoons could have been the spread of malaria, notoriously epidemic in the vicinity of Sardinian stagnant waters up to the 20th century. Among the potential unexplored consequences of reduced hardwood forest cover could also be the difficulty in finding materials for canoe manufacturing, conditioning and restricting navigation capability.

On the other hand, human practices have been shown across the Mediterranean to have had an early impact on the environment. Mining has recently been found to have a powerful transformative potential on the landscape (Jouffroy-Bapicot, et al. 2007), even as early as in the Late Neolithic and Copper Age (Maggi 1998), although no such evidence exists in Sardinia. The presence of copper and especially silver at late-4th millennium BC sites (Ugas 1993a; Usai 2005b) probably implies the exploitation of deposits that often involved breaking the rocks with heat to reach the mineral-bearing ore. This, and the following smelting and casting, all require large quantities of firewood. The adoption of specific gastronomic tastes may have led to the introduction of the vine, recorded in mainland Italy in the Neolithic but still undocumented in Sardinia, and cultivated olives, well suited to arid and rocky soils. The introduction of hulled barley for malting and brewing purposes can also have impacted the environment, rendering necessary larger tracts of land to be cleared for this product, probably by the Early Bronze Age (Bakels 2002). All these phenomena may have also coincided with the increasing aridity punctuated by the two important events around the 29th and the 24th centuries cal BC. However, the intensification of agricultural outputs by means of extending farmland and pasture and widening the pool of exploitable products is likely to be the single most important element of environmental impact during the Copper Age and particularly toward its conclusion. This may have been done by felling trees, especially up until the Late Neolithic (since more temperate forests are less easily burnt than Mediterranean-type macchia, and the real and symbolic value of hardstone axes could be related to this important aspect of Neolithic life), and increasingly through fire, as documented in Southern France, where the highest frequencies are recorded between the Late Neolithic and the Early Bronze Age, with a surge towards the conclusion of the Copper Age
(Carcaillt 1998). All these habitat modifications, coupled with hunting pressure, could be responsible for the decrease of Prolagus, which, contrary to some claims, became extinct probably in the later Bronze or Iron Age (Wilkens and Delussu 2002).

Technology as a factor to determine human practices is not to be considered in a vacuum but embedded in the socio-cultural system of pertinence. Keeping in mind this perspective, it can be underlined that changes in lithic reduction technology are more in degree and relative proportions than in kind (Locci 2000; Lugliè 2000b). Therefore, the availability of specific lithic technology does not appear to have been a factor in any of the changes. The preference for some over other types of artifacts seems to have been rather determined by the different functions of tool types: some have been hypothesized to relate to different ways of harvesting, others to the increase in hunting. There is no clear evidence for the adoption/introduction of the know-how of plowing (Wilkens 2004: 185) and the taming of oxen for the purpose. This does not imply that plows were not used, since even in the Middle Ages farming with hoes was prevalent. The absence of clear evidence may even confirm the elite connotation of possessing an oxen yoke, as a status symbol and as a means to strengthen social inequalities by lending or renting it, as the bovine heads of northwestern Sardinia may induce one to think. The availability of wool sheep probably from the Copper Age (Sherratt 1997a) and the previous experience in processing and weaving flax (witnessed by the widespread kidney-shaped weights), may have enabled the development of a flourishing woolen textile manufacture, as indicated by the increase in sophistication of loom weights (Melis 1993). Certain weight types that are not documented on the mainland are also the possible reflection of a further, uniquely Sardinian, innovation and complexity in weaving techniques.

A technical know-how that has been long recognized to have brought about profound changes is metallurgy. In Sardinia, it seems that local silver metallurgy may have preceded the beginning of copper metallurgy; alternatively its early development was a local adaptation of copper metallurgy to more valued, or simply more easily accessible or known metal ores. What may have changed in metalworking is the scale of production, which may have derived from a refinement of the knowledge necessary to make many sturdier tools rather than a few shiny jewels. The increase in utilitarian over ornamental objects points in this direction; in this light, the apparent temporary decline in metal finds in Monte Claro contexts could be a bias deriving from the higher production of utilitarian tools that were not
status symbols and therefore did not end their life cycle in a permanent burial (compare with the copper axe of the Alpine Iceman). Rather, the majority of tools such as knives, sickles, axes, spears and the like were likely used until blunt or broken, then melted again into new objects generation after generation. If this is the case, this technological leap would have occurred during the Monte Claro phase, and could be an example of subsistence needs and practices that prompted the adoption of a new technology (in this case possibly made available by contact with Bell Beaker groups). It may not be coincidental that such a technological innovation that, in absence of hoarding, can only be postulated ex silentio, occurred after the first of the two major arid events documented, in between the 29th and the 24th centuries BC.

The last three elements, the likely development of wool weaving, the ascertained development of silver metallurgy, and the adoption of more utilitarian-oriented metalworking, represent examples of the inverse causal link between practices and technology, since the previous practice of weaving and metalworking likely made possible the choice of innovations necessary for a finer textile production and for silver metallurgy.

Whereas the technology of fermentation may have had antecedents in processing wild fruits, that of malting cereals, which may or may not have been followed by fermentation, was first documented in the Near East around 4000 BC (Dineley 2006) and could have been adopted in the Western Mediterranean and Sardinia towards the end of the 4th or during the 3rd millennium BC. This could be related to the increase in grinding stones tentatively recognized in the Sardinian Copper Age, and particularly to the increase in ceramic liquid containers and beakers for individual consumption. Again, the ceramic shapes adapt to new exigencies that pertain to a symbolic, cultural order. The adoption of sugar-based cereal drinks could also match the increase in caries recorded at some Copper Age Sardinian sites (Coppa, unpublished; Vargiu and Coppa 2007). There is no clear sign of an effect of new technical-technological knowledge on basic nutrition; in other words, there seems to be no evidence that new technologies changed the basic diet, as has been documented by previous proxies and the stable isotope results.

From this discussion the inextricable ties between technological change and the social and symbolic milieu of social groups emerge clearly: metals seem to have been used first to express or create differentiation, due to their nature of exotica and to the association between objects, skills/means to acquire it. Both items and related skills and persons were connected
with the cosmological powers associated with them, as suggested for other contexts such as one mechanism to generate power (Helms 1993). In a later phase, their significance seems to have changed, and their practical value (or, the symbolic value of their practical utilization) to have acquired importance. It could be that the availability of better technology made metal items progressively lose some of their exotic, arcane power, or that, at the same time, the emergence of a more powerful status symbol eroded its significance, possibly causing the reduction of the protective exclusivity of a better technology that was already present. Among these could have been colorful textiles, for which wool is better suited than flax, and which seem to have become fashionable in mainland Europe around this time.

Alternatively, the labor resources necessary to acquire metal items could have pushed to surplus production and in- and extensification, which in turn benefited from metal’s practical functionality. This push for more production, which can be indicated by the increase in farming and cereal-processing devices in the Copper Age (Contu 1997: 344-345; Lilliu 1988a: 122, 140) could have been due to the additional demand of grains for making beverages, as indicated by the increase in bottles, jugs, beakers, and possibly by tall jars and frequent caries in the same period (Coppa unpublished; Melis 2000d: 51-55; Vargiu and Coppa 2007).

The implications of the adoption of such innovations in terms of gender relations and role definition may have been profound, due to the specific requirements of labor and time. Processing wool is faster than flax, and since flax cultivation is more likely to have been in plots near the village it is also more likely to have been carried out by both men and women or by the latter. Conversely, the herding necessary for wool production was likely within the masculine realm of activities, which agrees with clues for a progressive take over of public, external roles by men and the bounding of women to more domestic ones (Hayden 1998). Also, the tasks of systematically grinding into flour, malting and brewing have been cross-culturally found to be often associated with women, and specific drinking modalities, or drinking itself, associated with men (Dietler 2006). Such laborious and time-consuming tasks (Jennings, et al. 2005), together with that of weaving, could have been adopted and possibly exploited through insertion in a progressive redefinition of roles, contributing to steering toward an increase in male dominance and appropriation of women’s labor (see McCorriston 1997 although in a very different context), which the portable figurines have been associated with (Cámara Serrano and Spanedda 2002). The isotopic evidence shows that dietary
differentiation by sex, and likely gender, was already in place in the Early Copper Age, and evidence for male seasonal mobility points to a radicalization of such a phenomenon at the transition into the Bell Beaker and Early Bronze Age. Since there is definitely no evidence from the stable isotopes for an increase in animal product consumption, it is likely that male symbolism does not match males’ increased productivity in nutritional terms. Livestock accumulation was another strategy to maximize symbolic capital, which is reflected in burial decoration (Cámara Serrano and Spanedda 2002; Tanda 2007) and clearly did not match the nutritional significance. There is again no clue for any relevance of the plow, nor of oxen as draft animals, in the value system of Sardinian prehistory.

From these processes it appears clear not only the relationship between technological change and cultural context, but also the importance of available technology and cultural exigencies on practices that in turn have an impact on the environment. Another clearly symbolic activity that seems to have gained progressively importance in coincidence with a starker definition of gender differences is hunting. Whereas elsewhere there are representations of hunting scenes in the Neolithic, in Sardinia it seems that they date to the Late Neolithic or more likely the Early Copper Age, with the first clearly sexed male figures (Basoli 1992; D’Arragon 1999b; Dettori Campus 1989a). If this slight delay is real, it would not be surprising, since large game is the powerful symbol linked to maleness in the mainland and elsewhere even today; Sardinia lacked large mammals after the Mesolithic, so that before stray pigs drifted enough to be perceived as wild, and before red deer was introduced and slowly spread over the whole island, no big game was readily available. Considering how deer particularly attracted the Neolithic people’s attention (Morter and Robb 1999: 89-92), I would speculate that even wild boar was not as crucial in constructing identities through the practice of hunting. Neolithic Sardinians may have had a unique constraint in this respect.

This lack of large game may also explain why during the Late Neolithic and Early Copper Age the emphasis was rather on the largest animal ever visible in anyone’s experience, cattle, which provided alternative settings for displays of maleness, as in the traditional East African societies or in the American West cowboy image. If the dualism between megalithic and underground burials is understood as an ideological arena for Neolithic/Copper Age politics, and we reflect on the admittedly scanty evidence concerning the distribution of the two types (Depalmas 2001), it is also possible to see a clash, in northern Sardinia, between different conceptions of society. A Neolithic world where the
community was the living space, and assets and land were managed in common near the village, versus a Copper Age world, characterized by increasingly generalized male authority, drinking and hunting, where the enlargement of exploitable land opened avenues to social differentiation. This also emphasized the kin group and its ancestors traceable within lived memory, rather than the whole community and its mythical ancestors: dolmens mark the use of the space and is a claim of more direct occupation and use rights. This should not translate into a dichotomy between egalitarian Neolithic and ranked Copper Age as full structured realities, but rather as ideological-symbolic frameworks in constant modification: in fact, as Cámara Serrano (2002) notes, communal principles can be manipulated to disguise and maintain inequality. The role of an impressive site such as Monte d’Accoddi since the Late Neolithic was probably more important than previously thought for the setting of models that permeated most of Sardinia.

The Monte Claro period appears, in this dialectic, on one side as a break, in its different pottery, neglect of lithics, burial customs, total aniconism, efficient organization in construction and ritual; on the other side, it appears as a possible reaction to the use of tradition to mask inequality: while the Post-Ozieri-pottery users were representing images of ancestors on stelae, depositing figurines in tombs, carving scenes in rock shelters and building monumental cemeteries in northwest Sardinia and at Pranu Muttedu (Antona 1998; Atzeni 2004; Atzeni and Cocco 1989; D’Arragon 1999; Tanda 1998), for the Monte Claro-pottery users there is not a single human figure documented at any site, whether in pottery or stone. Megaliths are erected in ritual areas within the village and are not connected to funerary rites (Castaldi 1999; Moravetti 2002). The burial customs in the south, and the arrangement of houses in the northern villages, point to an organization based on households, with some kind of social glue that did not leave material signs of power inequality. The isotopic values at Scaba ’e Arriu M seem to indicate such uniformity, and egalitarian instances, in their tight clustering together. It is suggested here that the timing of the beginning of such changes in material culture and of the relative social dynamics is compatible with a climatic trigger. The signs of contraction in village size in the southern and western lowlands, together with internal signs of environmental deterioration already suggested by Locci (1988) and likely coinciding with the first dry event of the 29th-26th centuries BC documented by stable isotopes, seem to have provided an opportunity for a break with tradition and something that resembles what we would expect ethnogenesis to
leave behind in the archaeological record. Without any radical change in the quality of diet and in the relative proportion of its sources (grains, animal products), diet up to the 24th century BC had a similar basis. Efficient organizational knowledge may have been acquired precisely in times of stress in the parched lowlands, to prove successful later in spreading a model of large, nucleated, compact stone-built villages. Whether we interpret the large jars typical of this period (Depalmas and Melis 1989) as storage implements or festive utensils for large quantities of drinks at social events that provided bonding experiences to the many households composing the fabric of society, this element appears to have been a symptom of an important phenomenon. Definitely there was no loss of personal identity as in the collective burials of most Ozieri and Post-Ozieri tradition: skeletal parts were often placed in distinct spots within the burials, as in vessels or within stone cists or simply stone-defined areas. The nuclear family and close kin seem to have been then at the basis of society.

As the overall diet remains similar to that of the Late Neolithic, mobility, according to the first stable isotopic results presented here, did not take off during the Copper Age either. Both Post-Ozieri and Monte Claro communities are sedentary relative to the Bell Beaker and Early Bronze Age as documented at Padru Jossu. It is reasonable to infer that the following dry spell in the 24th century, with the good correspondence of stable isotopic evidence, paleopathology and interruption in settlement continuity, provided this time a temporary advantage to the more mobile Bell Beaker groups. All Monte Claro sites were deserted, and sporadic if any signs of Bell Beaker and Early Bronze Age frequentation are known; furthermore, at some sites there are clues pointing to a sudden abandonment that left construction works unfinished (Moravetti 2002). The logical inference is that drought struck harshly the Monte Claro-pottery users, bringing their social system to an end. The inference made above for an augmented forest clearing related to mining and smelting activity in this period, along with the extensification of farming and herding suggested by the choice of hilly areas and by the implements to process grains and fiber, makes it likely that a heavier impact on thinner soils was in place. It is this combination of sustained exploitation and sudden climate change that determined the crisis, an interaction of human and natural factors as has been described and conceptualized (van der Leeuw and Aschan-Leygonie 2000). The Bell Beaker-using community of Padru Jossu may have had a broader and especially more flexible resource base and/or specific know-how, as shown by a diet relatively similar to that of the Copper Age groups, or more likely the more mobile Beaker lifestyle could have
provided support between different groups that experienced critical phases at different times and locations, as opposed to strictly sedentary groups.

What accompanied and followed the environmental crisis well into the Early Bronze Age is a high incidence of chronic disease (Germanà 1999). This, coupled with the shift of the diet toward a much heavier reliance on plant foods (detected isotopically), seems to be compatible with the archaeological record of severe food insecurity and malnutrition. Shortage of food leads to the inclusion of grain parts normally discarded, possibly reflected in increased occlusal wear; to cutting meal size, which can be easily done with grains unlike livestock; further phases in responses to famine are the decline in consumption of animal products and preference for starchy, nutritionally poor products high in carbohydrates (indicated by isotopic evidence); violence, raiding and stealing, for which trauma is the best archaeological proxy; all these phenomena are documented in present-day famine-stricken societies (Shipton 1990) and in Early Bronze Age Sardinia. Additionally, there is evidence for the breakdown of the existing social fabric into smaller units, as inferred from the little available evidence (Perra 1997; Usai 1994). The decline in pottery quality, in both plastic and paste refinement, is paralleled by the decline in the human presence in the landscape itself, which is limited to caves and reused tombs. Another effect of nutritional crisis is the opportunity for increased gender-based unbalanced relations, with women often at a disadvantage.

This study shows one clear example of how the historical ecology of a given landscape can only be interpreted as the complex interplay of various elements in the environment, including human groups, which must be understood in their general nature and in their arbitrary, symbolic, historically-specific context in order to account for their practices, and the (past) randomness of climate change. The reconstruction and interpretation of these complex interactions in Sardinian prehistory during the 4th and 3rd millennia BC, here barely started, serves the purpose of contributing to the building of a long-term history of the resource-use and of landscape changes in the Western Mediterranean, which can be useful to policy-makers to assess potential outcomes of current dynamics (Crumley 1994). Stable isotopes have proved an ideal instrument that, integrated in a holistic perspective with all the other proxies, can provide unique insights into past natural and cultural history.
9.1. Conclusions: Main Findings of This Study

This chapter intends to summarize the main findings of this research endeavor. These include the synthesis of previous data, the newly generated isotopic data and their implications in dietary and climatic terms, and the historical processes and events that can be reconstructed by integrating such evidence holistically.

The first, important point is that climate apparently did change significantly over the 4th and 3rd millennia BC; climatic phases are real, although not well defined quantitatively and chronologically (Bintliff 2002; Dincauze 2000: 23-7). The accurate translation of such phases in terms of temperature, rainfall variation and seasonality is not clear and often proxies for climate change are intermingled with the effects of human impact on the environment. A reconstruction was attempted for a sequence of drier and moister periods based on western Mediterranean data, and such a sequence was independently corroborated by the δ\textsuperscript{18}O data from Sardinian bone samples. Particularly, dry events that occurred in the 29\textsuperscript{th}-28\textsuperscript{th} centuries cal BC (Drysdale, et al. 2006; Magny 1993; Magri and Sadori 1995; Zielhofer, et al. 2004), and 24\textsuperscript{th}-23\textsuperscript{rd} centuries cal BC (Drysdale, et al. 2006; Jalut, et al. 2000; Magri 1997; Swezey, et al. 1999; Watts, et al. 1996) were confirmed, events which, it is argued, had profound effects on local ecology and history. Human activities such as fires, deforestation for agriculture, pastoralism and mining-related practices, widely documented in the rest of the western Mediterranean, are highly likely though yet unsubstantiated in Sardinia by positive evidence.

The overview of material culture evidence pinpointed, among other problems, the non-systematic and non-quantitative nature of most of it, with notable exceptions mostly related to the sphere of so-called artistic expressions (D'Arragon 1999b; Lilliu 1999; Tanda
The lack of proper documentation and/or the lack of proper publication of the primary data for the vast majority of known excavated sites often prevents any independent evaluation of the data. It was observed that the classification into archaeological cultures often is misleading since it stresses ceramic styles over more important indicators of continuity and discontinuity. Clues for changing social and symbolic systems are outlined and briefly evaluated, with the conclusion that while no institutionalized differentiation was ever found, the reproduction of such differentiation in terms of prestige and wealth may have been carried out through the use of ritual settings within a framework of segmentary societies. A less communal and more household-based ideology seems to have gradually permeated Sardinian communities from the Copper Age through the Early Bronze Age, with maleness (compare with Hayden 1998) and generalized wealth opposed to non-convertible sources of prestige, more typical of Neolithic social structure. This paralleled a political shift suggested for the Final Neolithic of mainland Italy (Robb 1999, 2007), from the ethnographically defined Great-Person model to the Big-Man, which would be archaeologically reflected in the occasional single articulated skeletons in contexts of generalized collective burial. The role of the Monte Claro culture seems to represent ambiguously aspects of innovation along with aspects of reaction to the transformation of the previous system, and some signs of adoption of older practices with modifications.

Economic and dietary data from traditional proxies such as faunal and botanical remains are highly inconsistent, and several phases are not represented at all. Furthermore, not many published analyses of faunal remains involve a comprehensive approach that goes beyond the presence and counts of species. Lithic and ceramic material culture for the most part has been thoroughly studied stylistically but the functional and economic aspects are still largely unexplored. All inferences based on them therefore remain tentative.

For the first time on a large scale, the stable isotopic data were corrected for climatic/geographic variation, a procedure suggested by several studies for collagen (Schwarcz, et al. 1999; van Klinken, et al. 2000; 1994) but not applied to the investigation of long-term, broad-scale variation. This allowed a more reliable comparison of different groups than is common in the literature. Furthermore, the use of the $\delta^{13}C_{col-apa}$ spacing rather than collagen alone enabled a triangulation of data that is necessary to produce meaningful dietary knowledge in the prehistoric Mediterranean where no $C_4$ plants, nor marine foods seem to have been relevant in human diet. This study indicates, in fact, that seafood consumption was
negligible or non-existent at all sites and phases sampled. The Late Neolithic diet is known only from one site, San Benedetto, and it shows a substantial role of animal products. The Copper Age and the Early Bronze Age, despite the traditional interpretation that identifies them as periods of immigration or influence of pastoralists as opposed to an agrarian Neolithic society, do not show higher consumption of animal products. Instead, the reliance on grains did not decrease, but possibly even increased after the turn of the 4th millennium BC in both the Post-Ozieri and Monte Claro sites analyzed, and such a trend became stronger in the Early Bronze Age groups, when diet was mostly based on plants.

The integration of the processed information concerning material culture, ideology and ritual, and economy, coupled with trends recorded elsewhere in the Western Mediterranean and the evidence of the isotopic data, was used to produce a model to attempt to explain the dynamics of interaction between natural and cultural, and climatic and human factors (van der Leeuw and Aschan-Leygonie 2000). The impact of humans on the environment was probably moderate until the 4th millennium BC. It seems that the emergence of social inequality was within a context of egalitarian ideologies, but it seems possible that in the north of Sardinia, possibly specifically following the model of the unique trajectory of Monte d’Accoddi, ritual, mortuary practices and feasting activities were used to reproduce, legitimize and even increase differentiation. An increase in trade and availability of exotica, coupled with such an increase in feasting and display, seems to have prompted intensification, definitely in agriculture, possibly also in animal husbandry, although secondary products were not crucial on a wide scale, and their exploitation was selective: no intense use of the plow, nor increase in dairy products were responsible for the economic change, but rather an increase in cereal cultivation.

The possible intensification of ovicaprine herding was likely a byproduct of the higher demand for wool, and of the development of an ideology of maleness that received strength by separation from the domestic village activities, increasingly assigned to women, which plausibly included horticulture, weaving and cereal processing. Stable isotopes show that the nutritional importance of grains increased over time: this fits with the more frequent hoe weights and grinding stones; the diffusion of hulled barley points to a specialized destination of part of the cereals to the production of beverages, which matches the increase in pottery shapes related to liquids and to individual consumption. Conversely, the increase in arrowheads as a percent of the total lithic tools compounds the male ideal of the hunter-
herder, emphasizing the construction of gender around the relationship with large-sized animals. The gendered female figurines during the Ozieri and Post-Ozieri Copper Age mirror such developments while being secondary agents for such a construction through material culture.

Economically, these cultural transitions signify that increasingly vast extensions of the landscape were devoted to pasture despite the nutritional relevance of animal products that did not increase at all. The spread of dolmenic burial monuments, particularly during the end of the 4th and the early 3rd millennium BC, symbolize the occupation and use of the territory between villages, with the double effect of strengthening and legitimizing land use rights and subtracting the household from the social obligations toward the community, which were expressed in the collective burial that involves the disassembling of bodies as the epitome of the normative, formal suppression of individual families’ aspirations to wealth and authority. This suggests the progressive use of marginal land for grazing, likely to have increasingly put a strain on vegetal cover and soils. Metalworking and mining, activities little investigated for prehistoric Sardinia, must have been important, as shown by the early silver artifacts and by the increasing presence of copper items during the 3rd millennium BC. The consequences of all these practices in terms of deforestation are still to be assessed, through pollen, phytolith analyses and all the other tools available.

Nineteen new AMS dates, still few but significantly more than those available prior to this study, in connection with the stable isotopic data and evaluated in light of the general trends recognized from other proxies, make it possible to outline a first overall reconstruction of the historical ecology of central-southern Sardinia and suggest the possible interplay of causes and effects that can account for the recorded changes. Climatic variation appears to have been mostly gradual until the 3rd millennium BC. In the 29th century, an unpredictable climatic oscillation lowered water tables, putting a severe strain on lowland environments where rainfall is normally much lower than the highlands. This, unless it refers to an earlier time, could be reflected at Su Coddu by the excavation of wells and by the deepening of the sunken houses (Onesti 2001; Ugas, et al. 1989). Most sites in the Campidano, in the southern and western lowlands, show abandonment or contraction in the number of inhabited huts in the following period, characterized by Monte Claro pottery (Atzeni 1962; Locci 1988), which has been AMS dated to ~2700-2300 cal BC. It is in this critical time that the culture of Monte Claro-pottery users takes shape, possibly within a context of intense contacts with other
Mediterranean regions such as southern France and Sicily. Rather than focusing on the coasts and the lagoons, which probably became shallower and brackish, it seems that the preference for new settlements goes to hills and dominant locations. A new conception of the person and of the family is mirrored in the single burials of the southern lowlands; however, the adoption of the Monte Claro pottery in the rest of the island is accompanied by a continuation of the collective burial. On the other hand, there are signs of clearing of previous remains and restructuring of the burial (Pitzalis 1996; Usai 1998), which point to a somewhat different sense of identity. This is also reflected in the full aniconism (no figurative art) and sobriety in every craftwork expression, as opposed to the Post-Ozieri tradition, rich in anthropomorphism, painting, and decoration. If the ethnic interpretative key will be found to be correct, the borderlines between the areas of distribution of the two groups might be documented in the 25th century BC around the hills of Marmilla, Sarcidano, Mandrolisai and Gerrei (Atzeni 1996c; Atzeni and Cocco 1989; Perra 1994; Saba 2000), where there is a high concentration of statue-menhirs and megalithic monuments from the latest successors of the long Ozieri tradition. The first appearance of defensive-ceremonial enclosures in the north of Sardinia dates to this period, and while it regards mostly the Monte Claro contexts (Castaldi 1999; Moravetti 2000), it also characterizes some Post-Ozieri sites.

The opportunity for a faster pace of gender definition along the lines described above may have been provided by the dry event of the 29th-27th centuries BC: from this period on, there is an average difference in δ18O between males and females that can be connected with periods spent in the summer pasture preferably by men, a trend that is radicalized at Padru Jossu during the Copper to Bronze Age transition. This can be read both functionally and as a result of agency, since it had the purpose of preserving the assets (livestock) from loss during summer drought while providing a way of reproducing and emphasizing gender relations through practice. At this time, mobility was for short periods of time and/or within a shorter radius from the village.

Ovicaprine pastoralism may have been still related to wool production, as indicated by the loom weights at Monte Claro sites and as argued for the Bell Beaker period in the European mainland based on the new designs. Some dietary contribution of animal products is still documented isotopically for the Monte Claro sites and Padru Jossu A. The same practices that rendered the soils and the environment in general fragile at the moment of the 29th century BC dry event were likely still occurring in the 24th century BC. Metal was more
common, as shown by the common utilitarian items as compared to the prestige jewelry of the Post-Ozieri tradition; this probably involved exploitation of the local mines with the related wood consumption. Grazing of ovicaprids was likewise likely practiced, despite no faunal analyses being available so far for Monte Claro sites. We can imagine a landscape where land was mostly cultivated around the village, pasture lay between villages, with patches of evergreen oak, shrubs and secondary forest deriving from growth after periodic fires, which the presence of pigs and deer made hunting grounds. Some Bell Beaker groups, whether acculturated locals or to some extent immigrated, were present, possibly in ore-rich areas, probably since the 27th-26th century BC. Interestingly, no intermingled dwelling contexts have yet to be found, which could be due to the Bell Beaker users camping in perishable shelters and caves as opposed to the Monte Claro settlements.

After the second dry event struck the island as it did for the rest of the Mediterranean area in the 24th century BC, it appears that the Monte Claro pottery users were not as well equipped as the Bell Beaker groups: Monte Claro villages, whether they had been inhabited from previous phases or founded anew, were all deserted afterwards. Only sporadic frequentation is attested in the Early Bronze Age. The magnitude of the environmental crisis, which could have resulted in over 500 mm/year less than the previous several hundred years, was evidently greater than the coping capacity of the village-dwellers’ communities. A social system apparently concentrated on the large nucleated village and on the household, as shown by the data on house layouts and domestic economy (Castaldi 1999), which probably enjoyed fewer or weaker connections with neighboring groups for mutual support, and did not have the means to react to the changing conditions.

Conversely, the more mobile Bell Beaker groups, which quite limited faunal evidence (Sorrentino 1982) corroborated by isotopic evidence (both in terms of diet and in terms of mobility) depicts as communities reliant on grains and ovicaprids with a substantial role of seasonal movements, are the only group that leaves a visible and lasting legacy into the Early Bronze Age. It seems likely that the dry spell, after favoring the decline of the village social structure, within less than two centuries also affected heavily the Bell Beaker lifestyle. Average life expectancy may have declined, chronic illnesses due to malnutrition and possibly multiple interacting factors like parasites and infectious diseases are reflected in the high levels of cribræ. The apparent increase in tooth wear, particularly surprising if coupled with the lower average age at death, could have been due to a widening of the resource pool.
to less processed and ‘emergency foods’ (Shipton 1990), and possibly, to a certain degree, also to anxiety-related bruxism (grinding teeth). A broadened and highly diversified diet such as detected isotopically at Padru Jossu, not at a community scale but at an individual scale, also points to phenomena related to times of crisis. The crisis seems to have profoundly modified social relations at Padru Jossu as detected through stable isotopes, within a few generations. At Padru Jossu A we can recognize a structure where men and women had more distinct roles visible in a differential access to animal products and in their differential mobility; moreover, mature individuals also appear to have had a better access to animal products than young adults. The nutritional crisis of the 24th-23rd centuries BC broke these gender roles, reducing dietary differences between males and females and probably causing the contraction of the transhumance that characterized the Bell Beaker phase, which is not detected at the later site of Iscalitas. In this case, women seem to have taken the opportunity to redefine their identity, also based on their role in overcoming the crisis. If, as seems reasonable, agricultural production was part of their tasks, women could have gained negotiating power due to their fundamental role in providing daily foods in times of scarcity.

The assumed better adaptive fitness of mobile resources during droughts that was hypothesized at the outset of this study does not seem reflected in the data. As supported by present-day reviews on the effects of food insecurity and famine, grains and starchy foods have the advantage of being potentially partitioned in smaller units based on need, a quality that livestock does not possess. In fact, it appears that pastoralists today suffer from famine more than agriculturalists do, since their reliance on traded grains makes them more vulnerable (Shipton 1990). A pattern compatible with this scenario can be recognized in the Sardinian lowlands during the environmental crisis of the 24th-23rd centuries BC. This highlights an area of broader anthropological interest that, due to the type of evidence generally available, has been comparatively neglected by prehistorians, who lack historical sources: the archaeology of famine. Famine is commonly related to marginalization in the context of complex and hierarchically organized societies, whereas it has not been investigated as much in less complex organizational contexts.

Among the methodological contributions of this study to prehistoric archaeology, some revolve around the connection of two aspects rarely joined: one is the integration of several isotopic indicators providing data on diet, mobility and climate; the other is the time-depth, which aims at detecting change over time. Most in-depth isotopic studies examine
single sites or groups of sites, emphasizing a synchronic perspective. The rare attempts of synthesis have concerned only collagen (e.g., Craig, et al. 2006), and are a collection and commentary of previous studies, not original research designed as a unit. This is what was attempted here. Furthermore, the holistic perspective adopted in the interpretation brought insights to explain change in a framework of interaction of natural and cultural factors. This helped reconstruct the dynamics that shaped the Sardinian natural and cultural landscape between the 4th and 3rd millennia BC, showing the relevance of climate change in affecting environments that were already fully transformed by human practices. The importance of changing values, agents and roles in the history of ecological relations among the natural and human counterparts was also highlighted.

It seems that the likely intensification/extensification of agriculture, animal husbandry and possibly mining thinned the soils, making the ecological system vulnerable to climatic shifts. While this was part of a gradual development until the Early Copper Age for the communities of Post-Ozieri heritage (ca. 4000-2850 cal BC), a first impact of climatic change (ca. 2850-2600 cal BC) offered the opportunity for a different kind of social and ideological model to take shape and thrive. Such a different complex of practices and meanings that was advantageous, with better climatic conditions, to the Monte Claro pottery users (ca. 2600-2350 cal BC) became a disadvantage when conditions changed again. At this time, different lifestyles and maybe human groups had entered the scene, who were less sedentary, possibly more flexible due to their organization in smaller kin groups, and probably had better trade and exchange networks as buffers in critical times. The speed and magnitude of the second arid event (ca. 2350-2200 cal BC) was evidently enough to determine the breakdown of organized village life and of the cultural landscape as was known up to that period. The severity of the crisis is reflected in profound changes in the communities of descendants of the Bell Beaker users: gender roles were again redefined in a social context of largely autonomous yet intensely interacting households, which would be the foundation for the Middle Bronze Age societies (Sa Turricula and Nuragic).

9.2. Suggestions for Future Research and Final Remarks

A few directions can be suggested for future research to address the large gaps in our documentation and understanding of 4th and 3rd millennium societies in Sardinia. The huge
mass of data on material culture, particularly in ceramic and lithic implements and tools, needs to be organized and quantified. Old reports, both published and unpublished, should be used to gather such information and organize it meaningfully. Similar efforts are also needed concerning site sizes and location: the use of remote sensing, systematic surveys and GIS systems is still at its first steps. As far as prehistoric economy goes, zooarchaeological and botanical reports and studies are still scarce. An effort to include them in the design of excavation projects has to be made, rather than leaving their analysis to separate initiatives: this way, recovery can benefit from truly interdisciplinary teamwork, producing data that are better and readily available. Analyses of soils are still virtually unknown at most excavations in Sardinia.

As concerns osteology and paleopathology, there is a great need of data on specific aspects beyond basic age and sex identification and classification of skeletal elements. The production of large datasets using standardized methods, and their investigation through statistics, is extremely important to assess in a quantifiable and comparative way indicators such as dental health, trauma, malnutrition, infectious diseases, sexual dimorphism, and stress markers. Large, coordinated efforts are needed to take our knowledge of Sardinian skeletal collections above the consideration of single individuals or small groups.

Paleoclimatic studies are needed to test whether the data from the rest of the Western Mediterranean and those presented in this dissertation find correspondence in other proxies. Sardinia is still almost a black hole in the larger picture of the Middle and Late Holocene climate reconstruction in the Mediterranean area. Paleoenvironmental studies are absolutely necessary to provide the missing link between what can be documented in the cultural realm, in bioarchaeology and paleoclimatology. The effects of humans and climate on the environment, in the present work mostly inferred by analogy with the rest of the Western Mediterranean and from isotopic data of related indicators, need to be measured in terms of changes in pollens, soils and the like, which for Sardinia are still almost totally absent.

The use of AMS dating should as well be included in excavation budgets. This way it can be incorporated as standard information and it can also inform the project design in progress in campaigns lasting several years. The accuracy of the chronology of Sardinian prehistory is light-years behind if compared with southern France, Northern Italy, and even with Corsica and the Balearics, where the dates go by the hundreds or thousands. In Sardinia,
dates are still counted by the tens for each broad phase, over forty years after radiocarbon
dating technology became available.

Finally, in addition to the above points mostly related to methods and data collection,
more theoretical work is necessary to guide all such activities. Too much archaeology in
Sardinia is done with no clear research questions deriving from theoretical debates, and still
strongly attached to the culture-historical beginnings of the discipline where the main aim is
still documenting material culture and the related chronologic sequences per se. Relatively
little has been attempted to understand dynamics of social reproduction and change,
economy, and meaning systems. There are no specific courses in Archaeological Theory at
the main Sardinian universities, and a large part of scientific production is limited to the
presentation of data and their description. Signs of change are present, but slow to spread and
widen. Archaeology must be meaningful for the present, and this must go beyond the income
for local communities provided by museums. Archaeology has the unique strength of
possessing a long-term perspective, methods that can push back the extent of history several
thousand years earlier than the arbitrary cut off point of the beginning of writing. In this
sense, it is in a special position to identify long-term processes and punctuated turning points.

Making this history, and reading it as the historical ecology of interaction among
environmental elements and human groups (Crumley 1994), can help shape the public
opinion in view of modern resource management, at a time of incipient climate change and
fast-changing economic relations. It can also provide policy-makers with useful knowledge to
bear upon decisions on the use and management of a territory and, it is hoped, help solve the
problems of today’s world (van der Leeuw and Aschan-Leygonie 2000).

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Appendix
Appendix (continued)

**Table 28. San Benedetto, tomb II. All isotopic values.**

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<tr>
<th>USF#</th>
<th>enam (tooth type)</th>
<th>Subgroup</th>
<th>Context</th>
<th>Bone Collagen</th>
<th>Bone Apatite</th>
<th>Tooth Enamel</th>
<th>Averages</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>col apa (tooth type)</td>
<td># ind.</td>
<td>sex</td>
<td>age class</td>
<td>culture*</td>
<td>date</td>
<td>x1000 BC</td>
</tr>
<tr>
<td>6946.b</td>
<td>6962</td>
<td>Cr.1</td>
<td>M</td>
<td>Adu</td>
<td>POZ</td>
<td>-3.4-3.0</td>
<td>-19.6</td>
</tr>
<tr>
<td>6947</td>
<td>6963</td>
<td>Cr.2</td>
<td>F</td>
<td>Adu</td>
<td>POZ</td>
<td>-3.4-3.0</td>
<td>-19.6</td>
</tr>
<tr>
<td>6948</td>
<td>6964 7125 (ml1)</td>
<td>Cr.3</td>
<td>F</td>
<td>Adu</td>
<td>POZ</td>
<td>-3.4-3.0</td>
<td>-18.9</td>
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<tr>
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<td>6965</td>
<td>Cr.4</td>
<td>M</td>
<td>Sen</td>
<td>POZ</td>
<td>-3.4-3.0</td>
<td>-19.6</td>
</tr>
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<td>6966</td>
<td>Cr.5</td>
<td>F</td>
<td>Sen</td>
<td>POZ</td>
<td>-3.4-3.0</td>
<td>-19.5</td>
</tr>
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<td>6967</td>
<td>Cr.6</td>
<td>F</td>
<td>Sen</td>
<td>POZ</td>
<td>-3.4-3.0</td>
<td>-19.6</td>
</tr>
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<td>6952</td>
<td>6968</td>
<td>Cr.10</td>
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* OZI= Ozieri (40th-35th cent. BC).

**Table 29. Cannas di Sotto, tomb 12. All isotopic values.**

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<th>Tooth Enamel</th>
<th>Averages</th>
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* POZ= Post-Ozieri (34th-25th cent. BC).
### Table 30. Serra Cannigas, tombs A and B. All isotopic values.

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Averages: -19.0 10.9 -13.4 -4.3 -19.0 10.9 -13.4 -4.3 -6.3

* POZ= Post-Ozieri (34th-25th cent. BC).

### Table 31. Santa Caterina di Pittinuri. All isotopic values.

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Averages: -19.5 9.5 -14.6 -4.3 -19.5 9.5 -14.6 -4.3 -4.9

* POZ= Post-Ozieri (34th-25th cent. BC).

### Table 32. Mind’e Gureu. All isotopic values.

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<th>Bone Apatite</th>
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* POZ= Post-Ozieri (34th-25th cent. BC).
## Table 33. Scaba ’e Arriu (A, Post-Ozieri phase). All isotopic values.

| USF# | Enam (tooth type) | # ind. | Sex | Age class | Context | Bone Collagen | Bone Apatite | Tooth Enamel | Apatite | δ¹³C | δ¹⁵N | δ¹³C | δ¹⁸O | δ¹³C |
|------|-------------------|--------|-----|-----------|---------|---------------|--------------|--------------|---------|-------|-------|-------|-------|-------|-------|
| 6988 | 7021              | 4628   | F   | Adu       | POZ     | -3.1-2.6      | -19.2        | 9.6          | -12.5   | -3.5  | -6.7  |
| 6989 | 7022              | 3747   | F   | Adu       | POZ     | -3.1-2.6      | -18.9        | 10.3         | -11.0   | -3.4  | -7.9  |
| 6990 | 7023              | 5949   | M   | Adu       | POZ     | -3.1-2.6      | -19.4        | 10.4         | -7.7    | -1.4  | -11.7 |
| 6991 | 7024              | 4323+432 | 4   | M   | Adu       | POZ     | -3.1-2.6      |             |         |       |       |       |       |       |
| 6992 | 7025              | 5101   | M   | Adu       | POZ     | -3.1-2.6      | -19.5        | 10.1         | -11.7   | -3.8  | -7.8  |
| 6993 | 7026              | 6796   | M   | Adu       | POZ     | -3.1-2.6      | -18.8        | 11.8         | -11.3   | -3.1  | -7.5  |
| 6994 | 7027              | 4631+463 | 3   | M   | Adu       | POZ     | -3.1-2.6      | -19.4        | 10.4         | -11.5   | -3.4  | -7.9  |
| 6995 | 7028              | 6795   | M   | Adu       | POZ     | -3.1-2.6      | -19.4        | 11.0         | -11.7   | -3.7  | -7.7  |
| 6996 | 7029              | 5950   | F   | Adu       | POZ     | -3.1-2.6      | -19.3        | 9.3          | -10.5   | -2.5  | -8.9  |
| 6997 | 7030              | 1480   | F   | Adu       | POZ     | -3.1-2.6      | -19.3        | 10.0         | -12.3   | -3.9  | -7.0  |
| 6998 | 7031              | 4938   | Inf | Inf       | POZ     | -3.1-2.6      | -19.3        | 9.9          | -11.5   | -3.4  | -12.6 | -3.4  | -7.8  |
| 6999 | 7032              | 4332   | Inf | Inf       | POZ     | -3.1-2.6      | -19.3        | 11.2         | -11.2   | -3.5  | -11.9 | -3.1  | -8.2  |
| 7001 | 7033              | 7686   | Inf | Inf       | POZ     | -3.1-2.6      | -19.3        | 10.1         | -12.1   | -3.2  | -12.3 | -3.3  | -7.2  |
| 8697 | 8666              | 4325+432 | 7   | M   | Adu       | POZ     | -3.1-2.6      | -19.1        | 11.9         | -11.4   | -3.0  | -7.7  |
| 7015 | 7047              | 3222   | M   | Adu       | POZ     | -3.1-2.6      |             |             |         |       |       |       |       |       |
| 7016 | 7048              | 4575   | M   | Adu       | POZ     | -3.1-2.6      |             |             |         |       |       |       |       |       |
| 7017 | 7049              | 2138   | M   | Adu       | POZ     | -3.1-2.6      |             |             |         |       |       |       |       |       |
| 7018 | 7050              | 4886   | M   | Adu       | POZ     | -3.1-2.6      |             |             |         |       |       |       |       |       |
| 7019 | 7051              | 1479   | M   | Adu       | POZ     | -3.1-2.6      |             |             |         |       |       |       |       |       |
| 7020 | 7052              | 4151   | Inf | Adu       | POZ     | -3.1-2.6      | -19.0        | 10.9         | -13.1   | -3.8  | -13.1 | -3.5  | -5.9  |

**SCA Averages**

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<th>δ¹³C</th>
<th>δ¹⁸O</th>
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* POZ= Post-Ozieri (34th–25th cent. BC).
### Table 34. Scaba ’e Arriu (M, Monte Claro phase). All isotopic values.

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<th>Bone Apatite</th>
<th>Tooth Enamel Apatite</th>
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</table>

SCM Averages: -19.1 10.9 -13.0 -3.9 -12.0 -4.4 -6.0

* MCL= Monte Claro (27th-23rd cent. BC).

### Table 35. Seddas de Daga (cave II). All isotopic values.

<table>
<thead>
<tr>
<th>USF#</th>
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<th>Context</th>
<th>Bone Collagen</th>
<th>Bone Apatite</th>
<th>Tooth Enamel Apatite</th>
<th># ind.</th>
<th>sex</th>
<th>age</th>
<th>class</th>
<th>culture*</th>
<th>date</th>
<th>δ13C</th>
<th>δ15N</th>
<th>δ13C</th>
<th>δ18O</th>
<th>δ13C</th>
<th>δ18O</th>
<th>δ13C</th>
<th>col-apa</th>
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<td>a.</td>
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<td>F</td>
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SCM Averages: -19.9 7.3 -13.2 -4.3 -6.7

* MCL= Monte Claro (27th-23rd cent. BC).
Table 36. *Su Stampa ’e Giuannicu Meli*. All isotopic values.

<table>
<thead>
<tr>
<th>USF#</th>
<th>Subgroup</th>
<th>Context</th>
<th>Bone Collagen</th>
<th>Bone Apatite</th>
<th>Tooth Enamel Apatite</th>
<th>Tooth Collagen Apatite</th>
</tr>
</thead>
<tbody>
<tr>
<td>col</td>
<td>enam (tooth type)</td>
<td># ind.</td>
<td>sex</td>
<td>age</td>
<td>date x1000 BC</td>
<td>δ(^{13})C</td>
</tr>
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<td>M 9507</td>
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<td>~2.9-2.4</td>
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<td>10.3</td>
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<tr>
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<td>F 9508</td>
<td>355+179 =ad. 2 Casula F Adu ?</td>
<td>~2.9-2.4</td>
<td>-18.6</td>
<td>9.5</td>
<td>-10.2</td>
</tr>
<tr>
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<td>M 9509</td>
<td>303=ad. 3 Casula M Adu ?</td>
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<tr>
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<td>F 9511</td>
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<tr>
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<td>210=infant 2 Casula Inf Inf ?</td>
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<td>-9.3</td>
</tr>
<tr>
<td>9505</td>
<td>Inf 9514</td>
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<tr>
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Table 37. *Sa Duchessa (Via Trentino tomb I, Via Basilicata tombs I and IV)*. All isotopic values.

<table>
<thead>
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<th>USF#</th>
<th>Subgroup</th>
<th>Context</th>
<th>Bone Collagen</th>
<th>Bone Apatite</th>
<th>Tooth Enamel Apatite</th>
<th>Tooth Collagen Apatite</th>
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<tr>
<td>col</td>
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<td>age</td>
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<td>Adu</td>
<td>MCL</td>
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<tr>
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<td>Adu</td>
<td>MCL</td>
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<td>Adu</td>
<td>MCL</td>
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<td>Averages</td>
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</table>

* MCL= Monte Claro (27th-23rd cent. BC).
### Table 38. Padru Jossu A and M (Bell Beaker and Monte Claro). All isotopic values.

<table>
<thead>
<tr>
<th>USF#</th>
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<th>Bone Apatite</th>
<th>Tooth Enamel Apatite</th>
<th>Padru Jossu Averages</th>
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<td>sex</td>
<td>age</td>
<td>culture</td>
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<td>BKR</td>
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</tr>
<tr>
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<td>6927</td>
<td>Cr.70+71</td>
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<td>Juv</td>
<td>BKR</td>
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<td>6940</td>
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<td>M</td>
<td>Sen</td>
<td>BKR</td>
<td>-2.5-2.1</td>
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<td>M</td>
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<td>Juv</td>
<td>Juv</td>
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<td>6944</td>
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<td>Adu</td>
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<td>BKR</td>
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<td>M</td>
<td>Adu</td>
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<td>Inf</td>
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<td>M</td>
<td>Sen</td>
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<td>F</td>
<td>Adu</td>
<td>MCL</td>
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* BKR = Bell Beaker (27th-22nd cent. BC).
## Table 39. Padru Jossu B (Early Bronze Age phase). All isotopic values.

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<th>USF#</th>
<th>Bone Apatite ( \delta^{13}C )</th>
<th>Bone Collagen ( \delta^{13}C )</th>
<th>Tooth Enamel ( \delta^{13}C )</th>
<th>enamel ( \delta^{13}C )</th>
<th>col-apa ( \delta^{13}C )</th>
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</table>

* BNA = Bonnanaro A (23rd-20th cent. BC).
Appendix (continued)

Table 40. Iscalitas. All isotopic values.

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<tr>
<th>USF#</th>
<th>Subgroup</th>
<th>Context</th>
<th>Bone Collagen</th>
<th>Bone Apatite</th>
<th>Tooth Enamel</th>
<th>Enamel Type</th>
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<td>δ¹⁵N</td>
<td>δ¹⁸O</td>
<td>δ¹³C</td>
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<td>apa</td>
<td>enam (tooth type)</td>
<td># ind.</td>
<td>sex</td>
<td>age</td>
<td>culture</td>
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<td>M</td>
<td>Sen</td>
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<td>Adu</td>
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<td>Inf</td>
<td>Inf</td>
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<td>Inf</td>
<td>Inf</td>
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<td>8592</td>
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<td>Cr.C37</td>
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<td>Adu</td>
<td>BNA =</td>
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<tr>
<td>8622.2</td>
<td>8593</td>
<td>Cr.C42</td>
<td>M</td>
<td>Juv</td>
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<td>8595</td>
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<td>Juv</td>
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<td>Adu</td>
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<td>-2.3-1.8</td>
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</tbody>
</table>

Averages: \(-19.1 \quad 10.4 \quad -10.4 \quad -4.6 \quad -8.7\)

* BNA = Bonnanaro A (23rd-20th cent. BC).
### Table 41. Concali Corongiu Acca II. All isotopic values.

<table>
<thead>
<tr>
<th>USF#</th>
<th>Subgroup</th>
<th>Context</th>
<th>Bone Collagen</th>
<th>Bone Apatite</th>
<th>Tooth Enamel Apatite</th>
</tr>
</thead>
<tbody>
<tr>
<td>col</td>
<td>enam</td>
<td># ind.</td>
<td>sex</td>
<td>age</td>
<td>culture*</td>
</tr>
<tr>
<td></td>
<td>apa</td>
<td>sex</td>
<td>age</td>
<td>class</td>
<td>date</td>
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<td>Cr.1</td>
<td>M</td>
<td>Adu</td>
<td>BNA</td>
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<td>Adu</td>
<td>BNA</td>
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<td>Juv</td>
<td>Juv</td>
<td>BNA</td>
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<td>BNA</td>
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<td>6987</td>
<td>Cr.5</td>
<td>Ind</td>
<td>Adu</td>
<td>BNA</td>
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</table>

**Averages**

-18.9 | 11.4 | -15.6 | -4.3 | -3.4

* BNA = Bonnanaro A (23rd-20th cent. BC).

### Table 42. Is Aruttas. All isotopic values.

<table>
<thead>
<tr>
<th>USF#</th>
<th>Subgroup</th>
<th>Context</th>
<th>Bone Collagen</th>
<th>Bone Apatite</th>
<th>Tooth Enamel Apatite</th>
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</thead>
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<td>col</td>
<td>enam</td>
<td># ind.</td>
<td>sex</td>
<td>age</td>
<td>culture*</td>
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<td></td>
<td>apa</td>
<td>sex</td>
<td>age</td>
<td>class</td>
<td>date</td>
</tr>
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<td>M</td>
<td>Adu</td>
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<td>M</td>
<td>Sen</td>
<td>NUR</td>
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<td>Inf</td>
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<td>Sen</td>
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<td>Cr.13</td>
<td>Juv</td>
<td>Juv</td>
<td>NUR</td>
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</table>

**Averages**

-18.6 | 10.4 | -10.3 | -1.3 | -8.3

* NUR = Nuragic (16th-6th cent. BC).
Appendix (continued)

**Table 43. Montessu. All isotopic values.**

<table>
<thead>
<tr>
<th>USF#</th>
<th>Subgroup</th>
<th>Context</th>
<th>Bone Collagen</th>
<th>Bone Apatite</th>
<th>Tooth Enamel Apatite</th>
<th>δ13C col-apa</th>
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<td>col</td>
<td>apa</td>
<td># ind.</td>
<td>sex</td>
<td>age</td>
<td>culture*</td>
<td>date x1000 BC</td>
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</tr>
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<td>9556</td>
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<td>Adu</td>
<td>JUD</td>
<td>-0.8-1.2 AD</td>
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<td>9557</td>
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<td>F</td>
<td>Sen</td>
<td>JUD</td>
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<tr>
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<td></td>
<td>Montessu</td>
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<td>t.33</td>
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</table>

* JUD = Judges (10th-15th cent. AD); TUR = Sa Turricula (19th-17th cent. BC).

**Table 44. All isotopic values for faunal and botanical samples.**

<table>
<thead>
<tr>
<th>USF#</th>
<th>Site</th>
<th># individual</th>
<th>Species</th>
<th>Phase*</th>
<th>Collagen/ Soft Tissue</th>
<th>Bone Apatite</th>
<th>Tooth Enamel Apatite</th>
<th>δ13C col-apa</th>
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<td>δ15N</td>
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<td>Mugil sp.</td>
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<td>Merlucius m.</td>
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<td>Mrk 3</td>
<td>Mullus b.</td>
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<td>8.2</td>
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<td>Mrk 4</td>
<td>Aristeidae fam.</td>
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<td>Mrk 5</td>
<td>Mytilus sp.</td>
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<td>Mrk 6</td>
<td>Chamelea g.</td>
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<td>Mrk 7</td>
<td>Loliginidae fam.</td>
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<td>12.4</td>
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<td>Mrk 8</td>
<td>Anguilla a.</td>
<td>C</td>
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<td>Mrk 9</td>
<td>Xiphias g.</td>
<td>C</td>
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<td>17.6</td>
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<td>Sus s. merid.</td>
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<td>SCP A.89</td>
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<td>Sus s.</td>
<td>PO</td>
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<td>Sus s.</td>
<td>PO</td>
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<td>Cervus e.</td>
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<td>-4.4</td>
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<td>SCP A.1</td>
<td>Vulpes v.</td>
<td>PO</td>
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<td>7.0</td>
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<td>-2.7</td>
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<td>Prolagus s.</td>
<td>PO</td>
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<td>-11.7</td>
<td>-0.8</td>
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</tbody>
</table>

* C = Contemporary; M = Modern Age (19th century); PO = Post-Ozieri (mid-4th to mid-3rd millennium BC).
### Table 44 (continued). All isotopic values for faunal and botanical samples.

<table>
<thead>
<tr>
<th>USF#</th>
<th>Site</th>
<th># individual</th>
<th>Species</th>
<th>Collagen/ Soft Tissue</th>
<th>Bone Apatite</th>
<th>δ¹³C</th>
<th>δ¹⁵N</th>
<th>δ¹³C</th>
<th>δ¹⁸O</th>
<th>Site (Contemporary)</th>
</tr>
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<td>apa</td>
<td>Site</td>
<td># individual</td>
<td>Phase*</td>
<td></td>
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<td>PO</td>
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<td>F 566</td>
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<td>PO</td>
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<td>PO</td>
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<td>F 171</td>
<td>Ovis/Capra</td>
<td>PO</td>
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<td>7.1</td>
<td>-10.8</td>
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*C = Contemporary; PO = Post-Ozieri (mid-4th to mid-3rd millennium BC).
About the Author

Luca Lai grew up in Tertenia, Ogliastra, eastern Sardinia. He went to college at the University of Cagliari, graduating in Classical Literature in 1998, while gaining field experience in archaeological excavation. He pursued a Master’s degree in Sardinian Studies at the same university, graduating in 2001 with a thesis on Bronze Age sites in eastern Sardinia. Funded by a fellowship from the Autonomous Region of Sardinia, he started in 2002 a Ph.D. program in Applied Anthropology, Archaeology track, at the University of South Florida. His research interests span the prehistory and history of Sardinia and the western Mediterranean, in long term perspective and with emphasis on the dynamics of change. He focuses on the integration of scientific and historical approaches, using different methods such as stable isotopy and archival studies. He was awarded a Doctoral Dissertation Improvement grant from the National Science Foundation to fund the project presented in this dissertation.