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KARST AND AGRICULTURE IN THE WORLD

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Presentation

Continuing with the editorial policy of the last few years, we present a new issue of the International Journal of Speleology. The decision to publish a series of monograph issues was made with the aim of providing a panorama, as complete as possible, of some topics of general interest.

On this occasion, the topic is the complex relationship between karst and the development of agriculture. Few topics like this one are able to represent the technological evolution of human communities, their social relationships and the different modalities of resource exploitation, as well as the continuous search for an equilibrium between the need to assure the maintenance of food resources and the risk of generating serious, if not irreversible, degradation of the environment.

As in the case of the volume *Gypsum Karst of the World* (vol. 25 - 1996), we have tried to offer a panoramic view of the various environmental realities present throughout the world, for a broad comparison in which the current situation can be interpreted in the light of historical evolution. In fact, many contributions pertain to the Mediterranean area (the Balearic Islands, France, Italy, the Dinaric area, Turkey, Israel, Morocco), in which there is an age-old superimposition of various types of agricultural practices that have left indelible signs on the landscape. The situation in eastern Europe is analysed, with particular reference to forest contexts, in two contributions concerning Hungary and the Czech Republic. For the Americas, attention is directed to the Brazilian and Cuban situations. Finally, an article on China and one on Australia complete the panorama of the relationship between karst and agriculture.

*The Editors*

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AGRICULTURE, GRAZING AND LAND USE CHANGES AT THE SERRA DE TRAMUNTANA KARSTIC MOUNTAINS

Ángel Ginés

ABSTRACT
Karst landforms are one of the most outstanding characteristics of the Serra de Tramuntana range on the island of Mallorca, especially regarding traditional farming and the landscape wilderness. Good examples of polje-like depressions, dolines, karstic gorges and karrenfields are widely distributed over the mountain range. Owing to karrenfields occupying a large surface area in the Serra to the exclusion of arable land, the traditional activity based on the repetitive burning of the *Ampelodesmos mauritanica* brushwoods for cattle-raising promotes hastening deforestation and soil removal.

KEY WORDS: traditional farming, deforestation, agriculture on-karst, livestock on-karst, Mediterranean karst

1. Introduction
Karst is probably the most significant factor regarding land use and traditional farming in the Serra de Tramuntana range of Mallorca. About 65% of the mountains are built of limestone outcrops and many of them show the effects of karstification. Scarcity of water and soil resources have over centuries conditioned the human settlements. Rugged terrains have become a harsh restriction to cattle-raising. The difficult pathways climbing over the steep rocky slopes, as well as the prevailing large estates existing in the Serra, have promoted a kind of self-sufficient rural exploitation called possessions. On the whole, the current landscape of the Serra de Tramuntana is the result of a mixture of karstic wilderness and humanized features such as terraces, cultivated areas and farmhouses, whose economical upkeep is nowadays uncertain.

2. Geological and physical setting

The Serra de Tramuntana range is the main mountain area on the island of Mallorca (Fig. 1). Over a length of 90 km and a width of 15 km, this chain lies on the north-west border of the island and occupies a surface area of approximately 1000 km$^2$. It is aligned NE-SW, following the structures of the Balearic Promontory that are the prolongation of the Betic chains. The highest summit is called Puig Major (1445 metres in altitude), but the mountains exceeding 1000 metres number at least fourteen. Owing to the geometry of the thrust system imbrications, the slopes are steep towards the coast but a high energy relief is the common trend all over the Serra. Nearly a third of the total area exhibits a 20% gradient or more, which renders such terrain unsuitable for agricultural exploitation.

The structure of the Serra de Tramuntana is the result of Alpine compressive events occurred between Late Oligocene and Middle Miocene (Gelabert et al., 1992). The existence of a NW-directed fold and thrust system is the most outstanding characteristic. Thrusts are gently dipping to the southeast and the piles of thrust sheets are imbricated for several hundred meters in thickness on the central part of the Serra, striking NE-SW. Due to the sheet imbrications, the topographic recurrence of limestones and shale and marly rocks creates a distinctive sawtooth relief. Extensional faults, active since the Late Miocene, account for the boundaries of the mountain range.

Triassic, Jurassic and Miocene rocks constitute more than 80% of the outcrops in the Serra de Tramuntana area. Quaternary deposits, such as scree, colluvium and some alluvial sediments form almost 10% of the total surface. The stratigraphic column (Fig. 1) involves rocks from Upper Paleozoic to Middle Miocene in a complex sedimentary record stopped by the emplacement of the thrust events. The compressional structures are sealed by flat-lying sediments from Serravallian to Quaternary.

The main outcropping rocks are the Triassic deposits (marls, shales, sandstones, volcanic rocks, gypsum and some carbonate rocks), the Jurassic limestones (Lower Lias) and the preorogenic Miocene rocks (conglomerates, calcarenites and marls). Karst landscapes are strongly developed on Jurassic micritic limestones, both massive and brecciated, but also on Miocene carbonate rocks. Triassic soft materials are frequently found in the floor of the major karstic depressions or as valley bottoms, but they are more widely exposed in the terraced slopes at the foot of mountains. In many places Triassic and Lower Jurassic rocks unconformably overlay the Miocene deposits because the Triassic Keuper acts as decollement levels.

Rainfall values are relatively high, surpassing 1200 mm in the central area of the range. Intense rainfall events with over 250 mm in 24 hours are reported having a recurrence interval of 25 years. Mean temperatures are also high, but differs very much along the altitude gradients: from 13° C in the central part (around Lluc) to 17° C in the outermost Formentor and Andratx areas. Winter mean temperatures of roughly 6° C as well as summer means close to 25° C are common values. Snowfalls
3. Karstic landforms, terraces and agriculture

Specific karstic features can be recognized, particularly in the northern sector of the range (Fig. 2), conditioning the availability of soil for pastures and crops. Several kinds of karrenfields are used for stockbreeding, from the top of the mountains to sea level. Karstic depressions are the best lands for wheat, barley and other cereal crops. But the olive tree bearing man-made terraces (called marjades) and the almond tree plantations (Fig. 3) are related with unkarstifiable rocks, mainly colluvial deposits, marls and shales. Forestry resources are limited to Aleppo pines at lower elevations and dense woods of sclerophyllous holm oak, which define the treeline rou-

Fig. 1. Summarized geological map and stratigraphic column of Mallorca.
Fig. 2. Simplified map of the northernmost area of the Serra de Tramuntana range, showing its main exokarstic features.

Fig. 3. Agricultural and vegetational cover of the Serra de Tramuntana. Terraced surfaces devoted to olive and almond crops correspond to unkarstifiable rock terrains.
ghly over 800 metres in altitude. The karstified top of the mountains holds the so-called "balearic zone", where a remarkable richness in endemic species can be found. Uncultivated lands form garrigue and thorny cushion scrublands, both on limestone and on marly rocks.

The most characteristic features of the landscape in the Serra de Tramuntana are closely related to lithology. Relief features and vegetation show their dependence on rock substrates, remarkably emphasized in the field by the tectonic trends that cause imbrication of different materials over long distances. Human intervention is also different on marly rocks and colluvial deposits when compared with the restricted land uses developed on hard limestones, lacking in soil cover and frequently consisting of inaccessible ground. Lower slopes, soft substrates and deeper soils encourage the terracing of the hillsides by man. The terraces are constructed across the slope and the earth is supported by elaborate walls, whose skilfully laid and exceptionally close fitting stonework is built without mortar.

Terracing extends over large areas in the Serra, but rarely prevails over karstic grounds. Grimalt et al. (1992) estimates at 16765 hectares the total surface of terraced areas, which means nearly a half of the cultivated land and more than 10% of the total area of the Serra de Tramuntana range. Only 8.7% of the limestone outcrops has been subjected to terracing. Therefore, it implies that just a relatively small overlap of karstic features and artificial terraces exist, a fact easy to recognize in the landscape.

Exokarstic landforms are quite a common feature in the Serra de Tramuntana mountains, owing to the presence of extensive limestone outcrops as well as to the suitable bioclimatic environment that promotes the development of karst processes. Good examples of polje-like depressions, dolines, karrenfields and karstic gorges can be found, especially in the northern part of the range. Karrenfields are the most remarkable ones because of their morphological variety and wide occurrence. Besides the geomorphological significance of exokarstic landforms, the landscape of the Serra is strongly affected by a great array of solutional features.

Great karstic depressions are concave forms, similar to poljes, consisting of wide flat floored areas whose dimensions rarely exceed two kilometers in length. Many of them are not in fact closed depressions because they are drained by streams or karstic gorges. Their morphology is, in most cases, conditioned by the structural directions which are dominant in the mountain range as well as by the thrusting that puts into elongated contact soft marly rocks with limestone outcrops. The traditional farming chose these broad karstic depression to grow cereals, namely xeixa wheat in the upper depressions like Coma de Son Torrella. Dolines are frequent karstic features on a few areas sited in the intensively karstified sectors of Escorca, although they are less significant in the landscape than karrenfields. They form scattered groups and consist of medium sized depressions characterized by oval or subcircular perimeter that can enclose small surfaces, from 200 to 15000 m², thus corresponding to major axis lengths between 20 and 150 metres. These dolines feature a rather flat floor
occupied by silty soil (Fig. 4) where a particular fire-controlled plant community grows, dominated by heather, *Erica arborea*. The total surface area of dolines is negligible with respect to the surrounding karrenfields.

Karren features spread over large extensions of limestones, lacking a soil covering, to form large-sized karrenfields. These rocky assemblages are important absorbtional megaforms that can occupy up to several km$^2$. If the karrenfield evolution takes place for long, the dissolution progress gives rise to almost impassable terrain, interrupted by sharp ridges and spectacular pinnacles recalling some tropical karren landforms. The most impressive karrenfields are located on the NW slope of the northern sector of the Serra, between Sóller and Pollença, at rather moderate elevations (from 200 to 600 metres a.s.l.). Any kind of cultivation is hampered by such karrenfield outcrops.

Intensely karstified terrains are not suitable for agriculture. Karrenfields, steep slopes, cliffs, deep gorges and rocky surfaces hinder most farming activities. Only grazing by sheep and goats on the gentler karrenfields and cereal cultivation on the bottom of karstic depressions can be implemented, but always with severe restrictions.

4. Karrenfields, deforestation and grazing

As a general rule human activity tends to simplify the initial complexity of the ecosystems and tends to upset the bioclimatic equilibrium conditions that control the

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**Es Clots Carbons 2**

* (Escorca)

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<table>
<thead>
<tr>
<th><strong>Pistacia lentiscus</strong></th>
<th><strong>Estrat herbaci</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Smilax aspera var. balearica</strong></td>
<td><strong>Erica arborea</strong></td>
</tr>
<tr>
<td><strong>Ampelodesmos mauritanica</strong></td>
<td><strong>Calicotome spinosa</strong></td>
</tr>
<tr>
<td><strong>Hypericum balearicum</strong></td>
<td><strong>Estrat liquénico-muscinal</strong></td>
</tr>
</tbody>
</table>

*Fig. 4. Profile drawing of a typical doline affected by repetitive fire for cattle-raising.*
action of the main agents and geomorphological factors. Human settlement in Mallorca, a little more than 7,000 years ago, necessarily brought about changes both in the plant cover and in the predominant erosion mechanisms.

It is likely that during the first four millennia, human activity had few ecological consequences. But the men of different cultures who subsequently inhabited the island produced important cattle-raising and farming changes, so causing the regression of the steady-state forests of *Quercus ilex* and also of the more termophile ones of *Pinus halepensis*. The Roman colonization commenced in 123 BC, but the greatest agricultural changes in Mallorca took place during the Muslim epoch, between the 9th and the 13th centuries.

Since the Catalan conquest of Mallorca by King Jaume I d’Aragó in 1229, the mountain territories were divided between a small number of important landowning nobility. Through the centuries, until the remarkable shift in economics produced by tourism, the traditional farming over such large estates (possessions) were based on livestock, cereal crops, olive oil production and forestry. Firewood, timber and charcoal supplies caused the regression of the forests, but land reclaimed for cultivation especially, greatly modified the wild vegetation over centuries.

Because karrenfields occupy a large amount of surface in the Serra, and excluding arable land, cattle-raising has remained the major rural activity able to be developed on such generally unforested terrain. Woodfires have historically been the main cause of the plant cover decay in the karst landscape of Mallorca. To the former deforestation, due to the development of larger agricultural areas, must be added the deeply rooted habit of periodically burning the brushwood in order to renew the grazing lands.

The traditional activity based on the repetitive burning of herbaceous brushwoods of *càrrix*, (*Ampelodesmos mauritanica*) for cattle pasturing, has become the most influential human activity that affects the broad karrenfields of the Serra de Tramuntana range. The active soil removal produced after the deforestation and the progressive degradation of scrub formations, leads to a gradual increase of the bedrock surface exposed to the atmosphere. Because the most conspicuous karren landforms can be found on rocky outcrops on which the soil cover is less than 50%, obviously deforestation and soil removal enhance the spreading of karrenfield surfaces.

All along the Serra altitude range, from 0 to 1445 metres a.s.l., relict features of rounded subcutaneous karren are common. At the same time, progressive transformation of subsoil-generated tubes and hollows which are actively reshaped into typical bare karren features, is observed. Because the soil formation rate is very low in the karrenfields of Mallorca, any disturbance which facilitates an increase of the soil removal rate might provoke an irreversible imbalance. Forest destruction and the ready removal of small soil particles, all along the hillsides and also through karstified fissures, can be monitored with the aid of small-scale subsoil karren features (Gines, 1995).
5. Recent land use trends

Some changes in agricultural land use in the Serra de Tramuntana over the 19th and 20th centuries have been documented (Fig. 5), namely the expansion of almond trees on the southern hillsides and a gentle recession of olive tree terraced-plantations (GEM, 1998). But the most significant switch occurred after the fifties, due to the increasing economic and social impact of tourism in Mallorca.

Mechanization of farming was very difficult and the traditional possessions became inefficient in economic terms. Furthermore the availability of rural manpower was completely blocked because wages became too expensive for the landowners. During the 19th century, 80% of the working population in the Serra was devoted to rural activities but this percentage has fallen dramatically and hardly reached 12% in 1990. At present, in economic terms, the service sector accounts for 75% of the Gross Domestic Product of the Serra, whereas less than 4% only belongs to agriculture (GOB, 1998). The current increase of abandoned terraces and decreased cultivation is now clear evidence of this collapse of traditional farming.

Wild or spontaneous vegetation occupied 19% of the recognized terraces from the data collected by Grimalt et al. (1992) from aerial photographs obtained in 1979. The decrease in terraced land surfaces has been reported during the second half of the 20th century through statistical data and aerial photographs from Deià and Fornalutx municipalities (Fig. 6). After being abandoned, the terraces are affected by degradation processes produced by wall collapse and subsequent erosion, which leads in some cases to a progressive advance of the closer forest communities. Frequently also, abandoned terraces can be transformed into unforested slopes when periodic fire-raisings accelerate the destruction of the terraces and inhibit the forest recovery, favouring the growth of a monotonous grassland of càrritx, Ampelodesmos mauritanica.

Karrenfields and dolines are also subjected to the effects of periodical burning of
càrrix clumps for the renewal of cattle-rising pastures. Degradation of plant communities and soil removal threaten the sustainable exploitation of livestock and at the same time cause environmental problems concerning the protection of endemic species and outstanding wild plant associations. Many karrenfield landscapes in the Serra display several stages of regressive succession owing to the impoverishment of the vegetational cover that follows recurrent fire-raisings.

The sudden changes introduced by tourism in Mallorca after 1950 led to the crisis of the traditional farming, but in the beginning the direct impact of tourism on the Serra was limited to a few overcrowded places visited by coaches, such as Sa Calobra, Formentor and Valldemossa. However, trends in the tourist trade have launched during the last few decades new recreational and residential land uses, like rural urbanization for second homes, agrotourism facilities and outdoor activities related to the exceptional wilderness value of the Serra de Tramuntana. These new changes have potential environmental impacts that must be counteracted by proper land management.

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REFERENCES
IMPACTS OF AGRICULTURAL TRANSFORMATION ON THE PRINCIPAL KARSTIC REGIONS OF FRANCE

Jean Nicod and Jean-Noël Salomon

ABSTRACT
The recent extension of intensive agriculture on the karst plateaus has caused different types of impact: soil management, generalised and/or localised pollution. Yet paradoxically rural depopulation can also have negative impacts, which largely depend on the characteristics and the hydrological function of the different karst environments. They are often negative, particularly as far as the water quality is concerned, which is why protection measures are undertaken, either in a defined area for a catchment, or in the framework of regional parks. But this is not always the case, so it is appropriate to analyse the problem of karst pollution as a whole, and to propose to experiment new solutions to mitigate the impacts.

KEY WORDS: karst, intensive agriculture, pollution, reserves, France.

1. Introduction
Forty per cent of French territory is karstic, which gives an idea of the dimensions of the problems caused by the impact of modern agriculture there. These are both numerous and varied, according to the characteristics of the karst areas, bioclimatic conditions and the kinds of agriculture and stock farming which are practised (Tab. 1). In almost all cases the role of soils and epikarst predominate, but in pollution problems the hydrological function of the karst also has a part. The morphoclimatic classification of karst areas, represented by the map of "Karst of France" (Nicod, 1995) can serve as a reference point for this study, since the morphological types under consideration correspond closely to the potential agricultural use.

The most characteristic landscapes are those of medium altitude Mediterranean plateaus: Grands Causses, Causses du Quercy, with their pastures and cultivated karst depressions (dolines and uvalas). Mountain karst of the high alpine type or the forested mountain type (Jura, Alps, Pyrénées) are usually areas for stock farming, but some have been affected by the development of ski resorts. But the most important area for agriculture is the calcareous or chalk plateaus of north-east France, the Paris and Aquitaine basins. They are karst areas covered by residual deposits where the superficial karst forms are poorly developed, but where water percolation (loss) is a general feature. Because of their soil quality and relative flatness, they are suitable for intensive agriculture, but unfortunately also very susceptible to erosion. Moreover, the endokarst is mostly composed of conduits with underground streams, which facilitate the rapid transfer of pollutants.

If the intensification of agricultural production plays a major part in erosion and
Table 1. Impact of agricultural changes on the principal karst regions of France.

<table>
<thead>
<tr>
<th>Regions</th>
<th>Types of karst landscapes</th>
<th>Impact on surface</th>
<th>Rural depopulation</th>
<th>Pollution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normandie</td>
<td>Calcareous cherty plateaus and marls with chalky soils</td>
<td>Erosion</td>
<td>Forest clearance, cultivation of forests, clearing of meadows, abandoned forests</td>
<td>Effluents from purification plants into the karst, nitrates, etc.</td>
</tr>
<tr>
<td>Pays de Caux</td>
<td>Cherty plateaus and clays</td>
<td>Erosion</td>
<td>Forest clearance, cultivation of forests, clearing of meadows, abandoned forests</td>
<td>Effluents from purification plants into the karst, nitrates, etc.</td>
</tr>
<tr>
<td>High Jura</td>
<td>Karstified monothons, some forests, coniferous, etc.</td>
<td>Erosion</td>
<td>Forest clearance, cultivation of forests, clearing of meadows, abandoned forests</td>
<td>Effluents from purification plants into the karst, nitrates, etc.</td>
</tr>
<tr>
<td>Northern Alps</td>
<td>Montagne de Vercors, large poljes, valleys, meadows, forests</td>
<td>Erosion</td>
<td>Forest clearance, cultivation of forests, clearing of meadows, abandoned forests</td>
<td>Effluents from purification plants into the karst, nitrates, etc.</td>
</tr>
<tr>
<td>Ardeche, Lozère</td>
<td>High Alpine Karst, mountain pastures, small forest</td>
<td>Erosion</td>
<td>Forest clearance, cultivation of forests, clearing of meadows, abandoned forests</td>
<td>Effluents from purification plants into the karst, nitrates, etc.</td>
</tr>
<tr>
<td>Pyrenees</td>
<td>V璩les arborées, montagne, forêts</td>
<td>Erosion</td>
<td>Forest clearance, cultivation of forests, clearing of meadows, abandoned forests</td>
<td>Effluents from purification plants into the karst, nitrates, etc.</td>
</tr>
<tr>
<td>Languedoc</td>
<td>Mediterranean Karst, stone canyons, rocks, and terraces</td>
<td>Erosion</td>
<td>Forest clearance, cultivation of forests, clearing of meadows, abandoned forests</td>
<td>Effluents from purification plants into the karst, nitrates, etc.</td>
</tr>
<tr>
<td>Cevennes</td>
<td>Regional Natural Park of Causse Noir, dolines, valleys, depressions</td>
<td>Erosion</td>
<td>Forest clearance, cultivation of forests, clearing of meadows, abandoned forests</td>
<td>Effluents from purification plants into the karst, nitrates, etc.</td>
</tr>
</tbody>
</table>

Note: This table outlines the various impacts on surface, rural depopulation, and pollution concerning the principal karst regions of France. Each region is characterized by its specific type of karst landscape, which influences the extent and nature of these impacts. The table also highlights the measures taken for protection, such as the establishment of natural parks and forests.
pollution problems, it can be seen, paradoxically, that depopulation of rural or mountain areas, after other activities have been introduced, can play a harmful role: this is particularly the case for Mediterranean karst plateaus subject to urbanisation.

2. Changes on the karst surface: mechanisation and abandonment of traditional methods.

The advent of intensive agriculture has completely overturned the French rural landscape in a few decades. Karst regions have not escaped this fundamental change.

2.1. Soil erosion

Most of the karst plateaus of low and medium altitude have been cultivated since the Neolithic, once the soils were sufficiently thick and fertile. According to individual circumstances, these soils are developed on weathered residues (red earth from the Causses, clay with flints from the chalk plateaus or chert from the calcareous plateaus of Burgundy and Franche-Comté) and/or loess of varying thickness. Conversely, forests have often been maintained on siliceous cover deposits.

The amalgamation of landholdings and the development of mechanised agriculture have led to deep ploughing over large areas devoted to monoculture. Winter rains and also sometimes summer storms can cause considerable erosion. Turbid waters absorbed by infiltration into the epikarst and streamsinks contribute to the siltation of passages and to the pollution of springs. The impact of this amalgamation and agricultural practice has often been noted (Salomon, 1998), and particularly in the calcareous regions: calcareous plateaus of the Jura (Renault, 1990) and of eastern France (Treffot, 1992); Normandy (Rodet, 1992); Entre-deux-Mers in the Gironde (Audra, 1998).

In periods of flooding, there can be considerable turbidity at springs: in northern Lorraine on the interfluvial karst of Loison-Othain, measurements taken at the "Bouillons de Delut" (overflow springs) show that specific degradation reaches 104 t/km²/year in some small cultivated valleys, as compared to 34 for those under forest or grass cover, and that 70% of the transported material in the Delut basin leaves via the overflow outlet (Gamez, 1995). In the Grands Causses, evidence of accelerated erosion has been noted in the dry valleys of the Causse Noir, when torrential rain fell from 20-21 September, 1980 (Nicod, 1991a). On the Larzac Causse, in Portalerie aven (shallow hole), a huge accretion of debris resulted from material from recently cleared land (Bruxelles, 1995). Often the abandoning of traditional management techniques must also be questioned, sometimes resulting in cessation of the formation of concretions (Cabrol, 1989).

2.2. The filling in of dolines, a factor of instability.

Even if the practice to fill the dolines is an ancient use, the mechanisation of agric-
culture is making this widespread custom on many plateaus (Jura) and in covered karst. The dolines are more or less active, depending on their origin: accelerated solution in a fissured zone, a sink obstructed by a plug of debris, deep-weathering, etc. also in relation with the morphoclimatic conditions. Periods of prolonged rain often result in accelerated undermining; by changing the hydrological conditions, heavy showers can cause swift removal of blockages (Mouret, 1984; Rodet, 1992). On the Amancey plateau near Deservillers (Doubs), filling in of dolines as part of agricultural practice is very evident: in one of them a sack of fertiliser was buried under 40 cm of earth for over 15 years. There are many examples of undermining and re-opening of doline bottoms (Gaiffe and Bruckert, 1985).

With the help of a bulldozer, it is possible to reveal systematic filling in, like those at Villeguindry, on the plateaus of the Haute-Saône (Nicod, 1984). It consists of piling up branches, then stones and earth from neighbouring fields in order to level the slopes (Fig. 1 a and b). One may well wonder about the long-term stability of such a method. In the Grands Causses, in Larzac, in places where there is a depth of "terra rossa", farmers practice the systematic filling-in of dolines, but there is no lack of recurrence of undermining (Bruxelles, 1995). In the vineyards of Entre-deux-Mers, the levelling done by bulldozer are affected by a process of subsidence due to down-washing of surface deposits into the karst passages of the underlying limestone (Audra, 1998).

2.3. Abandonment of traditional crop farming methods

On the Grands Causses the "sotchs" (dolines) and uvalas were carefully managed areas for growing cereals: stony soils with dry-stone walls on their perimeter, banks created in dry valleys... The use of large machines and the extension of pasture (increased sheep rearing for the production of Roquefort) tends to destroy traditional management, particularly on the Causse Méjean (Fig. 1 c and d), and to encourage soil erosion.

In Provence and Languedoc, new vineyards established on slopes and in karst valleys are on a large scale and much more extensive than the traditional method, the "restanques". There are no walls and the stones are shattered. Deep ploughing done by powerful machinery attacks the base of the slopes, involving pockets of terra rossa. These extensions of vineyards are particularly prevalent in some communes of Var (the cantons of Cotignac and Lorgues) where this type of soil is sought after for production of A.O.C. wines (Appellation d'Origine Contrôlée). In periods of strong Mediterranean showers the crypto-lapies are exposed in the marginal areas of depressions and small valleys: erosion scars appear on the slopes and debris accumulates at the base. It is also noted that increased turbidity in springs and streams is one of the major causes of the cessation of deposition of travertine (Vaudour, 1986).

2.4. The role of rural depopulation: causes and multiple effects.

Numerous problems have also arisen from the decline or abandonment of agriculture, but the causes and effects are very different, according to the morphoclima-
Fig. 1. Transformation of the karst surface
a and b - Infilling of a doline at Velleguindry, on the Haute-Saône plateaus (Nicod, 1984).
c and d - Change in agricultural areas on the Causse Méjean.
c - conditions during Marres time in 1935: fields enclosed by stone walls and saltus;
d - present conditions: fields for grazing, brushwood and extension of pine forests (Cohen, 1995).

tic conditions and the location of karst areas.

1 - High mountain areas, the installation of ski runs on alpine pastures induces erosion and degrades the vegetation cover. Thus, on Margeriaz, in the Bauges massif in Savoy, the alpine pasture has been completely disrupted (Hoblea, 1990). The situation is worse on the alpine pastures of La Plagne, on a gypsum karst: sink holes have appeared on the ski tracks (Rovera, 1990). Moreover, heavy winter usage brings the risk of pollution because of a lack of a waste water purification plant, as is the case at Flaine in Savoy or at Pierre Saint-Martin in the western Pyrenees (Douat and Salomen, 1994), waste water from dwellings is discharged directly into the karst.

2 - On karst plateaus of medium and low altitude, the effects of depopulation are demonstrated by the extension of brush cover and pine plantations, as in the dolomite areas of the Grands Causses or on the Plans of Provence. In the latter case, the creation of the largest military camp in Western Europe at Canjuers in the 1970s had a particular effect. Generally the effects in Languedoc and Provence are the extension of fallow land in the face of "rurbanisation". Rural depopulation has two main consequences:
- the abandonment of traditional agrarian techniques (terracing, stone walls bordering rural roads and "drailles"), wells and dry-stone constructions (bories,
mazets)\(^3\), all leading to the deterioration of the rural landscape;
- an increased susceptibility to forest fires in summer, inducing intense erosion in periods of heavy autumn rains. On Mediterranean karst plateaus, forest fires have a more general impact than wine growing, which is limited to a few areas.

3 - In basins widespread urbanisation has serious hydrological consequences: the increasing impermeability of large areas, an increase in runoff, the lowering of the water table in the affected area and even in the karst aquifer as a whole. The karst lake of Besse in the valley of the Issole emptied abruptly in December 1989 when a sink hole appeared in the lake bed. This event was consistent with results of intensive sampling done in the aquifers in previous summers (Nicod, 1991b). In the well-known polje of Cujes-les-Pins, the urban growth, which now covers a third of the alluvial and colluvial bottom of the basin, increases the karst runoff and the pollution of water escaping through ponors, and thus to pollution (Nicod, 1990).

3. Pollution linked to intensive agriculture and changes in habitat.

3.1. Three types of pollution can be distinguished:

1 - Direct pollution on the karst. In spite of "Martel law" on public health and hygiene (15.2.1902), speleologists still, at the end of the 20th century, record occasional cases of animal carcasses which have suffered from disease found in caves (Causses, Pyrenees, Plans of Provence, etc.), grape must (Entre-deux-Mers) or dairy effluent as on the Comtal Causse (Dodge, 1982). Some disposal sites for carcasses, like that of Barrenc de Picausel in the Pays de Sault (Aude), have had to be cleaned up. The Hourat canyon at Laruns (Western Pyrénées) covered with bones and decomposing entrails over an area of several hundred metres, was even the subject of legal action. In Orcheval Cave (Doubs) forty car bodies had to be removed. Unfortunately, uncontrolled and illegal rubbish disposal are very frequent in karst areas. Even more serious is the disposal of industrial waste (chemical, pharmaceutical, hydrocarbons) in caves, and even the army has been guilty of this kind of practice: in the inter-war period, huge stocks of ammunition and gas were stored in Jardel Cave (Doubs) by the army. They are still there (F.F.S., 1993).

Organic matter and chemical products gradually break down and are washed into the stream systems, and spread into fissures, retaining their toxicity. These all constitute a serious threat to aquifers and springs in the countryside.

2 - Pollution by effluents which filter down into the karst comes mostly from farms, piggeries, dairy farms, especially in areas where production is dispersed, as in the Grands Causses or the Upper Jura. Residue from cheese factories constitutes a

\(^2\) "Drailles" are former transhumance tracks used mainly for sheep.

\(^3\) "Bories" and "mazets" are former stone shelters used by shepherds on a temporary basis. Because of the concentration of cheese maturing at Roquefort, pseudo caves ("caves bâtardes"), created for cheese makers on the Causses, have been abandoned (Gauchon, 1997).
veritable bacteriological soup which pollutes a large part of the Jura plateau. If the villages have a sewer system and a purification system, any breakdown in this system can cause concentrated pollution through the accumulation of effluents. On the Jura plateaus, this is illustrated by the example of Belleherbe village (Doubs), whose drinking water came from a karst spring contaminated by its own purification system (CREPSC, 1981)! Many other cases of virtually closed systems have been recorded, particularly in mountain areas where purification systems do not function well in winter. There are numerous sources of pollution in the countryside. There are numerous examples of hydrocarbons (from garages, quarry sites, road works, etc.) salt spread on the roads to counteract ice (Source des Godeliers, Le Torpt, Eure), industrial waste (toxic varnishes polluting the Dortan blue spring in Ain), or accidental spills (5,000 l of fuel-oil spilt in 1977 above Bourrugues Cave at Arette, in the western Pyrenees). Finally, on the Mediterranean karst plateaus, urbanisation carries an increased risk of pollution, linked to the poor functioning of septic tanks or waste water, spilled directly into the ground or into a drainage sink or into the soil.

3 - Generalised pollution from various sources.

The most widespread type of pollution on the karst plateaus comes from the use of liquid manure and fertilisers and the use of herbicides and pesticides, employed in either mechanised agriculture or intensive stock-rearing (battery farming of cattle, sheep, pigs and fowls). The general problem of the high nitrate levels in spring water and ground water is well known, as is that of the eutrophisation of rivers in summer. There are more specific cases of pollution on karst to be identified: the use of residual mud from purification stations, either used to encourage grass regrowth on ski runs (Hoblea, 1990), or as an aid to cultivation on stony or leached soils. On the Albion plateau (Vaucluse), residual mud very rich in organic matter and agents of bacterial activity from the SANOFI factory (manufacturing gelatine) at l’Isle-sur-Sorgue is used.


The extent, importance and evolution of agricultural pollution by various means in karst areas depends on different factors.

1 - Geographical factors.

Depending on the individual case, pollution is characteristic of the karst surface under consideration (e.g. the Grands Causses) or of catchments from which absorbed allogenic water originates (e.g. Ouyssse spring in Quercy, where according to Coustou (1979), 38% of the flow comes from upstream of the karst) (Fig. 2a). In general, pollution varies in inverse proportion to the extent of woodland, hence the importance of the conservation of forest areas in order to protect some spring used for water supply.

In the case of infiltration into the karst surface, the type and thickness of the soils
Fig. 2. Two cases of pollution transfer in karst plateaus.
a - In the Causse de Gramat (Quercy), pollution of the karst system of the Ouysse. Deposits from the sub-aerial basin upstream, and pollution sites on the Causse itself. Underground rivers and rapid transmission of pollutants (Coustou, 1974).
b - In north Larzac, pollution of Durzon spring (water catchment for La Cavalerie) and Esperelle spring, supplying Millau. Buffer effect of the saturated zone (Ricard and Bakalowicz, 1996).

and superficial deposits, the karstic meso-forms (dolines, sinkholes) and the structure of the epikarst play an important role in the ways pollution is introduced. In the Upper Jura, glacial deposits in synclinal valleys limits the introduction of pollutants. Yet on 21 June, 1986, the watershed of the Grotte des Foules supplying the town of St Claude was seriously contaminated after a heavy storm (causing run-off) by Septmoncel manure heaps on the slopes of the catchment. In the Pays de Caux (Normandy), which is a karst covered by clay with flints and loess, pollution penetrates in the winter period or in summer storms by the run-off absorbed in stream-sinks. The increase in mechanised agriculture and soil erosion have only made things worse (Conrad et al. 1988; Rodet, 1982, 1992).

Dolines with clayey bottoms are preferred sites for rubbish dumps everywhere, but the base is rarely impermeable (percolation, adsorption, reopening). An aberrant practice in Larzac consisted in removing the clay from the doline before using it as solid waste disposal (Bruxelles, 1995).
2 - Endokarstic factors

Hydrogeologists have published many works on the conditions of transfer of pollutants in karst aquifers (Mangin and Bakalowicz, 1989; Blavoux et al. 1991/1992; Guillemin and Roux, 1992; Ricard and Bakalowicz, 1996, etc.).

On the most of the karst plateaus, because of the slight thickness of the limestone series, underground circulation close to the underlying impermeable layer (aquiclude, a saturated zone of low capacity) often results in a rapid transfer of pollutants, especially if meteorological and hydrological conditions are favourable. An extreme case of transfer is that of Bramabiau - famous since Martel: the turbidity and pollution of the Bonheur stream, which comes from Aigoual, are transferred there solely by the cascading underground river (Fabre and Maurin, 1985).

Conversely, the Grands Causses (with thick limestone series and a synclinal structure) and the majority of Mediterranean karsts have a large saturated zone, complex networks and vaclusian-type resurgences. This endokarst structure assures some dispersion of pollutants and their storage at different levels. A part can be absorbed by clay and some self-cleaning is even possible by the activity of underground aquatic fauna, which develops due to the influx of organic matter and nitrogen coming from the surface and from the epikarst (Creuze des Chateliers et al., 1991).

Thus the Fountain of Vaucluse is relatively unpolluted, in spite of the agricultural zone of the Sault valley and the Albion plateau, the use of fertiliser and residual mud, various rubbish dumps and the effluent from purification plants. This is due to the extend of its catchment (more than 1,100 km$^2$), to the large proportion of upland and forested land, to the small proportion (8%) of absorbed river water (R. Nesque) contributing to its discharge, but mostly to a very large saturated zone with a considerable storage capacity (dynamic volume of the order of 100 x10$^6$ m$^3$ and the role of annexed reserves). Numerous dye-tracings and hydrochemical and isotopic analyses have revealed the complexity of the functioning conditions of the aquifer, and testify its relative immunity to agricultural pollution (Blavoux et al., 1991/1992; unpublished report by Puig). Similarly, in the Sainte-Baume massif, the Saint-Pons spring is still trouble free (Martin, 1991).

3.3. Consequences of pollution of agricultural origin or pollution linked to changes in the rural habitat.

We will not dwell on consequences of an epidemiological nature (Moreau, 1982), especially accidental ones, nor on the unpleasant conditions experienced by speleologists in some underground networks which are little better than sewers. The excessive use of fertilisers creates a more general problem of increased content of nitrates and phosphates in drinking water supplies (A.E.P.) or pollution of bacteriological origin as illustrated by waste effluents from battery farming (cf. infra.).

Two similar problems must be stressed since they have serious consequences on spring water and the resulting rivers:

- in the interior of karst, the hypogean subterranean fauna can be degraded and
then lose its capacity to purify (Creuze des Chateliers et al., 1991);
- in rivers, excessive amounts of phosphates (mostly from laundries) have an
inhibiting effect on Cyanophytes which fix CaCO$_3$ (Casanova, 1986). Because of
this it is difficult for travertine dams to be maintained, the damp ecological environ-
ment tends to dry out and thus lose its purifying power.

3.4. An example of "moderate" pollution: the northern Causse of Larzac

This karst sustains two main springs (Fig. 2b): Durzon spring upstream of the
Dourbie canyon, and the Esperelle spring which is tapped downstream for the town
of Millau water supply. They are Vauclusian springs from a complex aquifer in the
thick carbonate series of the middle and upper Jurassic of the Grands Causses: vado-
se systems and an extensive phreatic zone (Ricard and Bakalowicz, 1996). The pol-
lution is dispersed with the use of fertiliser for artificial meadows, a few dairy farms
and sewage disposal plants, a military camp and the Cavalerie treatment plant. This
pollution is introduced into the karst because of the nature of the topography (doli-
nes, fissures, avens, etc.) and fluctuates according to hydrological conditions
(Ambert et al., 1992). Water from the Durzon spring, polluted to some extent by agri-
culture on the Causse, is used for the Cavalerie water supply, while its treatment plant
accidentally pollutes the Esperelle spring, which provides Millau water supply!

It is of general note that on the karst plateaus, the expansion of the drinking water
supply system causes an increase in waste water, and so increases the risks of pollu-
tion.

3.5. Pollution linked to intensive agriculture.

The Causses of Quercy is an excellent example of pollution linked to intensive
agriculture (Salomon and Tarrisse, 1998). The soils are poor, thin and unsuitable for
intensive agriculture. They were traditionally used for extensive agriculture and
sheep rearing. Hence with the modernisation of agriculture, the Quercy plateaus have
been seriously affected by the rural exodus. To check this process, financial aid has
been provided, allowing the development of intensive stock rearing, particularly bat-
tery pig farms, with sometimes as many as 1,000 pigs per unit. Pigs are three times
more polluting than humans. Moreover, the pig farms have been developed with no
thought for the treatment of concentrated affluent nor for the increase in turbidity
linked to changes in surface land features (uprooting hedges, and amalgamation of
cultivable land) and cultivation methods (increasing use of machinery, deep plou-
ging). The result is increased pollution of springs, often visible by their reddish
discolouration.

Pollution has been proved by several studies based on sampling at the springs and
also inside the underground networks. In 1998, the Bramarie-St. Sauveur system
(NW Causse of Gramat) was in receipt of 10,110 human equivalents of pollution,
which constituted a doubling of amount in 15 years. Bacteriological pollution was
measured (coliform, streptococcal, faecal, spores) which made the water unfit for
human consumption, and its origin traced to the pig-rearing units. Similar studies
have been made on the karst system of the Causse of Cesarines (the eastern extension of the Causse of Padirac) and on the Causse of Cregols (12 km Causse of Limogne), giving equally disastrous results (Fig. 3).

More than a thousand analyses of the nitrates content of water from Dordogne,
the Lot, the Causses and Quercy Blanc show that there has been a considerable increase: some peaks exceed 100 mg/l (up to 160 mg/l at Lacave-Rocamadou), when C.E.E. limits should not exceed 25 mg/l.

In many karst regions, pollution has reached levels that pose a threat to public health, to babies and consumers in general. Some water supply catchments have already been abandoned. For a long time diffuse and slight agricultural pollution has been neglected, in spite of the low capacity of karst areas for self-cleansing. It was then denied by agricultural lobby, or sidelined by water supply authorities, who always advocate the treatment option in preference to prevention. But today pollution has reached a level that can no longer be tolerated, and its origins have been clearly identified. The authorities have the duty to act for the protection of karst and consumers.

4. Protection measures

The best protection would obviously be to have no activity on the karst, but this is clearly unacceptable, as it threatens the farmers existence. Solutions that are acceptable to everyone must be found.

4.1. The need for purification of water upstream of karst underground systems

A first set of measures would consist of separating rainwater from waste water. For that it would be necessary to ensure an impermeable layer in cattle sheds and stables in order to collect liquid manure and leaching from silage, and to treat water from washing down by collecting it in impermeable troughs. The aim is to reduce pollution before it penetrate the karst.

Then, in the absence of any effective natural filter, which karst soils do not provide, it would be necessary to create dispersion sites, with multiple levels of thick filtering beds. Karst protection requires a preliminary treatment of effluent and agricultural wastes, instead of the simple, traditional method of dispersion. Finally, the promotion of composting and drying of liquid manure are methods which deserve consideration. To reduce turbidity, it would be sensible to manage wastes: installing filters, stone-works, channels, etc.

This development will not be easy to achieve, as the techniques recommended here mean an extra production cost, but in many cases this is less than the cost of water treatment at springs. A comprehensive programme of information and publicity of the issues to the farming community must be instigated as soon as possible, to ensure the acceptance of these measures.

4.2. Defining water protection areas

The need to protect the catchment of karst springs dates from the end of the 19th Century when Paris, which had obtained its water from Vanne spring in the Othe forest via a long aqueduct since 1862, had to extend the area of forest cover to protect the springs. From early this century, the role of E. A. Martel in Public Health is well known. But the extent and complexity of the catchment of karst springs creates
a difficult problem in defining areas of protection and causes conflict between the rural environment and the urban consumers. Thus, the idea of legally well defined protection zone can, when implemented, clash with local economic constraints and with the lack of knowledge about karst and its hydrology. A few examples illustrate this problem.

1 - Delimitation of the protection zone of Arcier spring (Doubs)

This powerful spring, which was used in Roman times, has been used for Besançon's water supply since 1854. After a series of typhoid epidemics, a treatment plant was built to suppress bacterial pollution. But the recent growth in nitrates and nitrites necessitated a precise definition of the catchment area by extensive water tracing (Mettetal, 1985). This has revealed that it consists mainly of the polje of the Marais de Saône, which receives the leaching from agricultural land and effluents from small treatment plants in neighbouring villages, discharged through the Creux de la Roche stream-sink.

2 - Protection zone of the Lez spring (Herault)

The spring has supplied Montpellier by aqueduct since 1976. An increase in withdrawals, firstly by abstraction in the spring basin, then by pumping (1982) from the drowned conduit of the vauclusian spring, has changed the hydrological circulation in the karst system and made it necessary to define extensive protection zones. Multiple research (Avias, 1994) has enabled us to define:
- a protection zone including all the neighbouring limestone plateaus (150 km²), all the Causse of Viols le Fort, which make up the spring's main catchment area;
- an extended area, where there are probable connections between aquifers (positive water tracings), but where protection is limited to sensitive areas (near water courses experiencing water loss).

The protection zone which was suggested in 1979 was refused by the rural communes involved. Long negotiations were necessary⁴, requiring financial compensation and water supply from a new catchment for the protesting communes. The example of the recent contamination by effluent from the treatment plant at St. Martin de Triviers shows that monitoring (requiring the intervention of biologists specialising in underground fauna) remains necessary (Malard et al., 1997).

3 - Inclusion of karst areas in protected natural parks

There are currently a number of karst plateaus and massifs included in the boundaries of regional parks: Upper Jura, Bauges, Chartreuse, Vercors, Luberon, Grands Causses, Quercy and Verdon. However, since the limits of these parks are determined by the wishes of the communes involved, they do not necessary coincide with the extent of natural karst areas or the protection zones of the spring. Thus the Luberon regional park only covers a small part of the Vaucluse plateaus, as is the case

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⁴ A decree of 1981 reduced the boundary to enclosed 1 km²!
of the Grands Causses park compared to the extent of the Causses. It is true that the eastern part of the Grands Causses is included in the Cevennes National Park.

Having said this the statute for regional park, an important aspect of its action is devoted to the protection of water resources, especially the Larzac aquifers. This protection, which is assured by the communes involved, but with financial and technical aid from the park authorities, includes the delimitation of hydrological basins, the monitoring of water sites, the protection of caves and underground fauna. There is an attempt to improve the treatment of waste water, in particular pilot systems to treat waste water have been installed in isolated farms. The park is a party to the protection of springs and rivers.

The restoration of the classic landscape (Grands Causses, Quercy) is under discussion with local farmers: clearing the undergrowth, re-establishing grass pasture for sheep and rabbit breeding. Specific heritage actions include the restoration of farms in picturesque hamlets with their dry-stone walls (Roques Altes, on the Causse Noir), ponds and public wash-houses. Explanatory signs (Planagreze) and marked paths attempt to make summer tourists aware of the landscape and heritage of the Causses (Renard, 1998). They try to capitalise on the attractions of the large show caves (Padirac, Dargilan, Aven Armand), caves with cave paintings (Pech Merle, Quercy), and water recreation in the beautiful river gorges.

The impact of modern agriculture on karst areas and the protective measures, whether undertaken or planned, cannot escape the two classic environmental dilemmas:
- between economically profitable agriculture and ecological protection;
- between a general laissez-faire policy and local protection (parks currently represent about 10% of the area of France).

5. Conclusion

The protection of karstic agricultural environments is made difficult by their diversity and the complexity of actions and interactions, but we must remember that the need to protect spring water that was recognised thanks to the impartial actions of speleologists (Renault, 1990). Multidisciplinary research in progress involving hydrogeologists, geomorphologists, hydrobiologists, agronomists, etc. reveals the diverse aspects of how karst functions, and suggest solutions to the problems identified. There is everything to be gained by adopting solutions that avoid pollution: treating the effects of pollution, particularly for drinking water, will become economically more and more expensive compared to prevention of pollution; both ecologically and aesthetically, upstream prevention of pollution is much more satisfactory solution.

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REFERENCES


MARTIN Ph., 1991 - Hydromorphologie des géosystèmes karstiques des versants nord et ouest de la Sainte-Baume; étude hydrologique, hydrochimique et de vulnérabilité à la pollution. Thèse Univ. Aix-Marseille II.


POREL C., RAZACK M. et al., 1994 - The karst environment of the urban district of Poitiers, its features and water ressources management and protection. COST 65 Action, pp.11-123.


RENAULT Ph., 1990 - Agression sur le karst, synthèse et développement. Spelunca n°39: 25-34.
AGRICULTURE, LANDSCAPE AND HUMAN IMPACT IN SOME KARST AREAS OF ITALY

Ezio Burri, Benedetta Castiglioni and Ugo Sauro

1. Introduction

Italy is made up for about 1/5 of its surface by soluble rocks, which represent the arena of karst environments. The karst morpho-units, some hundreds, are mainly distributed inside the alpine structure of the Mediterranean mountains. A very large number of rock formations are present, different in facies, lithology, age, etc. Among these, carbonate rocks prevail, followed by gypsum and salt. Most of the carbonate rocks are limestones sedimented in a platform environment and they show a wide range of porosity, frequency of fractures and bedding planes.

Many of the mountain groups result from still-active tectonics and their recent morphodynamic evolution has been characterised by wide climatic and environmental changes. The parent materials of the soils of these karst areas are of many different types: insoluble residues of solutional processes, loess-like and dune-like eolic deposits, volcanic ashes, transgressive coastal sediments and different mixtures of the above-mentioned materials and/or colluvia of older soil covers. According to the climatic regimes, thick colluvial deposits have been accumulated in some karst depressions, resulting from the deposition of soil sediments and other materials from the slopes.

The climatic processes, the expression of some different sub-types of Mediterranean climate (from the typical Mediterranean to sub-atlantic and sub-continental varieties), are the main control of the recent morphodynamics inside the karst morpho-units.

In some areas the variability of precipitation is very high. The soil-water deficit during summer, together with the steep slopes, makes these environments highly vulnerable to human impact, especially in relation to soil use for grazing and agriculture.

The soils, with enriched mineral contents from the fall of loess-like sediments or of volcanic ashes, were surely very appealing to the first farmers.

2. Man and the karst areas

The first settlers of the Italian karst areas were Palaeolithic hunters, who utilised the natural shelters and the chert as raw material for the making of stone tools. In the

(1) The paper is the result of the cooperation of all the Authors. In particular the general parts are the result of a common discussion. Paragraphs n°6 is written by E. Burri, par. n°8 by B. Castiglioni, the others by U. Sauro.
Lamalunga Cave in southern Italy a complete skeleton of a pre-Neandertal man has been discovered.

The Lessini Mountains in the Venetian Pre-Alps and the Gargano promontory in Puglia are the Italian karst areas richest in good quality chert nodules and lenses. The chert resources of the Lessini Mountains have been exploited since the XIX century for the production of flints.

The first farming was established during the early Neolithic, about 7000 years B.P., as a result of the settlement of groups migrating from eastern countries and of their cultural transmission. Thereafter, forest clearing spread in order to claim land for agriculture and grazing. In the areas with a soil-water deficit, the deforestation and clearing of pastures were often achieved with fire.

The environments most vulnerable to human impact were both the Mediterranean woodland and the boreal mountain belt utilised for summer grazing and, during the first phases, also for hunting. The beech forest belt, a more stable environment less subject to fires, survived until the Middle Ages, when the increasing demand of towns for charcoal drove the mountaineers to exploit this important reservoir of wood. In his poem “The Divine Comedy”, Dante Alighieri drew inspiration from the beech forest to depict his “gloomy wood”: “Mi ritrovai in una selva oscura, che la retta via era smarrita” (I found me in a gloomy wood, astray / Gone from the path direct...).

3. Resource use and land reclamation

Traditional agriculture and sheep rearing were, until World War II, closely linked with the use of other environmental resources within an economy of mainly self-consumption and the exchange of a few products.

Forestry, the working of chert for the manufacture, trade of stone tools during protohistorical times and of flints during historical times, and quarrying activities for building and lime production were closely linked with farming.

After the forest clearing, the land use for agriculture needed continuous work for the maintenance of soil productivity, such as the removal of stones. The stone clearing in fields and pastures continued in time, due to the outcropping of rocks following soil erosion.

The problems of water scarcity were partially solved by excavating closed basins and tanks and waterproofing them with clay to store runoff water from the surrounding slopes and roofs of buildings.

The man-environment relationships, aimed at the optimal use of natural resources, have been expressed as strategies that have led to the creation of characteristic landscapes, rich in signs of human activities.

A distinctive character of karst agricultural landscapes is the subdivision into many small plots of land adapted to the peculiar landforms of the karst surface and marked by different types of land use, according to the productivity of the soils and the local microclimatic conditions. Some authors have applied to these landscapes
the term "oasised" agriculture. This oasisation is linked to the soil thickness, which depends on the topography. The soil is thicker on the bottom of closed karst depressions, such as dolines and poljes.

In the karst massifs of the central and southern Apennines, there is a great variety of examples of adaptation of agricultural plots to the various karst forms. The different land uses depend on the types, sizes and elevations of the karst forms. In particular:

a) broad karst plains surrounded by steep slopes, at high and medium altitude, are essentially used for collateral grazing activities; the presence of temporary ponds also permits the watering of livestock in summer. However, often if there are few animals or if they are directed elsewhere, the luxuriant vegetation is cut and used as forage; examples of these forms are in Marche (Montelago), Umbria (Colfiorito and Piangrande), Lazio (Rascino), Abruzzo (Campo Imperatore, Voltigno, Piano Cinquemiglia, Piano delle Rocche, Quarto Grande, Barone and S. Chiara), Molise (Civitanova) and Basilicata (Galdo, Rotonda);

b) smaller karst plains at medium altitude are in part still used for cultivation; sometimes the internal surface, delineated by the edge of the depression, is divided into long narrow cultivated fields crossed by a road used for the transit of wagons; this is a very ancient practice, preserved still today, to permit all the landowners easy and equal access and to allow easier crop rotation; a careful clearing of stones is performed inside the karst forms and the resulting detritus is collected in piles or it is used to build dry walls for protection, enclosures or terrace support; typical examples are located on the western slope of the Gran Sasso d'Italia (fig. 1);

Fig. 1 – The small karst plain of S. Stefano di Sessanio (L'Aquila)
c) in dolines of varying morphology, extension and altitude, the bottom is used for cultivation; in Abruzzo, and in the forms with greatest extension (e.g. the doline of Fossa Raganesca), the presence of stone clearing and dry walls inside the depression attest to a custom that is very deep-rooted and motivated by the need to make maximum use of all the available agricultural area; an example, perhaps emblematic, is the town of Gissi (Abruzzo), with a crown-like structure on evaporite gypsum outcrops that surround the broad internal doline intensely utilised for horticulture (Burri, 1985; 1994).

Other types of use of dolines are widespread throughout Puglia; also in this region the edges of the doline are protected by dry walls, which have the multiple function of defence from the dominant winds (at times cold, but also loaded with salinity) or protection of crops from excessive evaporation due to solar radiation. The tradition of using dolines for cultivation is further demonstrated by the works of artificial drainage of the basins found in the evaporite gypsum outcrops in the area of S. Ninfa (Burri, 1989) in Sicily, or in that of Verzino in Calabria, built to prevent swamp ing of the most depressed area. In the open fields, dominated by intensive cereal cultivation, the presence of sinkholes or dolines is considered a hindrance to the use of mechanical equipment; therefore they are filled or obliterated.

In the central Apennines, the predominant agricultural activities can be divided into wide altitude bands: the main crops in the higher band are chick peas, lentils, potatoes, grasspeas or any specialised crop (for instance, saffron in Piana di Navelli, in Abruzzo); at lower altitudes, the first almond and olive trees appear, and even lower, cereal crops predominate, traditionally associated with olive growing; however, today extensive tracts of olive groves and vineyards increasingly characterise the low altitudes of southern Italy. The cultivation of vegetables is limited in extent but concentrated, with the consequent necessity of irrigation and thus exploitation of the scarce water resources.

Other structures that characterise the karst landscapes and testify to a traditional transformation of the territory for agricultural crops are the nuclear settlements like the masserie of Puglia, the contrade of the Lessini Mountains, groups of houses built entirely in stone which because of the thickness of the walls seem to be constructed “caves”. Also characteristic are certain temporary residences and refuges like the trulli of Puglia; other small refuges (used for tools or livestock) built with limestone blocks from stone clearing can be found in the Berici Hills (Pre-Alps in northern Italy), in the central Apennines and in Gargano (Puglia). Completing the list of stone structures are the stone-clearing piles and the dry walls for enclosures, protection and terracing. Thus, the typical signs of the agricultural landscapes are:
- dry walls delimiting the agricultural plots,
- stone piles,
- terraces on hillsides supported by dry walls or artificial scarps,
- “terraccettes” or “pieds de vache”, dense patterns of subparallel tracks produced along steep slopes by cattle grazing,
AGRICULTURE, LANDSCAPE AND HUMAN IMPACT IN SOME KARST AREAS OF ITALY

“trous monticules”, nearly circular depressions with mounds of debris on one side, created where the soil and uppermost rock are torn up during the uprooting of tree stumps,
- small circular emplacements built on the slopes to host piles of timber for charcoal production,
- artificial ponds for grazing animals, created by sealing the floors of some dolines, digging depressions in clay and damming small dry valleys.

The water reservoirs, corresponding to the large karst springs at the boundary of karst morpho-units, have been exploited as far back as the Roman times in peninsular Italy, with the construction of large aqueducts like those of ancient Rome. In contrast, the waters of many large karst springs in north-eastern Italy have not been exploited by the towns of the Po Valley because the alluvial aquifers of the valley have been preferred. However, recently with the deterioration of the Po Valley water, the large karst reservoirs of some karst groups are becoming a strategic resource and their value has been reconsidered.

In the second half of the XX century, the techniques of utilisation of other resources, e.g. the marls, limestones, ornamental stones and marbles, have changed. Large quarries for cement production have been opened. In the Berici Hills, in a single quarry something like 2-3 thousand cubic metres of limestone are excavated daily. The Carrara Marble of the Apuan Alps and the Rosso Ammonitico of the Venetian Pre-Alps are exported throughout the world; the latter has been sold in some countries as “red carrara”.

4. Some typical aspects of human impact

The karst areas not affected by the Pleistocene glaciation were normally mantled by nearly continuous regolite and soil covers, with a thickness of a few decimetres on the steep slopes and many metres in the bottom of large depressions.

The first phase of human impact started as far back as Protohistory and mostly involved land reclamation for grazing and agriculture. The soil use for grazing and agriculture, along with the use of fire, accelerated soil erosion leading to desertification of large surfaces.

The vulnerability of the soils is mainly controlled by the lithological and structural conditions of the soluble rocks and by the climatic regimes. The vulnerability is lower where the rock is densely fractured, as in some karst massifs of central Italy (for instance in the Massiccio del Gran Sasso) or on densely fractured marly limestones as in the Venetian Pre-Alps and in the central Apennines (“Biancone” FM and “Scaglia” FM, both chalk-type limestones). In these types of limestones, desertification is less conspicuous because a thin soil develops even in a short period.

The intensely karstified massive limestones have shown greater vulnerability to human impact. The landscape of the upper part of the Sette Comuni plateau, mostly in Jurassic massive limestones, is strongly desertified despite the abundant precipitation (more than 2000 mm yearly), in contrast to the upper part of the Lessini Mountains, mostly in Cretaceous chalk-type limestones.
The table highlights the most typical resources of the karst environments and their spatial framework before and after the desertification induced by the human impact.

<table>
<thead>
<tr>
<th>FIRST PHASE OF HUMAN IMPACT</th>
<th>AFTER DESERTIFICATION FROM HUMAN IMPACT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Widespread resources</td>
<td>Widespread resources</td>
</tr>
<tr>
<td>Scattered resources</td>
<td>Scattered resources</td>
</tr>
<tr>
<td>Soil and vegetation for wood, grazing and agriculture</td>
<td>Natural shelters</td>
</tr>
<tr>
<td>Stone for building</td>
<td>Stone for the production of lime and cement</td>
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<tr>
<td>Stone for the production of lime</td>
<td>Clay for waterproofing of basins and tanks</td>
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<tr>
<td>Wood</td>
<td>Chert for the making of tools</td>
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<td></td>
<td>Special stone types for artefacts (massive limestones, marbles, breccias, etc.)</td>
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<th>Soil and vegetation for wood, grazing and agriculture</th>
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<tr>
<td>Special stone types for artefacts (massive limestones, marbles, breccias, etc.)</td>
</tr>
</tbody>
</table>

Table 1 - Typical resources in karst areas, before and after the desertification induced by human impact.

In some areas of the Venetian Pre-Alps, rocky spikes sculptured by typical sub-soil rundkarren are now as much as 1 m above the general level of the remaining soil. More advanced desertification can be recognised in some areas with a typically Mediterranean precipitation regime, frequent fires and excessive animal pressure on the pastures. In some karst environments of the Mediterranean mountains, e.g. the Supramonte Mountains of Sardinia, Madonie and some gypsum ridges in Sicily, the stony deserts are truly impressive.

The second phase of human impact, widely overlapping with the previous one, involved the construction of the human cultural landscape, through the building of many different structures for better use of the land, the division of plots, the reduction of soil erosion, etc. Some of these structures are among the signs of the human landscape described previously.

The third phase, the recent one, is marked by the marginalization and desertion of most karst areas, in which the recovery of soil and vegetation is now occurring.

The karst areas, like most marginal mountain and hill areas, have suffered an intense rural exodus and abandonment of agriculture since the mid-1800s, but especially in the last 50 years: among the main causes of this are the progressive decrease of competitiveness of small family farms and the search for more profitable jobs and better living conditions. Vast agricultural zones in northern, central and southern Italy have been strongly affected by emigration toward extra-European, and later European, countries.

In addition to the general factors characterising this phenomenon, the shortage of
water, the thinness of the soil and the small size of cultivated plots, which had already made the situation of farmers in karst areas precarious, have contributed strongly to the increased intensity of the agricultural exodus.

As a consequence of this abandonment, bush is expanding rapidly in most karst areas, at first exploiting the soil pockets inside the karren traps. After World War I, the rocky desert of the Classical Karst of Trieste evolved first into brushwood and then, in the last few decades, into a forest environment. In some mountain areas, e.g. the Supramonte di Oliena in Sardinia, a typical Mediterranean wood is developing, and in certain high mountain karsts a mugo pine bush is masking the rocky landforms. The revived arboreal vegetation is an expression of the high regenerative capacity of karst environments, even though the development of soil and vegetation covers similar to those destroyed by human impact will certainly require a very long time.

In the last decade, there has been a reversal of the trend locally and a partial agricultural recolonisation of previously abandoned areas. There are two basic reasons for this: the availability of low-cost, even clandestine, manpower from poorer European and extra-European countries, and market demands for certain agricultural products (artisan products or those guaranteed by a specific mark of genuineness and origin).

Finally, other forms of degradation or pollution due to agricultural practices in karst areas can be summarised as:

a) degradation of slopes and valley bottoms, obliteration of sinkholes, filling of dolines;

b) pollution of karst reservoirs by pesticide and fertilizer runoff;

c) heavy use of aquifers for irrigation, with loss of the natural refilling capacity. Near the coast, and very frequently in the zone of the Murge in Puglia, lowering of the level of karst aquifers causes occasionally irreversible pollution due to infiltration of salt water.

5. An example of the recent trends of the man–karst environment relationship: The Monti Lessini and Monte Grappa (Venetian Pre-Alps)

Because of the great diversity of the Italian karst morpho-units, it is not possible to provide an exhaustive framework here. Thus only some typical cases are briefly analysed.

Some typical aspects of resource exploitation and human impact in the Venetian Pre-Alps were illustrated by U. Sauro (1987, 1993). The Venetian Pre-Alps, the southern sector of the eastern Italian Alps, constitute a belt of well-defined karst morpho-units, marking the transition between the Alps and the Venetian Plain. The upper Venetian Plain is one of the most urbanised areas in Italy, characterised by a wide variety of well-diversified industrial activities.

The control of the towns on the resource utilisation of the pre-alpine karst areas has been evident since the Middle Ages. According to the distances of the karst areas from the towns and the importance of the mountain communities, different types of strategies have been developed, fundamentally based on the use of the same resources: stones, lime, forests, agriculture, pastures, the production of fuel, timber, char-
coal, cereals, vegetables, fruit, dairy products, meat, hides and wool. Phases of strong impact in some areas, e.g. the excessive pressure from sheep on the pastures of the Sette Comuni Plateau in the XVIII century, have been induced by arbitration agreements between the business of the local communities and that of the urban wholesalers and the State.

Following urbanisation and industrialisation of the upper plain, some mountain areas of the Venetian Pre-Alps have been partially integrated in the new territorial dynamic, while others have been marginalized.

The Lessini Mountains and Monte Grappa represent two different models of evolution.

The proximity of the Lessini Mountains to Verona and Vicenza and to their industrial appendices, situated in the wide valley bottoms, has favoured the progressive integration of the mountain area in the new urban and industrial dynamic. This dynamic has resulted in the growth of different economic activities and in land occupation by productive structures.

In the post-World War II period, a first phase saw the expansion of quarrying, marble cutting, tannery and clothes industries in the wide southern valleys and of tourist infrastructures in some mountain villages. From the 1960s to the 1980s, a second phase was characterised by the development of complexes of vacation cabins, condominiums, ski resorts and access roads, and by the rise in the hill, low and middle mountain belt of a large number of specialised sheds for hog farming, cattle breeding, poultry and turkey farming. This type of growth was favoured by the expansion of some animal feed factories in the valleys.

During this phase, while the traditional agriculture of the mountain ridges (aimed at self-sufficiency of the local communities) faded away, cattle breeding and the use of high pastures during summer increased. In the 1980s, the number of animals per surface unit in the high pastures was 2.5 times the average of pastures in the other pre-alpine groups.

This type of development led to the introduction of a huge amount of living biomass that exceeded the productivity of the local environment. The deficiency has been covered by the introduction of large quantities of animal feed. The raw sewage production of nitrogenous compounds greatly increased, roughly corresponding to that of cities of 200,000-400,000 persons (Sauro, 1993), with subsequent environmental problems due to the liquid wastes and pollution of the karst springs.

In the 1990s, there was a retrenchment of some breeding activities, especially hog farming, and the pressure on some areas, e.g. high pastures, also decreased. Today the trend is towards a standardisation of the breeding methods, with a gradually decreased use of local resources. Therefore, the mountain area is evolving into a simple container of agro-industrial structures, more and more independent of the local environmental framework. One benefit is probably that of greater salubrity than in the agro-industrial areas of the plain. In fact, a recent viral epidemic in poultry farms of the plain did not spread to those of the mountain area.

The increased human impact in areas with high tourism pressure and rich in natu-
ral monuments, biotopes, etc., has prompted much debate on conservation problems, leading to the institution of the natural park of Monti Lessini. Today the development of the park is clashing with the many problems caused by the different types of human pressure.

The territorial dynamic of Monte Grappa is relatively simpler, also because of its marginal location with respect to large urbanised areas. A strong impact occurred during the World War I, when the area became a theatre of battles (fig. 2). The development of cabin complexes took place on a few ridges between the 1960s and 1980s, but it stopped in a short time because of the lack of permanent villages.

A progressive decrease in the use of high pastures has also occurred, with overgrowth of the forest. Frequentation of the high mountain is mostly linked to weekend tourism.

Therefore, even though the intensity of human pressure on the two karst morphounits is greatly different, a progressive distortion of the traditional man-environment relationship has taken place in both, illustrated by the consequent obliteration of the human signs in the landscape that were the expression of this relationship. The landscapes are acquiring new identities, partially linked to the urban-industrial network inside the complex economy integrated at a regional, national and worldwide scale.

In this perspective, besides the land, the only typical environmental resources that are assuming strategic importance in time are the stone and water reservoirs: however, the former is a non-renewable resource, while the latter is undergoing continuous

Fig. 2 – Soil erosion by pasture and bomb holes in Monte Grappa.
deterioration. Nevertheless, the characteristics of natural and/or seminatural space remain and the areas are rich in environmental niches, potential laboratories for city-dwellers in the discovery of both natural habitats and problems of human impact.

The challenges for the next few decades will be to mitigate some types of human impact and to rediscover, within the parks and natural reserves, the traditional styles of resource use, linking these with the promotion of agricultural tourism.

6. Fucino: the lake that became land

The Fucino depression is a typical Apennine intermontane basin and, from the morphostructural point of view, a tectonic fossa (graben). Its hydrographic basin extends for around 900 km² and is delimited by carbonate peaks of the Lazio-Abruzzo Apennines. It is a large closed basin characterised by an extensive alluvial plain of more than 200 km² (see picture in front cover).

This depression is not properly a karst basin, but rather a complex tectonic-erosive form; however, it is closed topographically on account of a karst-type drainage. Thus it can be considered a “tecto-karst” depression. The carbonate slopes and masses surrounding it are karst. The filling by detrital alluvial and lacustrine sediments has a thickness of a few hundred metres, even exceeding 1000 m locally. The tectonic processes are still active, as shown by strong earthquakes like that of Avezzano in 1915, one of the most serious natural calamities to strike central Italy in the XX century.

In the past, in natural conditions the superficial water courses and aquifers of the carbonate masses fed, by means of springs and underground flows, both a phreatic aquifer housed in the alluvial complex of the basin and a vast lake.

The water level of this lake was subject to large oscillations, caused by climatic variations and the discontinuous operation of the karst sinkhole called “la Pedogna”, situated NW of the town of Luco dei Marsi, and of others not well identified. Many factors affected the operation of the sinkholes, including the inflow of sediment by means of runoff waters and streams.

In the Palaeolithic, man was an idle spectator of the large oscillations of the lake level. In the Neolithic and in Protohistory, following the development of agriculture, the plain became a “cultivated oasis”, surrounded by slopes used for grazing. However, forest clearing and grazing accelerated the soil erosion, favouring the temporary obstruction of the sinkholes and consequent expansion of the lake and reduction of cultivable areas in the plain.

The problem of oscillations of the lake surface was tackled in the I century AD, when the Romans constructed a 5640 m long underground tunnel. It was able to drain the excess water and expose around 80 km² of land that was particularly fertile on account of its muddy texture.

The remaining lake was used for fishing and acted as an expansion area for possible flooding. There are no historical accounts of the types of crops, although it is probable that in addition to wheat and grapes, vegetables were grown for the markets of Rome.
After the fall of the Roman Empire, the progressive lack of maintenance of the tunnel, together with other natural causes (collapses inside the tunnel perhaps related to strong earthquakes, wet climatic phases), favoured expansion of the lake, perhaps starting from the VI/VII century AD.

In the mid-1800s, a new artificial underground collector was built. This led to the definitive disappearance of the lake and the reduction of the present water reserve in the basin by a quantity estimated at more than $1 \times 10^9$ m$^3$ of water. Thus the natural ecosystem (hydrogeological and biological) was upset and with it the social and economic order of the population.

The State assigned ownership of the reclaimed territory (more than 140 km$^2$) to the financier of the hydraulic work. The owner then built over 200 km of roads, 100 km of canals and 600 km of drainage ditches. The immense property was then divided into direct-management farms (2,800 ha), métayages (900 ha) and tenancies (9,300 ha). The system of tenancies was established to allow the recovery of capital invested in the reclamation. However, this system led to an extreme fragmentation of property, since each tenant then divided his land into smaller portions to be leased. This had an effect on the pro capite income, derived essentially from traditional crops (wheat, corn, beet, potatoes and beans, with triennial rotation) and limited water demand. In fact, the waters in the basin were sufficient for the agricultural activities and the dense net of artificial canals created by the reclamation permitted a good territorial distribution of the water resources. In 1951, the immense property was expropriated and divided into plots of 1/1.5 ha, which were assigned to the inhabitants of the plain.

Since the 1960s, human pressure on the Fucino area has gradually increased because of the development of urban centres but especially the modifications of agricultural organisation and cultivation systems. In particular, the water demand has increased, also in relation to new horticultural crops which are extremely water-needy (fig. 3). Indeed, the current exploitation involves two/three crop cycles. This causes strong pressure on the water resources, which is aggravated by two factors:

a) a system of sprinkler irrigation, not rationalised according to the needs of the crops and able to disperse a larger quantity of water than theoretically needed;

b) the lack of a responsible authority, able to discipline the withdrawal and use of the water resources.

To understand the problems of human impact on this geo-system, it should be considered that the Fucino plain constitutes a hydrogeological unit that is well defined but dependent on the adjoining units: it is a sedimentary complex derived from alternations of detrital-alluvial levels (gravels, sands, muds and clays), whose permeability is extremely variable according to the grain size.

From the point of view of natural dynamics, the inflow is determined by precipitation and by superficial flows. The latter consist of streams and karst springs feeding the hydrographic network, which only minimally penetrate in depth to reach the alluvial water layer because of the limited permeability of the sediments on the plain’s surface. The water layer in the alluvia of the plain is instead fed mainly by under-
ground flows from the surrounding karst aquifers.

The losses are due to evapo-transpiration, estimated at 450 mm/year. The water excess in the basin, concentrated exclusively from October to April, can be estimated at only 240 mm/year (Burri, 1991; Burri e Petitta, 1998; Burri e Petitta, 1999).

7. The Murge

The Murge is a low karst plateau in Puglia (southern Italy), marked in its central part by a honeycomb system of very large, closed, relatively shallow depressions. Their surface areas can reach a few square kilometres (fig. 4).

Wide dry valleys with flat bottoms, called Lame, are nested on the slopes of the depressions and on the external scarps. A few large deep dolines, called Pulo, form geomorphological peculiarities inside the plateau.

This karst may be considered a low relief energy “cockpit karst”, according to its morphological style. Some fluvio-karstic features were superimposed following different episodes of volcanic ash falls that mantled the relief and induced the development of a hydrographic network (Sauro, 1991).

Volcanic ashes are the parent material of the plateau soils, very fertile for cereal cultivation. The human impact started with forest clearing and continued mainly with sheep grazing. Soil erosion on the slopes led to desertification of the slopes and to
accumulation of soil sediments in the valleys and depression bottoms. In this way, agriculture became oasised in nearly circular plots inside the large depressions and narrow strips in the flat valley bottoms. Outside the cultivated areas, there is barren pasture, used today for sheep grazing. A complex system of dry walls encloses the cultivated plots.

Because of wheat growing, bread is a typical product of the small towns of the plateau.

8. Two examples of the analysis of agri-karst landscape evolution

"Le paysage est très précisément et tout simplement ce qui se voit" (Brunet, 1974): this statement, among several that can be attributed to the idea of landscape, makes us understand landscape as an appreciable datum, as a display, as an evident sign of the interplay of natural and human processes, phenomena and factors interacting within the territory. The essential characteristics of an agro-karst landscape derive from peculiar natural dynamics (karst), peculiar human dynamics (agriculture) and peculiar relationships between them.

However "Ce qui se voit est un signe pour le chercheur" (Brunet, 1974): although everybody can see it, the appreciable datum can be an interesting starting point to investigate the dynamics of natural and human factors and processes. Also in karst areas, a large amount of information concerning man–environment interactions can be obtained by the analysis of landscape signs.
Landscape analysis can be performed from very different perspectives: for example, it can be directed towards a simple description of landscape elements in a didactic perspective, or towards the evolution and changes that occurred in different time scales for geomorphological or historical reviews, or towards environmental planning.

Two examples of landscape analysis are presented here: using different methods (quantitative vs. qualitative), they indicate the most important events of landscape evolution in the last few decades in two Italian karst areas.


The main aspects of agricultural impact in the southern plateau of the Berici Hills have been studied through an analysis of land use evolution with a geographic information system (GIS) application.

The area is a rather low karst plateau (150–300 m a.s.l.) with Eocene marly limestone outcrops; there are many dolines and uvalas intercalated with knolls on its surface. Agricultural activities occupy a large part of the plateau, but their nature has changed in the last 50 years due to the profound changes in the social and economic context.

This analysis was carried out according to quantitative criteria, using data drawn from 1:5000 scale regional technical cartography and aerial photos, verified by field investigations. Three time situations (1956 - 1982 - 1996) were compared, relating to three available air photo strips. With the IDRISI GIS, it was possible to create a land use thematic map for each examined situation. This material, together with a relief map, was the basis for further surveys and processing (by means of the GIS). Percentage areas of each category of soil exploitation were calculated in the three phases, allowing a quantitative comparison; moreover it was possible to relate each feature to the geomorphological framework.

For the thematic maps, different kinds of soil exploitation were collected in some categories: wood (mainly a coppice still used or with recently ended cutting, present in fairly narrow plots of lands); scrub (typical thermophilic brushwood of the zones with highest soil erosion, or thin forest connected to extents of wood or to its extreme exploitation); meadow - cultivation (mostly mown meadows and maize and forage fields); vineyard and buildings.

a. General land use evolution

The graph (fig. 5) illustrates the percentage subdivision of land use categories in the area in the three time situations and allows us to observe their evolution. The percentage of productive land (meadow-cultivation and vineyard) is nearly constant in comparison with less or non-productive land (wood and scrub); however, in the chronological sequence obtained by comparing the 1956, 1982 and 1996 situations, some basic changes in soil exploitation can be noted.

The first one is the change of scrub into wood, due mostly to the increase of the
Fig. 5 – Land use evolution in the sample area in Berici Hills.

The second profound change in the landscape in recent years (mostly from 1982 to 1996) is the decrease of meadow-cultivation categories and the progressive increase of vineyards. This is a very considerable landscape variation, marking the transition from a type of agriculture requiring a lot of labour and little machinery (mainly for self-consumption) to a kind of company agriculture that seeks the most fruitful and suitable cultivation (in a sunny unfoggy place, characterised by thin, water-poor soil) and increasingly rejects economically unfavourable, albeit traditional, cultivation (fig. 6).

Moreover, the changing land use and the consequent impact on the landscape are increasingly profound because of different vine cultivation techniques that considerably change the features of the area: narrow rows of vines linked to live supports (fruit trees, maples, mulberry trees, etc.) alternated with meadows (1956 situation) were replaced by real vineyards with wooden stakes as supports (1982) and then by wider and wider plots of land with concrete piles, mostly in the softer morphology zones and wider dolines (1996).

In the 1982 and 1996 situations, poultry or rabbit breeding farms are also considered in the “buildings” category; they can be clearly seen in the landscape, with their huge sheds extending onto the knoll from doline to doline, and they make the landscape seem less “agricultural”; they look like a sign of “industrialisation” on these hills which instead maintain their traditional traits of agricultural landscape.
b. Distribution of land use categories according to the geomorphological framework

The landscape of this part of the Berici Hills is characterised by the fragmentation and continuous alternation of small and medium-sized landforms (dolines with their sometimes terraced slopes and rather flat bottom, and small ridges and knolls among contiguous depressions). The size and distribution of plots of land and different soil exploitation typologies are related to these landforms. The result is the typical landscape structure of this and other doline landscapes, which can be defined as “leopard spotted”. Some quantitative analyses of the relation between relief shapes and land use have been carried out; they show the different uses linked to these factors and illustrate how this relation has changed in the last 50 years.

With the GIS analysis, it was possible to distinguish the external areas of depressions from the inner ones and, within this category, between the inclined slopes and the doline’s central subflat area (the bottom). Some observations can thus be made on the basis of table 2.

The general trend of landscape evolution is generally observed both inside and outside the dolines (unchanging percentage of cultivated areas, progressive increase of vine cultivation and decrease of meadows and cultivations, change of scrub into wood); however, a distribution of land use categories in exact relation to morphology is noticed.

The bottom of the depressions is almost 80% cultivated, reflecting its characteri-
Table 2 - Evolution of land use in the sample area of Berici Hills, according to geomorphological framework.

<table>
<thead>
<tr>
<th>Year</th>
<th>Category</th>
<th>Bottom</th>
<th>Slopes</th>
<th>External Areas</th>
</tr>
</thead>
<tbody>
<tr>
<td>1956</td>
<td>wood</td>
<td>6.44%</td>
<td>18.11%</td>
<td>8.24%</td>
</tr>
<tr>
<td></td>
<td>scrub</td>
<td>15.11%</td>
<td>36.79%</td>
<td>43.72%</td>
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<tr>
<td></td>
<td>meadow-cultivation</td>
<td>68.78%</td>
<td>39.50%</td>
<td>37.19%</td>
</tr>
<tr>
<td></td>
<td>vineyard</td>
<td>9.68%</td>
<td>5.24%</td>
<td>9.01%</td>
</tr>
<tr>
<td></td>
<td>buildings</td>
<td>0.00%</td>
<td>0.36%</td>
<td>1.82%</td>
</tr>
<tr>
<td>1982</td>
<td>wood</td>
<td>15.75%</td>
<td>40.28%</td>
<td>32.49%</td>
</tr>
<tr>
<td></td>
<td>scrub</td>
<td>6.10%</td>
<td>17.27%</td>
<td>20.59%</td>
</tr>
<tr>
<td></td>
<td>meadow-cultivation</td>
<td>58.74%</td>
<td>32.92%</td>
<td>30.35%</td>
</tr>
<tr>
<td></td>
<td>vineyard</td>
<td>19.36%</td>
<td>8.64%</td>
<td>13.09%</td>
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<td>buildings</td>
<td>0.05%</td>
<td>0.90%</td>
<td>3.46%</td>
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<tr>
<td>1996</td>
<td>wood</td>
<td>14.55%</td>
<td>38.82%</td>
<td>30.25%</td>
</tr>
<tr>
<td></td>
<td>scrub</td>
<td>8.08%</td>
<td>20.38%</td>
<td>20.30%</td>
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<tr>
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<td>48.28%</td>
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<td>27.77%</td>
</tr>
<tr>
<td></td>
<td>vineyard</td>
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<td>16.38%</td>
</tr>
<tr>
<td></td>
<td>buildings</td>
<td>0.29%</td>
<td>1.00%</td>
<td>5.27%</td>
</tr>
</tbody>
</table>

Two observations can be made about the external areas of the dolines. First, the percentage of uncultivated areas seems to be slightly higher, with scrub being most frequent: indeed, the external areas of dolines have favourable conditions for the establishment of thermophilic and xerophilic scrub communities (they are the driest and sunniest areas). Second, the category “buildings” shows a clear preference for the areas between one doline and the next, and this preference remains as time goes by: in fact, for this kind of use, the exposure and ease of access are more important than soil thickness.

8.2. A qualitative method of landscape analysis: the case-study of Gargano (Puglia, southern Italy)

GIS land use analysis is very problematic where large-scale maps are not available. Therefore, different criteria were applied to the study of the landscape of the inner part of the Gargano promontory.

This region is a large inclined doline plateau, from 900 to 400 m a.s.l., crossed by

stics of soil thickness and high humidity. The percentage of vine cultivation, which was very low with respect to the other kinds of cultivation in 1956, increases with time more than in the other places, while there are virtually no buildings.

In the time period considered, the doline slopes are the only areas where a slight decrease of the meadow-cultivation and vineyard categories is observed; their percentages, however, are less than the general average (from 44.74% in 1956 to 41.56% in 1982 to 39.8% in 1996). In contrast, the slopes are the areas with the highest percentage of wood, even when wood areas are rather reduced (1956). This condition is due to their steepness, which hinders cultivation, and sometimes to unfavourable exposures, which make the lower parts of the slopes rather cool and extremely moist.
some low ridges. In places, there is very intense soil erosion, while elsewhere there are quite deep colluvial covers of soils previously evolved on volcanic ash.

Since the landscape is “what we can see”, in this case the landscape analysis is based only on the identification of the principal elements, recognised on maps, aerial photos or in field work. The significance of each element can then be defined, in a kind of reading process. In the end, many elements together allow us to recognise the most important features of the present and past situations: they allow us to understand the dynamics in which natural and socio-economic factors are and were involved.

The changes from the traditional agricultural landscape, with a large number of isolated farms and almost all the land used for cultivation and grazing (as can be recognised in the aerial photos of the 1950s), to the present situation, with only a few active farms, extensive grazing and a rural exodus from most of the region, are well identified with this method of landscape analysis. Although natural and human features are closely linked, they have been differentiated in the following description so as to better analyse each element.

Natural elements

There are limestone outcrops and karst landforms on the entire Gargano plateau, especially dolines, uvalas and dry valleys. One very large doline (Dolina Pozzatina) is 600 m long, 400 m wide and more than 120 m deep, while other forms are in general small or medium-sized.

The natural vegetation is oak wood (Quercus cerris) and its distribution depends on the type of human exploitation: due to the present abandonment of agricultural practices, it is growing in increasingly larger spaces. A general condition in the first phases of the abandonment of cultivation and intensive grazing is the explosive growth of two weed shrubs, fern (Pteridium aquilinum) and asphodel (Asphodelus sp.). This makes it difficult for other natural species to grow: the re-establishment of vegetation in equilibrium with ecological conditions and with a high level of biodiversity requires a rather long time, especially in areas where extensive grazing still exists.

The analysis of aerial photos indicates an area in which wood was present until the 1970s and then was quickly cut; many circular charcoal pits (5-8 m in diameter) are distributed in this area, especially on the bottom of dolines, together with stone shelters for charcoal burners. It was an area of coal production until recent times, and probably in the last phases of land abandonment, wood was cut and utilised as the only remaining resource.

Many fruit trees and large chestnut trees are distributed in this area, especially near old buildings; they represented an important resource for farmers, as well as a shady spot in the hot summer.

Human elements

Many of the human elements in the Gargano plateau landscape refer not to pre-
sent settlements or activities but merely to human presence in the past. The current
activities can be found only along the two or three asphalt roads.

An important sign of past human presence is the large number of farms and iso-
lated small houses that are now only ruins, but in which some aspects of the peasant
and shepherd way of life can be recognised. In particular, various systems to collect
and preserve rain water are very interesting: wells, large stone tanks, gutter systems
and waterproof paving.

Many ruined dry walls divide plots of lands that had different uses or follow old
tracks. Many of them support the terraces on doline slopes; the practice of terracing
was well developed, with some examples of six or even seven steps on a single steep
slope (fig. 7).

In the areas where human activities are still present, different signs can be found in
the landscape: cultivated plots of lands with corn, fodder plants, sunflowers and legu-
mes are distributed according to the relief characteristics; zones with deep soil are pre-
ferred, and doline bottoms are also cultivated. In places, the slopes have been arranged
with the help of bulldozers to enlarge plots and to eliminate stones; large stone blocks
are often thrown into the dolines, in correspondence to sinkholes.

Some old farms and houses have been restored and new houses have been built; in
some cases there are permanent settlements, especially large farms with grazing and
fodder plantations; in many other cases, people (often old people) live in the nearby
villages and come to their small holdings during the weekend for part-time farming.

Fig. 7 - A large doline on the
Gargano plateau: the 7 terras-
ces on its slopes are comple-
tely abandoned.
In conclusion, the analysis of landscape signs indicates that, in the Gargano karst plateau, agricultural practices were well developed with traditional characteristics until a few decades ago. A general rural exodus then completely changed the area, which now appears abandoned. Even though this area is part of the National Park of Gargano, no attention seems to be paid to making good use of the resources for sustainable development: obvious signs of this absolute negligence are the wrecked cars thrown down into almost every doline!

9. Conclusion

In Italy, there is a wide variety of karst morpho-units with different geological and geomorphological evolution, land reclamation and human impact history. The mosaic of human landscapes is complex and varies in relation to the different types of land use, the pattern of agricultural plots, the utilisation of peculiar resources (e.g. the different types of soluble rocks), the structure of settlements, and the variety and “stratigraphy” of the signs left by man.

Most of the landscapes present oasis agriculture according to the thickness of the soil cover, which depends on the morphodynamic processes and types of landforms.

In recent times, while a few karst areas have been integrated in the new economy, most karst morpho-units have been gradually deserted and are now undergoing the expansion of wood.

REFERENCES

AA.VV., 1989. Implications des modifications climatiques dans la région méditerranéenne. UNEP (OCA) MED IG., 1/inf. 9, PNUE, Athènes.
Agriculture, LANDSCAPE AND HUMAN IMPACT IN SOME KARST AREAS OF Italy


BURRI E., PETITTA M., 1999. Farming and water management in the Fucino Plain (Central Italy) in the last century, Int. Com. on Irrigation and Drainage (ICID), Seven. Cong. Granada, Q. 48- P. 45


GAMS I., NICOD J. and SAURO U., 1993. Environmental changes and human impact in


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LAND USE AND HUMAN IMPACT IN THE DINARIC KARST

Ivan Gams and Matej Gabrovec

ABSTRACT
The article presents Dinaric karst, human impacts in the area, and its long history of deforestation, transformation into stony semi-desert, and a century long reforestation, where plans to restore the primary thick soil were just hoping against hope.

KEY WORDS: Dinaric karst, farming methods, reforestation

1. Introduction
The area dealt with in this paper is the Dinaric mountain system between the Soca river and Montenegro. In geology the name Dinaric karst has approximately the same meaning as the Outer Dinarides. Schematically, the age of Mesozoic carbonate rock is decreasing in the Dinaric karst from the north-east towards the south-west. In the north-eastern zone, Triassic dolomite - in some locations only partially permeable - prevails, allowing larger rivers to remain on the surface. Here, fluviokarst prevails (Roglic, 1965). Eocene flysch occurs primarily near the coast and on the islands. In the majority of limestone, the share of carbonates is above 92%. Therefore, after the corrosion, not much material remains available for the formation of soil. In the higher central Dinaric karst plateaux prevail, from which steep mountain ridges and isolated mountains rise. Larger plains are found only in the Istria peninsula, in Zadar hinterlands, in Zagora, and in some parts of Herzegovina. The average annual precipitation in the area is around 1500 mm, less on the islands, highest coastal mountains receiving up to 3000 mm and over.

As the north-western part of Dinaric karst called Kras (the term karst is derived from the name of this region) was a part of the Austro-Hungarian empire, and on the main route from the Danube basin to the Adriatic coast, it was easily accessible and thus attractive to many naturalists. They described it as a stony semi-desert with dolines (Gams 1974, 1991a). This article presents and explains the transformation of forest into semi-desert and, due to the recently abandoned cultivation, the growth of scrub and forest.

2. A short deforestation review
The first larger-scale deforestation was brought along by a denser settlement of prehistoric tribes in last centuries BC. Numerous later movements of peoples in this area resulted in additional deforestation such as the migration of the people from the mountains in Montenegro, Herzegovina and Southern Bosnia which began in the 15th century when, before the advancing Ottoman empire, the primary inhabitants fled
toward West and North. The emigrants who brought their slash-and-burn economy spread the Orthodoxy and the Serbian language 200-300 km westward from the river Drina (Cvijic, 1922). Seasonal movement of pastoral farmers (transhumance) - along with burning, later also cutting of the forest - was preserved (partially due to the Turkish occupation) locally until this century, when they were observed by first researchers (Cvijic, 1922, 1931). According to the eyewitness Gusíc (1957, 1971), the main reason for deforestation was clearing the land for new pastures or meadows and sowing of grain in "novine" (new fields), used only once. Secondary reasons were gathering of firewood for wasteful open fire-places, charcoal-burning, protection from animals, rebels (hajduks) and robbers, hunting, natural and intentionally set fires during the wars. On the islands, which were under the rule of Venice between the 13th and the end of 18th century, and along the coast, one of the reasons for deforestation was also selling of firewood and oak timber for ship construction and pillars for the construction of buildings in Venice.

Protecting role of the forest for soil conservation is essential in Dinaric karst. After the Alpine orogenetic phases the vast horizontal uninterrupted strata are an exception. The tree roots which hold the soil in the fissures lose their function in preventing the denudation after deforestation, and especially burning. Most of the annual precipitation on the coastal mountains fall in form of downpour, 70% of it in colder winter months.

3. Types of karst adaptation to agricultural land use.

The main obstacle for the intensive agricultural use of Dinaric karst is its stony surface. Without removing of stones, the land was suitable for ploughing or spading (i.e. cultivation) mostly only on the alluvium at the bottom of rare river valleys, some uvalas, karst poljes and rare dolines, or on non-karst patches of impermeable rock which decomposes faster. Before the intervention of man, two types of land use predominated in the Dinaric karst: non-karst areas, suitable for cultivation without stone removing, and karst areas, permitting mostly grazing of sheep, goats and cattle. Pastures were turned to meadows only after stones had been removed from the surface. In the low littoral region along the Adriatic coast and especially on the islands, man added the third, garden-orchard-vineyard type of agricultural landscape to arable farming and grazing.

As a consequence of natural and historical conditions, the following types of adaptation to agricultural land-use developed in the Dinaric karst (Gams, 1992):

3.1. Transforming forests to pastures

The type with denuded soil and stones protruding from the surface developed after the forest had been cleared for grazing. Morphologically, this is a type of semi-barren or barren (stony) karst. After the deforestation, particularly on the slopes exposed to the sun, less compact protruding stones decomposed into rubble forming scree on steep slopes. Smooth surfaces on compact carbonate stone are proof of sub-soil origin, generated at contact with humus and clay. After soil erosion the atmo-
spheric processes, above all, mechanical weathering and corrosion by meteoric water, generate rough surfaces of these stones. From the vertical distance between the lines which denote the smooth surface and the rough one, the reduction of soil can be estimated (Gams, 1973). On steep coastal mountains and high plateaux in their immediate hinterlands, where - particularly in the south-eastern part of the Dinaric karst - the summer is the driest period of the year, the karst was the most stony and barren in the old Montenegro, in low Herzegovina and in the coastal mountains in Dalmatia. In the Modern Age, these were the first places where agricultural population lost its source of existence due to eroded soil. A typical example is the old Montenegro (Crna Gora). The name derives from the Montenegrine word "crnogori- ca", meaning dark submediterranean coniferous forest which initially covered the area and was removed in the Modern Age. After the slash-and-burn system was abandoned, forests recovered faster and more successfully in the inland Dinaric area with continental climate than in the coastal area.

3.2. Transforming pastures into meadows

The second type was established by the introduction of meadows. Farmers cleared the stones protruding above the surface to transform pastures into meadows, where they could cut the grass. The removed stones were buried under the soil, accumulated in heaps or in lines (groblje, also gomile) or used for building dry (karst) walls at the edges of meadows, dolines or plots of land. The oldest dry walls
I. Gams and M. Gabrovec

Fig. 2 - Some forms of the transformation of the karst surface due to cultivation.

1 - Field terraces on slope in semicovered karst. 2 - Transformation of the funnel-shaped doline into a more bowl-like doline. 3 - Transformation of the semicovered karst into the covered karst in a meadow.

Forms of accumulated rubble collected at the process of cultivation: 4 - a heap of stones, 5 - heaps of stones arranged in a row, 6 - a single-row wall, 7 - a double-row wall, 8 - a double-row wall with inner filling, 9 - "kamenar" - rectangular tower (Acc. to Gams, 1974).

are recorded from the Roman period.

3.3. Making ploughing possible

The third type came into existence together with adapting karst surface to arable land. This type developed with removing of stones from the surface and from the soil which was spaded at first and ploughed later. Therefore, accumulations of rubble are
larger in this type. The depth to which they had to clear the stones had been increasing in accordance with modernisation of ploughs - tractor ploughing requires a depth of over 28 cm. Along with types 1 and 2, type 3 is more common in more densely populated littoral lowlands with submediterranean climate. The karst surface remained more stony and with fewer walls where refugees from the Ottoman Empire settled and continued with grazing (Ravni kotari, Bukovica, part of Herzegovina). For different reasons, substantial part of the low Herzegovina and the old Montenegro out of the coastal area, as well as Rumija, also belong to this type. Removed stones are also found by cave explorers at bottoms of potholes, they are uncovered in road cuttings, in the course of digging ditches for various pipelines or cables, they are used for construction of buildings and levelling of field roads and cart tracks. On the western edge of the Kras region, it was crushed by cannon anti-infantry mines during the World War I (1915-1917) at the site of the stationary Austrian - Italian front, or it was built into military buildings in the hinterland of the front (Man's Impact..., 1987). From such removed stones the so called enclosing walls were built, i.e. dry walls on the border between pastures and arable land, around the dolines and on both sides of village roads, preventing livestock from grazing on meadows and fields.

3.4. Artificial terraces with scarps

At the lower end of artificial terraces supporting walls were built from removed stones. The shelves were levelled with accumulated remaining stones behind the supporting walls and covered with the soil which was transported from the vicinity. If the walls surround all four sides of the parcels, a "box-like landscape" is formed, in which dry walls rise above the scarps, usually up to the chest height (building to such a height did not require additional help).

3.5. Adaptation of dolines for cultivation

Stones, removed from the doline slopes, were thrown into a hole, dug into the ground at the bottom of the doline. Then the bottom of the doline was covered with the soil from doline slopes or from the closer surroundings; in this way, a larger level area suitable for ploughing was acquired. Places of removed soil, characterised by high stones with smooth surface, can be detected only by an expert geomorphologist.

3.6. Trench-ploughed vineyards

This type differs from the fourth type (3.4.) in deeper removing of stones. Therefore, scarps and dry walls are more numerous.

3.7. Narrow stair-like vineyards

They are typical on the Adriatic islands and coastal areas on the continent, exposed to the sun and sheltered from the bora. Larger uninterrupted areas are on the islands around the villages, and on the mainland coast mainly around larger cities
Fig. 3 - The first phase of karst cultivation is visible in a newly settled area: arable land in irregular patches with thicker soil between the more stony surface is cultivated with spade. The high stones with smooth surface on the slope behind prove the removing of soil for the accumulation on the near acre now abandoned for meadows (the Banjscice plateau, 800 m of altitude, 1970, Slovenia).

Fig. 4 - A new vineyard in Vrboska where the dry walls take up more surface than soil (the Hvar island in 1992).
"Fig. 5 - A new vineyard torn from the stony desert at Primosten, Dalmatia. To protect the soil from the bora also the soil around the vines is covered by rubble.

(Rabac, Zadar, Sibenik, Split - on the northern slope of Marjan mountain, above the cities of Boka Kotorska and Dubrovnik, etc.)

This type spread mostly in the last two centuries on the stony steep slopes when better land was no more available. It largely expanded in the second half of the previous and in the first half of this century when the price of wine increased abruptly after the occurrence of Peronospora, Phyloxera and Oidium in France in the middle of the previous century, while in coastal Dalmatia it appeared several decades - on the islands even half a century - later. Since better agricultural land had already been cultivated, new vineyards were made on higher and stonier slopes. After the Second World War, the Dalmatian municipality of Primosten distributed stony common lands among the villagers so that they could convert them into vineyards. Surfaces covered with accumulated removed rubble are there larger than surfaces covered with soil. The image of these stony vineyards, symbol of the struggle for survival in a harsh environment, decorates a wall in one of United Nations buildings in Geneva. Where an access with carts to inner parcels is impossible due to piled stones, abandoning of land cultivation has been general in recent times.

On the islands, the amount of removed stones during the introduction of more intensive crops was much larger comparing to continental areas due to Mediterranean crops and especially due to immigration of refugees from the Ottoman part of the continental Dinaric karst (Carter, 1992), who settled the remaining land of a marginal quality. In Istria and on Slovenian karst, types 6 and 7 are generally not so common.

Removed stones were piled in several meters wide mounds, following the slopes,
usually at the contact of land belonging to different owners (on the Krk island, especially around Punat, named barbakan or varvakan).

3.8. Adaptation for orchards

The last type of adapting occurred with plantations of fruit trees. Among them, olive trees, and to a lesser degree fig trees have always been prevailing in the Mediterranean climate. Soil funnels are smaller than crowns of trees so that the soil between individual trees need not be cleared so deeply.

4. Karst dry walls as an indicator of the adaptation of karst for cultivation.

The stones removed from soil have mostly been accumulated in dry walls. The thickness of walls depends on the construction type (single-row, double-row or double-row with smaller rubble in the middle) and on the volume of removed stones and their thickness. Special and rarer forms are stony rectangular or rounded "kamenari", several meters wide and up to 50 meters long, 1.3 - 2.5 m high heaps of stones. Some were formed by joining of smaller walls or stone heaps, gaining more arable land. In the vicinity of settlements, thick walls were built along the roads on which merchandise was carried (Gams, 1974).

The amount of accumulated stones on the surface increases in accordance with the intensity of land use or higher range of adaptation type. From the volume of stones and from specific weight (2.7), the weight of built-in stones was calculated for selected locations and divided by the surface of cultivated land from which the stones originate. The average amount on Slovene Kras region ranges between 50-200 kg/m². On the 1830 m long profile across the Velo Polje karst plain on the Hvar island, where fields prevail over the orchards, it was 236 kg/m². On the measured orchard (especially olive tree) parcels on the Krk (Punat), Vis, Bisevo and Hvar (Starigrad) islands, it sometimes amounts to 1000 kg/m², in vineyards up to 1400 kg/m². An extreme weight of removed stones in the seventh type of karst adaptation was measured on the Hvar island above the village of Dol, where it amounted to 2070 kg/m². On the measured olive tree parcel above the town of Punat, the soil was thinned by 11-30 cm only because of stone removal. The weight of scrapes which remained in the soil after the removing of larger stones and which amount to several % of the total weight of the soil, is not included in these calculations. They also contribute to higher temperature of the soil. Locations with above-the-average number of walls were chosen for measurements (Gams, 1992, Man's Impact..., 1987).

On the littoral Dinaric karst, special kinds of buildings were built from the removed stones. In the corner of the parcel two walls were added to two corner walls and the rectangular room was covered with branches to make a shelter for the protection of shepherds and other people against the rain and the wind. From stratified limestone, rectangular buildings with domed roof were built, used as shelters by farmers from remoter villages (so called field). Especially on the Hvar island, several 2 - 3.5 m high buildings, named "trim", remained (Fig. 6). Outer walls, built from stratified limestone, are closing up towards the centre as they become higher, so that on the
outer side, a stone path can lead upwards for carrying stones, needed for the construction of the top of the 3 - 4 m high dome. With its name alone, the trim reminds us of a building without inside rough coating, named trullo in the Italian Puglia region, nowadays used mainly as a storage, while more comfortable variants are used for living.

Fig. 6 - A stony shelter built of cut-off stones for man or cattle in the field (the Losinj island near Veli Losinj).

5. Modern reforestation

In the continental part of the Dinaric karst, vast forests existed throughout the history in some mountainous areas. On the islands and in some places along the coast, man turned the majority of the forest into evergreen scrub associations of maquis type with jasmine, ash, hop hornbeam, Quercus pubescens, myrtle, etc. Larger cities (Dubrovnik, Split, Zadar, Trieste) have been issuing orders and regulations since 12th century, limiting deforestation to protect drinking water, to provide protection against the bora, for hunting and other reasons, or they even enacted reforestation decrees (Gusic, 1957, 1971). The pollen analysis of the stream delta at the coast in the town of Starigrad on the Hvar island, where a Greek, and later a Roman settlement was located, showed sedimentation of the alluvium from the nearby slope in the time of forest clearing to acquire the land for cultivation. After the forests returned, the stream dried-out (Gams, 1992, p.68). The first larger and planned reforestation took place at the beginning of 19th century during the short existence of French Illyrian Provinces. The second scheme, implemented on a larger scale and more successfully, took place in the second half of the 19th and at the beginning of the 20th century under the Austro-Hungarian Empire, when non-agrarian jobs reduced agrarian pressure on land in the north-western Dinaric littoral karst. This reforestation in the region Kras was of great
importance. In the years 1870 – 1911 the government planted 26,000,000 plants only in a part of Kras. After many trees of the world had been tested, the black pine (Austrian pine, *Pinus nigra* Arn.), imported from other parts of the state, was planted there and 56,000 local people collaborated. Foresters from all Europe came to observe the experiment which proved successful. But the new 2 – 4 cm thick soil cover built of not yet fully decomposed pine needles in the more than 100-year old monoculture of black pine forest is acid. The biodiversity of the soil fauna is therefore reduced. Besides the timber of black pine has a low price when sold.

In the region of Kras, the share of the forest increased from 10 to 50% in a 200-year period (1800-1998). This data is approximate because the Kras region belonged to different statistical and administrative units and because definitions of land use categories have been changing over time and space. However, within a few decades, it can become a type of forested karst. A similar expansion of the forest area is also characteristic for Slovenian Dinaric karst in the continental climate zone. The Kocevje district was most severely affected during the World War II (1941-1945). In

![Cart track above Veli Losinj village with abundant dry walls on both sides (called ulica = street).](image-url)
1870, the forest share was 34.4%, while at present it amounts to 90% of the same area. Towards the south-east of Dinaric karst, however, this transition occurred much later.

6. Changes of land use in the Dinaric karst after 1960 in the light of the official statistics

The area of the Dinaric karst, shown on the map, is today divided among four states, i.e. Slovenia, Croatia, Bosnia and Herzegovina, and Yugoslavia (Montenegro). In order to acquire maximally comparable data, the period when the whole area belonged to one state, i.e. former Yugoslavia, was chosen for the analysis of land use change, and a single source - Statistical Yearbook of Yugoslavia (Statistički godisnjak FNRJ 1962, Statistički godisnjak SFRJ 1963, Statistički godisnjak SFRJ 1990) - was used. Two kinds of data on agricultural areas exist. For the former social sector, data was acquired on the basis of reports of agricultural companies and cooperatives, while for the private sector, estimates were made according to data compiled by statistical authorities. They relied mostly on recent cadastral data, but they also gathered information from other sources. Data for forest areas was acquired with the use of forest fund inventories made in 1961 and 1979. Unfortunately, agriculture and forestry sources are not always harmonised. In some cases, the same areas (usually overgrown pastures) are recorded as forests by the forestry sector, and as pastures by the agriculture sector. In these cases, the sum of total area exceeds 100%, or obvious errors occur. These errors were eliminated by assuming data of the previous or the following year. Basic territorial units - municipalities were joint into 12 units, homogenous to a largest possible degree in a natural geographic sense. The earliest available data is for the year 1961, the latest available data is for the year 1989, while for the forests, unfortunately, the latest available data is for the year 1979.

Due to general agriculture intensification, the share of fields in this period was reduced in the whole area, in Croatia especially vineyards and olive-tree plantations. The spread of forests, which is the consequence of the overgrowing of pastures, is a general phenomenon. Meadows and pastures combined are declining in spite of the fact that the area of meadows expands on the account of abandoned fields. There are of course considerable differences among regions. In littoral Slovenia, in flysch hills, agriculture intensification and expansion of vineyards is taking place. In the continental Slovene Dinaric karst (the Notranjsko region) the share of a high forest is increasing rapidly on the prevailing high karst plateaux. In the lower Dolenjsko region, densely inhabited since prehistoric times, grassing over prevails in recent decades (Gabrovček, Kladič, 1997).

On the Slovene Dinaric karst, differences between the land use on limestone and dolomite areas have been more thoroughly studied. The most evident differences occur in the share of meadows - on dolomites, their share exceeds the share of pastures by 10% (dolomite 27%, limestone 17%). On limestone, there are fewer meadows due to more stony surface preventing grass cutting, which results in a larger share of
pastures. On dolomite, meadows were very frequently set on very steep slopes, where the use of mowing machines was impossible. These steep meadows were consequently frequently left to overgrowing and are already entirely overgrown by the forest in some places. Therefore, the forest area expanded much faster on dolomite than on limestone. On the Dinaric karst of continental Slovenia, the forest area on dolomite increased by 17% in the period 1953-1987, while on limestone it increased only by 7%. On limestone and dolomite, pastures are being heavily overgrown by forests - their area was reduced by 36% on limestone and by 29% on dolomite. In the test areas, a detailed land use analysis was elaborated on the basis of the first, so called Emperor Francis' Cadastre from mid-twenties of the 19th century. At that time, there were fields in virtually all bottoms of small dry valleys with thicker soil on dolomite. These were preserved up to the present only on 10% of former area, while

Fig. 8 - Land use in the Dinaric Karst 1961 - 1989.
the rest is, like meadows, being overgrown by forest (Gabrovec, 1995).

In Croatia, the greatest reduction of agricultural land occurred on the Adriatic islands where the area of vineyards decreased by more than a half in the last thirty years. Here, the abandoning of agriculture is related to high emigration levels (Cede, Steinicke, 1997; Crkvencic, 1992). Croatian statistics also publishes data on fallow and uncultivated arable land. In 1996, their share in Croatia amounted to 28%, while on the Dinaric karst it was approximately twice as large. In coastal Zadar and Sibenik-Knin districts, the share of uncultivated arable land even exceeded 70% (Statisticki ljetopis 1997), which is obviously also the consequence of the war in the 1991-1994 period and the emigration of Serbian population. Before disintegration of the communist Yugoslavia, only slightly over 10% of arable land in Croatia was uncultivated, 22% in Dalmatia, while in the nationally mixed Lika region it amounted to 39% already at that time (Statisticki godisnjak SR Hrvatske, 1998).

Unlike in Croatia, the share of (though small) vineyard and orchard areas in Bosnia and Herzegovina and Montenegro increased. In Herzegovina, large state-owned agricultural companies with large fruit plantations and vineyards in the Neretva valley contributed to the increase. In Herzegovina, pastures absolutely prevail among the land use categories - together with meadows, they amount to approximately 50% of total area. In 1961, there were only 10% of meadows in this area. In Montenegro, large hydromeliorations were carried out in the vicinity of Podgorica, Danilovgrad and Ulcinj, where fruit trees and vineyards were planted. Otherwise, livestock breeding remains the principal agricultural activity in Montenegro.

<table>
<thead>
<tr>
<th>Region</th>
<th>Cultivated fields</th>
<th>Orchards</th>
<th>Vineyards</th>
<th>Meadows and pastures</th>
<th>Forest</th>
</tr>
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<td>1.1</td>
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<td>0.9</td>
<td>0.7</td>
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<td>0.9</td>
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<td>2.4</td>
</tr>
<tr>
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</tr>
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<td>4.0</td>
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<td>2.2</td>
<td>0.2</td>
<td>0.3</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Table 1 - Land use on the Dinaric karst in the mediterranean and submediterranean climate in the period 1961-1989, in %.
I. Gams and M. Gabrovec

(Enciklopedija Jugoslavije, 1987).

The process of overgrowing of pastures and marginal meadows and spreading of forests due to deagrarization initially appeared at the end of the previous century in the north-western part of the Dinaric karst, while the remaining karst area met changes mainly after 1945 in the new communist state of Yugoslavia which forced industrialisation and deagrarization and banned goat-breeding in 1948 and 1949. Especially on the islands, the abandoning of intensive crops was accelerated by rapid depopulation after 1945. Along with the increase of areas overgrown with bushes and young trees, and along with the increasing number of summer tourists, forest fires are becoming more common every year. According to a source from 1970 (Androvic, 1970), 2407 hectares of forest were burnt every year. However, in the devastating year 1998, the burned-over area was considerably larger.

After 1956, a considerable portion of pastures on the Dinaric karst, especially on steep slopes, was overgrown with scrub and - in the hinterland of the coast - a young deciduous forest. On the islands, the scrub vegetation (maquis) is already gradually transforming into a low forest. Because during the war period (1991-1994) in the continental part of the Dinaric karst many settlements, especially those with mixed national and religious composition of the population, were abandoned, and because some refugees never returned, a lot of agricultural land was abandoned (Lika, Ravni kotari, SE Herzegovina). All these changes haven't been recorded in the cadastre yet, while other published data is not reliable if sources are not quoted. The same holds for the study by Androvic (1970) who for the Dinaric karst area in Yugoslavia (covering 56,618 km$^2$) quoted 38% of non-forest area, 6.4% of degraded forests, 14.1% of thicket and macquis, while total agricultural land amounted to 18%. In the Mediterranean and submediterranean area, 12.2% of the area was infertile.

Considering this data, we must bear in mind that forest was a natural vegetation before the arrival of man, even in the coastal Dinaric karst. This was already proven to doubters in the time before planned reforestation in the previous century in the Kras region by successful plantations of black pine which today spreads with its own seed.

7. Conclusion

Most of the Dinaric karst within the influence of Mediterranean climate belongs to the so-called semi-barren karst. This is a type of karst with outcropping rocks which do not only reach to the level of turf but outcrop for several centimetres, or even decimetres, from the ground. Such forest and stony karst had to be adapted for land use by clearing off forest and stones from the surface and out of soil respectively. The degree of adaptation depended, above all, on the purpose of agrarian use of the land; but as concerns the appearance, it reflects in the forms and modes of depositing the removed stones which are typical of the karst cultural landscape. The amount of the removed stones from soil is up to 2000 kg/m$^2$ in vineyards.

The deforestation and adaptation of karst land for agricultural use in the Adriatic islands and in the coastal area was similar as elsewhere in the Mediterranean. In the
mountainous Dinaric hinterland the process of massive migration of tribes since 15th century renewed the deforestation and slash-and-burn cultivation which brought the heavy soil erosion and stony character of the surface. The research in northern Vancouver Island in British Columbia has recently proved the fatal effect of primary deforestation upon limestone slopes for soil erosion (Harding, Ford, 1993). The same causes for deforestation are still active in the karst countries of Southeastern Asia. There, the soil erosion is still rapid, e.g. in the 69,742 km² large studied mountain karst region in Guangxi in South China the annual mean soil erosion is 265 t/km², as an effect of augmentation of population and spreading of cultivated area (Xiaoping, 1998). For them, the results of our research on the rapid soil erosion after deforestation of karst and the long-term, yet partial recovering of to the natural vegetation in the Dinaric Karst, may be of interest. A planned forestation began in the north western part of the littoral karst in the second half of the 19th century and in the rest of the Dinaric karst after the Second World War, when the rapid transformation of the social structure to the nonagrarian jobs, depopulation and the ban of the goat breeding began. Where the maintenance of dry walls was abandoned in the time of deagrarization, they are either decaying or were removed in some places due to machine ploughing or widening and levelling of roads; sometimes stones are also crumbled and used for the maintenance of roads. The highest decrease has been recorded in the areas with olive tree plantations and vineyards on steep slopes, where dilapidated scarps and walls turned some terraced slopes into scree (i.e. around Bakar), on which scarce scrub grows.

Although the quoted data is only approximate, the nations in developing tropical areas where population grows rapidly, can take it as a warning. The land degradation on karst can be caused by unplanned slash-and-burn cultivation or clearcutting of forests for timber or their conversion to pastures.

REFERENCES


CVIJIĆ J., 1931. Balkansko poluostrvo i juznoslovenske zemlje. II. Beograd.


AGRICULTURE AND NATURE CONSERVATION IN THE MORAVIAN KARST (CZECH REPUBLIC)

Ivan Bašák, Jozef Janěo, Leos Stefka and Pavel Bosák

ABSTRACT
Moravian Karst is a narrow strip of limestone with long history of settlement, agricultural use and man impact to karst. It is naturally divided into smaller units - karst plateaus - separated by deep valleys (glens). Each plateau has different proportion of land use, i.e. the percentage of agricultural land, forests, etc. The agricultural land constitutes now up to 70% in the north and max. 30% in the centre and south of the total area of plateaus. Intensive agricultural use of the arable land since 60ties of this Century caused great impact to quality of soils and groundwater by overdoses of fertilisers and other artificial chemical substances. Detailed research in 1980 to 1997 resulted in a plan of care based on the zonation of land. There were defined zones with different degree of restriction of land use, agricultural activities and application of fertilisers and biocides. Arable lands has been gradually changed to meadows and pastures by introduction of grass since 1987 in the most strictly protected zone to protect especially subsurface karst forms.

KEY WORDS: Moravian karst, land use, pollution, nature conservation

1. Introduction
Moravian Karst represents the largest and most important karst region of the Czech Republic. Typical forms of endokarst and exokarst are developed here. There is an evidence of life of man in this region even before 100.000 years. The region is characteristic by important cultural and technical monuments.

Moravian Karst represents the region with the longest history of the research of karst sites in the Czech Republic and it played important role in the development of many scientific disciplines. Simultaneously, there are numerous inhabited places with intensive economic activities. The tourism is one of the most developed activities.

The first attempts to protect this unique area are dated back to the time just after the constitution of the independent Czechoslovak republic in 1918. The first natural reserves were established in 1930 and 1933. The Landscape Protected Area of the Moravian Karst was set up on July 7, 1956 by the Decree of Ministry of Education and Culture. The aim of the protected area is to preserve all unique forms of living and lifeless nature, and cultural and technical monuments during the development of considerate forms of the economic utilisation of the region. Nevertheless, the stated intentions have not been completely fulfilled. The document stated the first conditions for the protection of karst phenomena: “Karst forms, subsurface and surficial, especially rocky forms and abris, dolines, sinks, resurgences, caves, shafts, etc. are
not allowed to be damaged, dolines cannot be filled up". The principles of the utilisation of the agricultural land are stated here, too: "The farming on the cultural land will be carried out according to the present methods. Meadows and pastures will not be changed to fields or other cultures except of the forest, wet places will not be drained".

2. Geological background

Moravian Karst represents the strip about 25 km long and 3 to 6 km wide developed on Devonian limestones (Fig. 1) north of the city of Brno.

Crystalline basement of Paleozoic formations is built of the intrusive body of the
Brno Crystalline Massif (Proterozoic) composed mostly of granitoid rocks. Devonian sequences started by the sequence of siliciclastics, often varicoloured, sometimes with limestone intercalations. Basal clastics form the rim of the Moravian Karst on its whole western contacts with crystalline basement. The most important carbonate sequence of Middle/Upper Devonian age is the Macocha Formation consisting of Josefov, Lazánky and Vilémovice Limestones. The uppermost Devonian and Lower Carboniferous is represented by the Ľíšen Formation composed of nodular Kőtiny Limestones in the north and Hády-Øíëka Limestones in the south. The total thickness of limestones exceeds 1.000 m. Limestone sequences are overlain by Lower Carboniferous flysh sequences (shales, greywackes, conglomerates) of a great thickness. Paleozoic sequences are highly faulted and folded during the Variscan Orogeny (Dvořák et al. 1993).

The platform cover is preserved only in denudation relics. Jurassic sandy limestones with cherts and spongilites occur near village of Olomuèany (Bosák 1978; Hanzlíková & Bosák 1977). Deep Lower Cretaceous paleokarst forms filled with the Rudice Formation ( sands, clays, iron ores) are well known especially from the Rudice Plateau (Bosák 1980, Bosák et al. 1979 a, b). Freshwater and marine Upper Cretaceous (Cenomanian to Turonian) sequences ( sands, sandstones, marls) commonly overlie Jurassic and Lower Cretaceous sediments. The preservation of Mesozoic sequences is connected with the sunkened blocks of the Blansko Graben (Burkhardt 1974). Rests of marine Badenian sediments (clays, marls, sands, gravels, Miocene) fill some of deep karst valleys and smaller karst depressions (Burkhardt 1979; Dvořák et al. 1993). Variety of sediments and residual sediments of the Quaternary age cover the surface with variable thickness (river terraces, loesses, soils, etc.; Dvořák et al. 1993).

3. Karst forms

Favourable climatic and geological conditions supported the development of karst forms in several karst periods and phases (Kettner 1970; Bosák, Horáèek & Panos 1989; Bosák 1997) which resulted in highly developed karst relief and subsurface karst drainage. Karst forms are developed especially within Devonian Lazánky and Vilémovice Limestones of the Macocha Formation.

Denudation surfaces (sensu Panos 1963), so-called plateaus, represent the typical form of georlief with altitudes of 400 to 550 m a.s.l. Plateaus are dissected by deep karst valleys (locally called glens) having NNE-SSW to NE-SW, NNE-SSE and approximately W-E axes. Valleys are commonly dry, flooded only during high precipitations. Only in some valleys, or in their lower courses stable streams are developed. Some plateaus show dense network of dolines (Ostrov and Harbechy Plateaus) and paleokarst forms (Rudice and Babice Plateaus). Some dolines were newly opened (diameter up to 10 m, depth of 1 to 6 m), especially on Ostrov, Sosuvka and Harbechy Plateaus as the consequence of wash down of artificial fillings in agriculturally utilised land.

About 1.000 caves have been known in the Moravian Karst. 200 of them are more
important. The longest is the cave system of the Amáterská Cave in the northern part of the Moravian Karst with about 30 km of passages which are situated mostly under agricultural land.

The region is divided into three principal hydrological units with independent, especially subsurface hydrographic systems with unified base level. The Punkva River represents the main drainage of the northern part of the Moravian Karst. It is formed by subsurface confluence of the Sloupsky Creek and Bílá voda Creek in the Amáterská Cave. The larger part of the system of Amáterská Cave is lying below forests. The catchment area is 170 km² and the average discharge is about 1 m³/s. There is another, very poorly known, drainage system genetically related to so-called Maly vytok in the Pusty Valley. The system drains the Ostrov Plateau and represents the confluence of three allogenic streams, i.e. of Lopáè, Krasovsky and Vilémovicky Creeks.

The central part of the Moravian Karst is drained by the Kôtinsky Creek and by the Jedovnicky Creek, which is its tributary. The catchment area is 70 km² and the average discharge is 0,25 m³/s. The Jedovnicky Creek created the second largest cave system of the region - Jedovnické propadání-Byèí skála Cave with the length of 13 km. The creek appears in resurgences near the Byèí skála Cave as the Kôtinsky Creek. One of important subsurface tributaries is the Tipeèk Creek supplying the Rudice village by potable water.

Another cave system was created by the Kôtinsky Creek, nevertheless its dominant part in-between its ponors near village of Kôtiny and its resurgence close to Byèí skála Cave has been still unknown. Hydrographic and hydrogeological conditions and connection are still waiting for detailed investigations. The drainage system lies below forests.

The southern part of the Moravian Karst is drained by several streams, i.e. the Ochozsky, Hostinicky and Hádecky Creeks. The catchment area is 76 km² and the average discharge is 0,16 m³/s. The biggest cave of the region is Ochozska Cave representing level flooded by the Hostinicky Creek. Subsurface streams form complex hydrographic net resurging as the Ófèka Creek in two springs. Forests prevail above cave systems.

4. Karst plateaus and agriculture

On the territory of the Moravian Karst, the agricultural production is concentrated especially on karst plateaus. In a lesser extend, it is situated in the ponor areas of karst streams (e.g. Holstejnské and Sloupské Valleys) and at bottoms of karst valleys (Hradsky and Ostrovsky Glens). The agricultural land constitutes about 60 to 70% of the area of plateaus in the northern part of the Moravian Karst, while only 20 to 30% in the central and southern parts, where forests prevail (Fig. 1). Therefore, the clashes of interests of agriculture, karst systems and nature conservation is concentrated dominantly in the northern regions of the Moravian Karst. The list of plateaus below introduce briefly into the problem of karst forms and agriculture exclusively in the northern part of the Moravian Karst. Plateaus are listed according to orographic clas-
sification of the Moravian Karst summarised by Bosák, Bříková & Stárka (1994).

1. Suchdol-Vavóinec Plateau

The plateau is a part of the catchment area of the Sloupsky Creek. Several ponors of allogenic streams (i.e. of the Vavóinecky, Veselicky and Novodvorsky Creeks) are aligned along the contact of the Brno Massif and basal Devonian siliciclastics with limestones. Smaller steeply inclined caves are developed below sinks connecting sinks with the level of the subsurface Punkva River in the Amatérská Cave. Tracer experiment in the Suchdolsky Ponor in 1992 proved the connection with Stajgrovka Cave in Pusty Glen. The group of shallow dolines on arable land near village of Nové Dvory is also drained into Stajgrovka Cave. The cave represents resurgence channel about 200 long aligned along the limestone/granitoid boundary. The inflow sump is utilised for local water supply of the most important tourist sites of the Moravian Karst. The arable land prevail on the surface of the plateau (about 70% of the area).

2. Ostrov Plateau

The plateau is the model area with important problems of agriculture and nature protection of the karst. It is extensive plateau intensively karstified limited by the Pusty Glen on the west and by the Suchy Glen on the east. Intensive agricultural production utilises about 80% of the plateau surface (Figs. 2 and 3). The plateau is subdivided into several smaller plateaus.

The northernmost part, known also as the Sosuvka Plateau, is developed at the boundary of limestones and flysch siliciclastics. Several lines of dolines are developed here. Some of dolines are opened to shaft-like caves with the depth of about 90 m (e.g. Sosuvská Chasm). Several small allogenic streams sink in these sinkholes feeding most probably some tributaries of the Punkva River in Amatérská Cave. The Holstejnská Cave of Nezamistnanych is the largest below the plateau surface.

![Fig. 2 - Ostrov Plateau-the view to the central part with the dominance of arable land (photo J. Janěo, July 12 1998)](image-url)
Fig. 3 - Ostrov Plateau (for location see Fig. 1)
The Simonův Hill and Zadní Bukovinky are the most intensively karstified part of the plateau. Zadní Bukovinky are the example of the relief with densely packed dolines. The most known cave here is Stará Amatérská Cave with active stream of Bílá voda Creek and several subsurface tributaries connected also with the region of Holstejnské Valley. In the depth of 70 to 120 m Amatérská Cave continues below the Ostrov Plateaus towards Macocha Chasm and the Punkva resurgence.

Amatérská Cave is the longest cave system in the Czech Republic with the length over 30 km. Typical tunnel-shaped passages are periodically flooded by the Sloupsky, Bílá voda Creeks and Punkva River. Several smaller allogenic streams are connected with the cave system. Active subsurface stream of the Punkva River, except of several fragments, is generally unknown now.

Surface karst of the Ostrov Plateau is typical by numerous dolines, the largest ones (Dolina and Místiká) are directly connected with Amatérská Cave. Uvala above Amatérská Cave originated by amalgamation of line of dolines with the length of about 1.100 m and width of 200 to 400 m. The uvala is parallel to Amatérská Cave by it lies about 250 m to the east.

Several smaller lines of dolines are developed in the southern part of the Ostrov Plateau. Dolines are probably connected with drainage of the Ostrovsky Glen.

3. Harbechy-Vilémovice Plateau

The region lies at the eastern border of the Moravian Karst. It is intensively utilised by agriculture, owing to its relatively thick cover of Quaternary sediments (loesses etc.). Typical groups of dolines are characteristic for the Vilémovice Plateau (Fig. 4). Some of dolines function as sinks of small streams (e.g. Vilémovicky Creek). The major part of ponors are explored up to the depth of 100 to 120 m. There are drained towards the Maly vytok resurgence in Pusty Glen. Chasm-like caves with the length of about 1 km are developed here. Arable land prevails here (about 90% of agricultural land).

The Harbechy Plateau has somewhat different character, especially in the south. Extensive line of dolines with isolated groups of dolines is typical. Chasm-like caves (up to -100 m) lead to an active subsurface stream. Arable land dominate here (95% of agricultural land).

The Stádlska Plateau represents the highest part of the area above the Suchy Glen. Surficial karstification is only slight with shallow depressions. Meadows and pastures prevail here. The arable land represents only 30% of agricultural land.

4. Rudice Plateau

The plateau is forested, only the closest vicinities of villages of Rudice and Habrůvka serve as agricultural land (from it 65% is the arable land). The plateau is known by extensively preserved forms of Lower Cretaceous paleokarst. Sands and clays of the Rudice Formation were excavated for ceramic and foundry industry. Iron ores were mined here even in pre-historic times. Several more recent dolines are developed on the surface, as well as some fossil ponor valleys.
5. Babice Plateau

Stádle and Zadní pole Plateaus are agriculturally utilised parts of the Babice Plateau. The surficial karst relief is developed only scarcely on both plateaus. Shallow and extensive depressions prevail. The dominant part of group of dolines in Zadní pole Plateau were filled in the past. Subsurface drainage has not been known, except of rare exceptions. Borehole exploration and some speleological activities indicate intensive karstification with stabilised groundwater level at-100 m below the surface. Arable land represents 70% of agricultural land.

5. Farming on karst plateaus

5.1. Agriculture and karst landscape

Agricultural activity has taken part in the formation of the character of landscape of the Moravian Karst since the historic times. There were changes connected with the development of agriculture as a consequence of increasing number of inhabitants and the intensification of agricultural activities. Ecologically equilibrated landscape occurred here up to the half of 20th Century. Levelled relief of karst plateaus with relatively thick cover of Quaternary sediments enabled the farming on fields. Slopes of valleys were suitable for farming on meadows and pastures. Therefore, arable land prevail on plateaus.

Character of settlement and type of housing in villages (around green or along
road) determined also the arrangement of pieces of land within the cadaster. Plots formed either star-like arrangement from the centre of villages (e.g. Vavóinec, Vilémovice) or nearly closed circle around the village (e.g. Ostrov u Macochy). The estate of soil gradually disintegrated owing to increased number of inhabitants. Relatively less favourable natural conditions forced inhabitants to intensive utilisation and cultivation of each piece of land. Municipal forests on slopes of valleys were gradually cleared and changed to pastures. The whole upper part of the Suchy Glen was deforested which caused rapid soil erosion and limestone surface and karren were uncovered. According to photographs from the end of 19th Century, the surface around village of Ostrov u Macochy and the major part of the Suchy Glen were deforested. Even deep dolines were then filled with material on fields of plateaus. Walls constructed from stones cleaned from fields preserved in some places up to the present time.

The intensification of agricultural exploitation started at the beginning of sixties of this century. It influenced unfavourably both surficial and subsurface karst forms (Fig. 5). Soil erosion was enhanced by amalgamation of fields and by the clearance of balks with scattered vegetation. The ploughing of fields up to the edges of dolines accelerates soil erosion. The eroded soil is transported through dolines and vertical
cave systems into subsurface streams and through karst springs into surface streams. The extension of damages are illustrated by balance calculations of the content of dissolved and loaded matter in streams after the sudden storms. For example, on May 23, 1984 total precipitation of 35 to 45 mm was registered in the northern part of the Moravian Karst. During the maximum discharges (12.1 m³/s, Tab. 1) with maximum rate of erosion, totally 51.3 t of load and 1.47 t of nitrates was transported by the Punkva River at Skalní mlyn site during 1 hour (Tab. 2).

The intensity of the utilisation of karst landscape is clearly visible in the structu-
Ivan Salak, Jozef Jano, Leos Stefka and Pavel Bosak

Date
Ma 23 1984 1.36
Ma 24, 1984 12.12
Ma 25 1984 8.43
Ma 26, 1984 4.93

Table 1 - Discharges of the Punkva River at Skalni mlyn site after the sudden storm in the catchment area

<table>
<thead>
<tr>
<th>Date</th>
<th>Discharge (m³/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>May 23, 1984</td>
<td>1.36</td>
</tr>
<tr>
<td>May 24, 1984</td>
<td>12.12</td>
</tr>
<tr>
<td>May 25, 1984</td>
<td>8.43</td>
</tr>
<tr>
<td>May 26, 1984</td>
<td>4.93</td>
</tr>
</tbody>
</table>

Table 2 - Contents of nitrates (NO₃⁻) and load in the Punkva River at Skalni mlyn site during maximum discharge after the sudden storm in the catchment area.

<table>
<thead>
<tr>
<th>Date</th>
<th>Hour</th>
<th>Nitrates (mg/l)</th>
<th>Load (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>May 24, 1984</td>
<td>09:30</td>
<td>300</td>
<td>1.050</td>
</tr>
<tr>
<td>May 24, 1984</td>
<td>15:15</td>
<td>31</td>
<td>550</td>
</tr>
</tbody>
</table>

The increase in plants highly demanding the nutrients caused also the quantity of applied industrial fertilisers. Average doses of pure nutrients (nitrium-phosphate-kalium (NPK) type) per 1 hectare of agricultural land exceeded 400 kg/year during the period of 1972 to 1980 in cadastres of villages of Ostrov u Macochy, Lazánky u Blanska, Holstejn, Veselice na Moraví and Sloup. The highest doses of 606 to 680 kg of NPK per 1 ha in 1972 and 1975 were applied on several tracts of land on the Ostrov Plateau (Stefka 1982; cf. also Fig. 6). The average doses for the whole Czech Republic was about 220 to 260 kg of pure nutrients (NPK) per 1 ha at this time.

Industrial fertilisers are leached from soils and they enter into cave systems. The influence of the style of farming to the quality of dripping water can be stated from the monitoring and comparison of quality of dripping water below agricultural land and below forests. The water quality was monitored by the former Institute of Geography of the Czechoslovak Academy of Sciences (up to 1980; Adámek and Rauser 1977; Adámek 1980), by the Authority of the Protected Landscape Area of the Moravian Karst (1981 to 1985; Stefka 1982; Kovařík 1985) and by the Authority of Show Caves in the Moravian Karst (1991 to 1994; Zajíček 1997). High content of dissolved matter in dripping waters in caves corresponded to high doses of industrial fertilisers on the surface. Nitrate content below agricultural land increased 10 times and chloride contents increased 3 times as compared with dripping waters below forests. The maximum nitrate concentration of 880.8 mg/l was reported from sampling in Amaterská Cave in 1979-1980 (Adámek 1983). This extreme value was not proved by repeated sampling in 1981-1996 carried out by the Authority of the
Landscape Protected Area (unpubl.), when only 60 to 80 mg/l of nitrates were detected. Distinctly better water quality was detected below land covered by grass (nitrate content: average of 9 mg/l and maximum of 14 mg/l). Unfortunately, analytical results from subsurface below places newly covered by grass are not available owing to the fact that were not successful to find responsible subsurface locations.

Table 3 - Quality of dripping water below arable land and forest (note: the variations of values depend on the type of plant production and treatment, specific permeability at site and hydrological situation).
The information on water quality can be obtained also from the monitoring of sources of potable water carried out by the District Centre of Hygiene in Blansko. The distinct increase in nitrate contents was detected in 1970 to 1980, at some site even up to 1990. The slow decrease or stagnation was detected in last years. Above mentioned data completed in the knowledge on impact of different concentrations of solutions of industrial fertilisers to speleothems (Dusková 1982) enabled to the Management of the Landscape Protected Area of the Moravian Karst to enforce some changes in agricultural exploitation of karst plateaus as follows: introduction of liquid industrial fertilisers, division of the total doses into several applications, extension of application of organic fertilisers, adjustment of sowing methods, changes in pesticide assortment, and introduction of grass to selected fields. About 20 ha of arable land was transformed to meadows (mostly above cave systems) and to infertile land (especially around dolines) during 1987 to 1989. Another 30 ha of arable land was changed to meadows in 1995 to 1997. The largest changes occurred on the Ostrov Plateau for the protection of the system of Amatérska Cave. In spite of mentioned changes, the arable land constitutes 80% of the area of agricultural land here (Fig. 7).

The dumping of wastes from production of animals represents special problem. Liquid waste is dumped in concrete pits. In the present time, the only open field dump of solid waste is situated near village of Ostrov u Macochy, and the construction of open field dumps are permitted only in the outer, 3rd zone of protection of the Moravian Karst. There is long-lasting discussion concerning the connection of increased CO₂ contents in caves and the location of open field dump of solid waste from animal production. Otava (1990) and Havel (1991) reported CO₂ concentration from 7.5 to 13.5% in caves in Harbechy and Babice Plateaus. Nevertheless, increased concentration were detected also in caves situated below forests.

5.2. Protection of karst region and agriculture

The protection of surficial and subsurface karst forms on plateaus and of their biocenoses is possible only when the intensity of agricultural production is decreased and followed by the change of arable land to meadows. The change represent the principal conflict of interests between agriculture and nature conservation in the present time. The problem of changes of field cultures due to nature conservation has not been yet finally solved because of financial questions and practical interests of agricultural subjects.
Fig. 7 - The succession of grass introduction on the Ostrov Plateau (dark grey - meadows; grey - settlements; light grey - forests; thick line - roads, ovals and circles - sinkholes; contour of caves are expressed by double or single line)
The principal tool for nature conservation is the law on nature conservation from 1992. The protection of caves and other karst phenomena was introduced here for the first time. The law protects e.g. dolines from their filling by waste or other materials. The protection of the Moravian Karst was specified by the Ministry of Environment in 1994. The whole region was divided into three zones of protection. Zonation of agricultural land considered surficial and subsurface karst phenomena. The major part of arable land was included in the 3rd zone of protection, smaller part into the 2nd zone (about 200 ha) and the rest (about 120 ha) into the most strictly protected 1st zone (cf. Fig. 8).

![Fig. 8 Proportions of agricultural cultures in individual zones of protection in the cadaster of the Landscape Protected Area of the Moravian Karst.](image)

<table>
<thead>
<tr>
<th></th>
<th>1st zone</th>
<th>2nd zone</th>
<th>3rd zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>arable land</td>
<td>162</td>
<td>199,9</td>
<td>2625,4</td>
</tr>
<tr>
<td>meadow</td>
<td>98,9</td>
<td>177</td>
<td>126,8</td>
</tr>
<tr>
<td>pasture</td>
<td>26</td>
<td>97,4</td>
<td>99,4</td>
</tr>
</tbody>
</table>

According to law on nature conservations, in the 1st zone of protection, there is forbidden to apply fertilisers and liquid waste from animal and plant production. The zone includes agricultural land in small-scale especially protected areas (reserves) and lands (partly also arable land) with high concentration of surficial and underground karst forms (e.g. on Ostrov and Harbechy-Vilémovice Plateaus; cf. Figs. 9 and 10). There is the plan to introduce here the intensive farming on meadows and pastures with production of cattle, sheep and goats without application of pesticides and fertilisers. Arable land will be gradually transformed to meadows and pastures by introduction of grass cover.

In the 2nd zone of protection, there is not allowed to farm on land outside build-up areas using intensive technologies, application of biocides, to change water regi-
me and to make extensive changes of the terrain. The zone includes agricultural land with scattered occurrence of surficial and subsurface karst forms and protection zones of important karst phenomena classified into the 1st zone. There is expected intensi-

Fig. 9 - Zones of nature protection of the Ostrov Plateau (for explanations of symbols see Fig. 2).
Fig. 10 - Zones of nature protection of the Harbechy-Vilémovice Plateau (for explanations of symbols see Fig. 2).

ve farming on meadows and pastures, eventually farming on arable land with decreased application of pesticides and fertilisers and preferred use of organic fertilisers. Selected areas of arable land will be gradually changed to meadows and pastures.

Land intensively exploited were classified into the 3rd zone of protection (i.e. arable land, gardens) with rare occurrence of karst forms. The reasonable support of agriculture in the optimal form, including development of ecological agriculture, is the aim here. Air application of pesticides and fertilisers should be excluded.

The regimes of farming in individual zones of protection and proposals of practical changes in agricultural cultures and conservation and stabilisation of karst phenomena are stated in the Plan of care on the Landscape Protected Area approved in 1997. The Government of the Czech Republic approved the territorial plan of the protected area of the Moravian Karst in 1998 stating, e.g.: “the farming had to be subordinated to conditions of nature and landscape conservation and water management. The introduction of grass have to be finished on arable land within the 1st zone of the Landscape Protected Area above cave systems”.

6. Proposals of future management

The adjustment of farming on the territory of the Moravian Karst represents one
of the most important factors influencing future protection of the area. However, assumed changes are connected with the economic development of the region. Pražan, Drlík & Novotná (1998) evaluated economical impacts of adjustment of farming from the point of view of nature conservation. After the consultations with farmers, following variant seems to be optimal, i.e. to finish the introduction of grass on arable land within the 1st zone of protection (162 ha), and to introduce specific sowing methods in the 2nd zone of protection (277 ha). The cost of grass introduction in the 1st zone will total 1.7 mio CZK during the first year, and about 1.1 mio CZK in following years annually (exchange rate approx. 35 CZK = 1 USD). The impact of changes of sowing methods is individual according to individual pieces of land. If the land in the 2nd zone is not extensive, the costs are considerably low. Where areas of land are extensive, e.g. on Ostrov Plateau, the cost of the introduction of alternative sowing method is high owing to decrease in areas with wheat production. Another problem is representing by small farmers with low area of owned land. Here, the introduction of grass and new sowing methods would completely change the style of farming bringing no profit from the production.

The system of long-lasting financing of the project of adjustment of farming resulting from nature conservation has been still unsolved. The budget regulation do not allow to sign contracts for period of several years with the full guarantee of refund after the first year finished. The finances are approved each year repeatedly. To be closer to a common practice in the European Union, it would be necessary to sign the eco-agricultural programs at least for five years and to deepen the co-operation of agriculture with nature conservation to enable to introduce program of careful farming within specifically protected areas.

REFERENCES


BOSÁK P., GLAZEK J., GRADZIŃSKI R., WÓJCIC Z. 1979a. Genesis and age of sediments of the Rudice type in fossil-karst depressions. Řasopis pro mineralogii a geologii, 24,


ABSTRACT
The karst regions are found in the medium altitude mountains of Hungary. Their land use types are natural and sustainable forestry, grazing and vineyards. In international comparison, Hungary belongs to those countries of Europe where arable land is abundant, therefore, in the future its extension has to be reduced. That means agricultural activity has to be restricted on the sensitive karst surfaces. This paper presents ways of sustainable forestry and other land use types for three karst regions of Hungary.

KEY WORDS: Hungary, human impact on karst, nature conservation.

1. Introduction
The majority of the Hungarian karst terrains is situated in the Transdanubian and Northern Mountain Ranges: only smaller patches of isolated karsts are found in the north-western and southern parts of Transdanubia (Fig. 1). Somewhat less than 1.5% of the area of Hungary is limestone and dolomite karst (Jakucs, 1977). Parts of the
Bakony, Vértes, Budai and the Mecsek Mountains are nature conservation areas. The karst regions of Aggtelek and Bükk Mountains are National Parks. All of the caves of Hungary (3179) are protected. The karstic mountains of Hungary are built up of Triassic limestones and dolomites, which are well karstified.

The tectonic movements were intensive in the Transdanubian Mountains; thus, a lot of horsts and grabens were formed. This formation is called the "Transdanubian type" of karst. Nevertheless, in Northern Hungary, less faulted and characteristic karst forms also developed, and this type is distinguished as the "Aggtelek type". Moreover, the Mecsek Mountains and Villányi Range are classified as Aggtelek type karsts.

During the different geological periods, intensive karstification processes occurred on several occasions. Thus, traces of the Cretaceous and Tertiary karst formation can be found in the Bakony and Aggtelek Mountains. This means that the forms of both fossil and recent karst formations occur on Hungarian karst. As an effect of the Tertiary and Quaternary tectonic activities, a part of the karst surfaces have deeply subsided and today are only revealed in deep boreholes.

During the last decades, nature conservation in land use has received a rather strong emphasis in Hungary. With the establishment of the Bükk and the Aggtelek National Parks, two of our really important karst regions acquired protection, but also the rest of the karst areas are under nature conservation regulations. The majority of Hungarian karst regions are situated in mountainous areas, and unsuitable for intensive farming and are also under threat from soil erosion. The karst terrains constitute significant areas of forestry and grazing. Therefore, in any case, it is important to examine how sustainable agricultural land use of karst can be planned. The karst terrains of Hungary are important resources for drinking water, and require more effective protection in the future. Moreover, in the course of their agricultural land use, nature conservation regulations - concerning a particular area - have to be observed. In Hungary, the Nature Conservation Act of 1996 claims that in karst terrains every spring with at least 5 l/min water yield is protected. It is also true for sinkholes and caves or caverns. Endemic flora and fauna species as well as their biotopes are also protected. This means that anthropogenic alteration of natural ecological conditions can only be minimal in the strictly protected areas.

2. The structure of Hungarian karst terrains and their characteristic landforms.

The karst terrains of Hungary are also rich in subsurface features. The intense tectonic movements fragmented the tectonic units of the Transdanubian Mountains. The karst of the Mecsek Mountains folded: this process hindered the extensive formation of the subsurface caverns. Moreover, hydrothermal karst phenomena are common in the Buda Mountains, which are also linked to tectonic movements. The uplifting in the Bükk and Aggtelek Mountains was accompanied by no significant folding or faulting, and large undisturbed systems of caverns formed.

The most extensive karst regions can be found in the Transdanubian Mountain Range (Fig.1). From the south-west, the first one is the dolomite karst of the
Keszthely Hills which is adjoined by the karst of the Balaton Highlands (with older Devonian and Sarmatian limestone). The karst areas of the Southern Bakony Ranges are built up mainly of Dachstein dolomite. (Triassic Rhaetic layer), but also the Muschelkalk (Triassic Anysian, Ladinian) limestone constituents of the karst.

Mesozoic karst terrains are the Vértes and the Gerecse. The Pilis Mountains and Budai Hills (Wetterstein and Budaörs dolomites) are composed of dolomite and limestone. The hydrothermal phenomena and forms are characteristic karst features here. The Triassic and Jurassic limestone karst of the Mecsek mountains, the karst of the Villány Range (with the Cretaceous limestone of Nagyharsány) together with the Beremend Horst as well as the Leitha limestone horst adjacent to the Ferto lake (Neusiedler See) all stand out as isolated hills in Transdanubia.

The typical karst phenomena of the Bükk Mountains are formed of Triassic limestone. The most significant products of the Triassic period here is the limestone of the Greater Plateau and of the Smaller Plateau of Repashuta as well as the Hámos dolomite. The extended karst highland limestone was covered by Ladinian, Carnian and Noric sediments. The upper Triassic limestone of the Smaller Plateau is a light Megalodontic limestone.

The Aggtelek Mountains with the Rudabanya Mountains are the southern extension of the Gőmör-Tornai Karst. It is not only exposed on the surface but it also has subsurface connections to the Baradla and Domica caves. The cave system called Baradla is the longest, its total length is 24,816 m together with the Domica cavern; from this, 18,836 m are in Hungary. The main enclosing rocks are the Gutenstein thin-layered greyish-black and the light grey Wetterstein-Ladinian limestones and dolomites.

As mentioned above, tectonic activities played an important role in the karst terrains of Hungary. In the karst regions of the Transdanubian Mountains, transversal faults were created perpendicular to the northeastern-southwestern main tectonic axis. Hydrothermal karst phenomena are a result of tectonism in the Transdanubian Mountains. Hydrothermal phenomena are common in the Main Dolomite (Jakucs, 1977).

3. The impacts of agricultural land use on the karst terrains.

As the karst terrains in Hungary are situated in mountains, forestry and grazing are the most important agricultural activities in these areas. A significant part of them enjoys a certain level of protection. In this paper the cases of Bükk, Aggtelek Mountains and Villány Hills will be discussed. The first two of these areas are already national parks today, and a part of the Villány Hills (Templomhegy) is a Nature Reserve.

3.1. Sustainable forestry on the Bükk Highlands

In 1977, the Bükk National Park was established as the third national park, it extends over a surface of 9,661.865 hectares in the Bükk Mountains, 95% of which is covered by forest. Additionally, it has 853 caves and the deepest cavern of the
country: the István-lápa cavern that is 250 m deep and 454 m long. It is famous for its dry spring caves, which served as a dwelling place for the ancient human population of the area (Istállóskő, Szeleta and Subalyuk caves).

From 1514 to 1945 it was a state forest area. From 1818 onwards plantations were established. Grazing and deforestation were significant until 1880. In 1935, a new type of forest law was introduced which changed the natural characteristics of the landscape. After 1945 deforestation was too intensive, especially on the western parts where clear-cutting occurred, as a profitable forestry was identified as a primary objective. From 1977, following the establishment of the National Park more natural sustainable forestry became dominant (In 1972, at the FAO convention in Buenos Aires, the Hungarian approach was accepted: forests have a triple function: economic, conservation and recreation).

The ownership changed in 1989. The ownership changes led to the partition of the state forest area. Since 1996, several laws have decreased the protection of the forests from grazing as well as the protection of the environment.

In the National Park, as a consequence of reforestation, the fundamental land use is forestry (Fig. 2), while, however, small patches of arable land are found in the vicinity of settlements. Forests, together with meadows and grazing lands are semi-natural land use types.

The timber mass in the Bükk National Park is 8 million m³. As only 18% of Hungary is covered by forests, this area cannot be excluded from timber production. At the same time, excessive exploitation increases the soil erosion hazard especially on the Highlands, where rendzina and brown forest soils can be found. Reforestation
remained unsuccessful on the site of cleared woodlands. Forests have a great importance in the uniform infiltration of precipitation water, thus, it is very important from the point of view of karst protection.

With increasing elevation above sea level, several zones of forests can be distinguished:

a) up to the elevation of 200-250 m forests with maple and hornbeam (Aceri-campestrri-Quercetum petreae-roboris, Quercus pubescens and Q.petreae) are found.

b) to the height of 450 m turkey oaks occur (Quercus petreae-cerris).

c) in the elevation between 400 and 600 m the, hornbeam-oak forests (Querco robori-Carpinetum) can occur on any basement rock.

d) at the elevation of 600-700 m, sub-montane beech forests (Melitio fagetum) occur with hornbeam and oak. Even small changes will cause fast deterioration of the environmental here.

e) on the typical karst terrains of the Highlands, dry forests (Aconito fagetum) occur over 800 m of elevation.

The deforestation of the late 19th century caused severe damage. Special grass and meadow types (Festuco ovinae-Nardetum) formed in their sites to replace them. At the bottom of dolines, daily recurrence of frost hinders the recovery of beech trees.

Their azonal forest associations reflect topographic, rock, soil and microclimatic conditions. In these associations, a lot of endemic and relict species found only here in Hungary have survived. Rock beech forests (Seslerio hungaricae-Fagetum) thrive on northern slopes, whereas karst scrub forests (Cotino-Quercetum pubescentis) live on surfaces with rather shallow, easily warming soils. Fig. 3 shows the species of trees on the High Plateau.

<table>
<thead>
<tr>
<th>Age group</th>
<th>Year</th>
<th>Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1-10</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>11-20</td>
<td>7</td>
</tr>
<tr>
<td>3</td>
<td>21-30</td>
<td>10</td>
</tr>
<tr>
<td>4</td>
<td>31-40</td>
<td>8</td>
</tr>
<tr>
<td>5</td>
<td>41-60</td>
<td>22</td>
</tr>
<tr>
<td>6</td>
<td>61-80</td>
<td>20</td>
</tr>
<tr>
<td>7</td>
<td>81-100</td>
<td>17</td>
</tr>
<tr>
<td>8</td>
<td>&gt;100</td>
<td>14</td>
</tr>
</tbody>
</table>

Today the steppe-meadow and steppe-swards, typical of karst terrains, occur only at a rate of 0.8% of all the area of the karst terrain. The predominant associations of dolines are the subalpine limestone rock-sward (Campanulo - Festucetum pallentis) under microclimatic inversion.

In the 1994, the age composition of the forest in the Bükk National Park was the following: 50% of the commercial forests is between 20 and 60 years old, above 70% of the protected forests are more than 60 years old. After clearings ash tree renewals have developed on the site of beech trees, whereas hornbeam renewals have replaced oaks in clearings.

There are two old forest areas in the region. One of them is the primeval pine forest in Javorkút, planted in 1815; the other one is the backwoods called "Őserdő" where in 1946 any kind of forest management was prohibited. From the 1960s to the 1980s, the excessive timber felling decreased the share of the old forest areas.

The aim of sustainable forestry is to manage forests in such a way that its con-
Fig. 3 - Tree species of the High Plateau of the Bükk Mountains.

servation and recreational functions can continue their existence overlong periods of time. At the same time, it should preserve its biological diversity, its semi-natural conditions, its capability to recover and its vitality. It should also unite conservation and economic requirements in accordance with social demands. Moreover, it should satisfy health, social, tourist as well as educational and research demands (Keszthelyi et al., 1995).

In the Bükk National Park 70% of the forests are commercial forest, 29% is protected and 1% is amenity forests. It is shown from the above figures that felling should be practised in a way that should not endanger the ecological equilibrium of the forest. From the foundation of the National Park, nature-friendly forestry is practised, which means that clear cutting is only permitted if it ensures the maintenance of the diversity and equilibrium of the ecosystem.

This requires a careful choice of species for the habitat and the application of methods sparing the habitat and the plant. Pine plantation is not allowed, only the renewal of the damaged forests can be made by planting spruces, Douglas firs and Scotch pines. After their future clearing, the spreading of indigenous species can be expected. Pesticides can be applied only where the old forest areas cannot be renewed in any other way, and the area of the connected surface cannot surpass 12.3 hectares. The age for cutting maturity must be raised to 100-120 years in the beech forests and to 120-140 years in the oak forests.

Forestry is feasible in a planned way, plans containing the proportion and age of the tree species. Sustainable forestry has to be implemented without damage to the
ecosystem. This means that timber should be produced so that it should not decrease the tree layer of the forest, thus, the microclimate does not alter and no damage is done. On the western part of the Bükk Mountains there are trees of nearly the same age. It means that they reach felling maturity at the same date and in order to maintain ecological equilibrium and uninterrupted renewal, the ages of the trees should be prolonged for 130 years. Certainly, it is very important from an esthetical aspect; thus, natural seedling renewals should be ensured. In hornbeam-oak forests, a renewal lasts 15-20 years whereas this is 25-30 years in beech forests.

Additionally, one of the important tasks is to maintain recreational functions. Today it is not permitted to enter by car in the area of the Great Plateau; however, further restrictions should be introduced in the use of automobiles along the borders of the National Park.

3.2. The impacts of land use in the Aggtelek Karst

Ten years after the establishment of the Aggtelek National Park in 1985, its caves and caverns were declared to be part of the World Natural Heritage in 1995. This means that the protection of the area was further enhanced. The preservation of subsurface geomorphological features requires strict protection at any rate; therefore, the utilisation of surface areas is regulated. As the major part of the Aggtelek Karst is open karst, with shallow soil, the land use of both the immediate karst surface and the adjoining non-karst terrain influence the condition of the karst system. There is significant agricultural activity in the close vicinity and this causes problems in the caves.

77% of the National Park is covered with forests (Fig. 4), the main land use type

![Fig. 4 - Land uses in the Aggtelek Mountains.](image-url)
is sustainable forestry. Landscape planning defined forest use for the coming years (1988):

<table>
<thead>
<tr>
<th>Forest use</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Felling</td>
<td>43.8%</td>
</tr>
<tr>
<td>Cultivation for other purposes</td>
<td>4.6%</td>
</tr>
<tr>
<td>Forest for protection</td>
<td>23.0%</td>
</tr>
<tr>
<td>Forest for soil protection</td>
<td>25.8%</td>
</tr>
<tr>
<td>Forest for recreational purposes</td>
<td>1.4%</td>
</tr>
<tr>
<td>Forest for other purposes</td>
<td>0.1%</td>
</tr>
</tbody>
</table>

The mosaic pattern of the landscape was created by natural land use. In this type of land use forestry used to be predominant. Until the establishment of the National Park, forests were felled for timber at high rates. In the clearings grassland developed; and, therefore, hay production dominated.

In the course of forestation, indigenous oak forests and beeches can be planted in the place of pine and acacia forests. Renewal is gradual here and the area of clear cutting cannot surpass 5 hectares, moreover, no contiguous clearings can surpass an area of 3 hectares. In the planted forests the formation of multiple layer associations should emerge. This at the same time serves to protect biodiversity.

The objectives of the Aggtelek National Park also include conservation of karst forms. Therefore, a zonalisation, making the further operation of traditional agriculture possible is introduced. In this way, fodder, fruit and other plant cultivation would be sustainable. This implies certain requirements such as the prohibition of pollutants which endanger natural values (e.g. karst water, stalagmites etc.), and also fertilisers, chemical insecticides which can have an access - through seeping water - to the karst system.

The National Park is planning the creation of three zones (1998). According to this plan, zone “A” is the natural core area where cultivation is not permitted. The existing pine forests should be replaced, and the natural association of deciduous forests, should be formed. Similarly to the previous, Zone “B” should be undisturbed. Zone “C” is the site for display and traditional agriculture. The utilisation of this terrain - in my opinion - is dangerous, because of the doline rows which are situated at the border of karst and non-karst terrains. The use of pesticides and chemicals and the sediments pollute the water which reaches the caves.

3.3. Land use in the Villány Hills

The Villány Hills are situated in the southeastern part of the Transdanubia, isolated from the Mecsek Mountains. Its highest point, the Szársomlyó is 442 m above sea level. Mediterranean climatic influence prevails, and, accordingly, an area of wine production has developed especially on the southern slopes, (it is one of the important wine regions in Hungary).

The main soil type is rendzina on the southern slopes and the brown forest soils. In the highest region of the hills, the soil layer is shallow and bare karst surfaces can be found in large areas. Hornbeam oak forest (Asperulotaurinae-Carpinetum tilieto-
sum argenteae) can be found on the steep southern slopes, while the karst scrubs (Inulo spiraeifoliae-Quercetum) as well as the rock and steppe association (Sedo-Festucetum dalmaticae, Aspleno ruta-murariae, Cleistogeno-festucetum rupicolae) also appear.

The distribution of the associations changes on the different levels of the hills. In the highest area scrub association, below grasslands and almost entirely bare surfaces occur. The pediment surfaces are covered with loess-hornbeam-oak-forests as well as arable land, and vineyards are also to be found there. It is important to note that the natural vegetation is constituted by scrub association on the Upper Jurassic limestone surfaces and by grassland associations on the Lower Cretaceous limestones which indicates the firm connections between the exposed rocks and the flora. The continental and sub-mediterranean flora elements can be found on the Jurassic limestones. Some subatlantic and Balkan flora elements also occur on the terrain (Lehmann, 1975).

In the more distant environment of the Villány Hills extended tillage is practised, which is directly connected to the grape and fruit producing areas (Fig. 5) of the southern slopes. Another human activity; quarrying had already started to a great extent at the turn of century. Recently, mining ceased on the eastern part, where an international open-air sculpture exhibition was established.

In other parts of the area, deforestation of the last century created more arable lands. Under intensive viticulture; this land use caused soil erosion. The settlement

Fig. 5 - Land uses in the Villány Hills and its surroundings.
pattern is dense in the area and the utilisation of the landscape is mosaic-like. Landforms and rare plants underline the need for the strict protection of the Villány Karsts, which, therefore, should be endeavoured in the near future. This terrain, rich in Mediterranean plant species, should retain its ecological conditions, and reclamation should be practised here only by observing conservation laws.

4. Conclusion

The paper tried to present the land use types of three karst terrains in Hungary. Natural, sustainable forestry, grazing and viticulture in favourable areas is practised on the karst.

1. In the Bükk National Park the fundamental land use type is sustainable forestry. Nature conservation and forestry are in conflict with forest management.

2. In the Aggtelek National Park, in addition to sylviculture, grazing is the main agricultural activity. Until the establishing of the National Park, forests were felled for timber at high rates. On the clearings grassland developed; and, therefore, hay production dominated.

3. Extensive farming and viticulture is the land use in the Villány Hills. In the intensive vineyards on karst soil erosion is common.

4. It is an important task for the future to create buffer zones in the interlocking belts of the karst and non-karst areas in order to decrease the harmful environmental impacts of the agricultural activities on the adjoining terrains.

5. In international comparison, Hungary belongs to the countries of Europe where arable lands are extensive. For this reason intensive farming should be banned on the sensitive karst terrains. Tourism and recreation should ensure the economic survival of Hungarian karst areas.

REFERENCES


INTERACTION BETWEEN KARST, WATER AND AGRICULTURE OVER THE CLIMATIC GRADIENT OF ISRAEL

Amos Frumkin

ABSTRACT
The dry climate of Israel and the karstic nature of its rocks have always imposed human innovation for utilisation of water resources and agriculture. Large perennial karst springs are available only in the lowlands, but sophisticated water supply systems were built both in the lowland and highland regions. Marl layers interbedded within carbonates give rise to local perched springs and allow terrace construction. Deforestation has taken place for some 4000 years, causing intense soil erosion, but terraces have reduced this impact.

KEY WORDS: fluviokarst, karst springs, east Mediterranean, water supply, deforestation, human impact.

1. Introduction
Israel displays a gradient of karst features from the intensive karstification of Lebanon in the north to practically no karst in the southern Negev desert.

This is attributed mainly to the climatic gradient from alpine-Mediterranean climate in the Lebanon - Hermon mountains in the north, with precipitation >1000 mm/year, to the extremely arid southern Negev, with <50 mm/year. Another factor is the southward decrease in carbonates/clastics ratio of the phanerozoic stratigraphic column, due to the increasing distance from the Tethys Sea which deposited the carbonates.

Carbonate rocks crop-out in some 75% of the hilly regions of Israel. They are predominantly of Jurassic to Eocene age. However, much of the carbonates contains marls which inhibit extensive karst development, promoting the dominance of fluviokarst features.

Israel is geographically a part of the Fertile Crescent, where several ancient civilisations practised agriculture and utilisation of water resources during their evolution. Most of the Fertile Crescent enjoys an arid to semi-arid climate, in which potential evaporation exceeds precipitation. Such conditions pose a challenge for agriculture and human use of water, especially in karst terrains.

Both Egypt at the south-western part of the Fertile Crescent and Mesopotamia at the north-east relied heavily on large rivers - the Nile, Euphrates and Tigris, deriving their waters from distant, wetter regions. A centralized power was needed in these regions to develop the water resource and regulate its use. However, in Israel a basic precondition is the absence of allogenic sources of water, and the availability of some local karstic sources. Thus the scarce water resources might have limited the deve-
lopment of ancient (e.g. Bronze Age) large agricultural economies and centralized civilizations. During more recent periods the special natural conditions of Israel seem to have promoted diverse hydrogeologic and engineering solutions which overcame the scarcity of water.

Many settlements in Israel depended heavily on rain and runoff collection during most historical periods. Utilization of more reliable supply from perennial karst springs, rivers and ground water depended on available technology as well as on the knowledge of hydrogeologic and topographic conditions.

2. Climate, water and people

The present climate of the northern half of Israel is Mediterranean to semi-arid, while the southern part is semi-arid to hyper-arid. The summer, June to October, is warm and dry, while most precipitation falls during the winter.

Some authors have suggested that the pattern of human habitation was determined mainly by climate (e.g. Huntington, 1911; Issar, 1990). This assumption should be checked by natural proxy paleoclimatic evidence which is as independent as possible from human interference. Several lines of evidence indicate that the last considerably moister period was the Early Bronze, with moistest conditions ~5000 calendar years B. P. (Frumkin et al., 1994). The highly developed urban civilization of the Early Bronze age which developed even in the arid regions around the southern Dead Sea (Arad, Bab edh-Dhra) apparently lacked sophisticated water supply systems. Their development is rather attributed to the moister climate, and their destruction is associated with abrupt climatic degradation. About 4500 calendar years B. P. climate indeed deteriorated rapidly towards the drier regime prevailing since the Middle Bronze age until today (Frumkin et al., 1991). The dry climate of the last 4500 years was however interrupted by some slightly moister episodes as indicated by speleothems and other proxies (Frumkin et al., 1999; Issar et al., 1991).

Rainfall in Israel is typically in the form of high-intensity showers. Therefore the impact of rain drops is large, causing intense erosion of soil, unless the soil is protected by vegetative cover.

3. Geology of karst regions

The rocks exposed in Israel were mostly deposited in continental and marine environments during the Mesozoic and Cenozoic eras. Of these, the backbone of Israel's mountains consists mainly of marine sediments of Albian to Middle Eocene age. The country is located between the Mediterranean Sea and its predecessor Tethys Ocean to the north-west, and the Arabo-Nubian shield to the south-west. The variations of sediments in space and time were mostly determined by the relative positions of the sea, depositing biochemical sediments, and the continent, supplying terrigenous material. During the Cenomanian-Turonian age the common deposition environment was a wide shallow platform lagoon with barrier reefs isolating the lagoon from the open sea (Sass & Bein, 1978). The resulting rock is mainly dolomi-
te, interbedded with thin marl layers. Some deeper basins produced limestones and chalcs. Reefs produced several massive permeable limestone bodies. Variable deposition rates could control the relative amounts of carbonates and clays within a particular bed. During the Senonian age deeper seawater environment gave rise to chalky deposits, while Eocene age sediments are mainly limestone in some regions and chalk in others.

Regional uplift followed the Middle Eocene, terminating the continuous marine deposition. Since then the highlands of Israel underwent continuous erosion, mainly karstic and fluvial (Frumkin, 1993). The Late Cenozoic northward movement of the Arabian plate formed the Dead Sea Rift, producing a deep depression with inland drainage since ~6 million years ago (Steinitz & Bartov, 1991). The rifting, as well as Quaternary uplift of the backbone mountains and associated accelerated erosion sculptures the recent topography of the country, while Neogene and Quaternary sediments fill the valleys. Volcanic eruptions have overlain the Golan Heights and parts of Eastern Galilee with relatively flat basalt sheets.

Consequently, in most of the mountain regions karstic rocks crop-out, and their degree of karstification depends mainly on local climate, topography and the amount of clay within the carbonate rocks.

The most common soils on karstic hilly terrains of Israel are terra-rossa and rendzina (Dan et al., 1976), derived from allogenic aeolian dust and residue of local rocks (Yaalon & Ganor, 1973). Grumusols with abundant clay are common in karst depressions.

The major carbonate karst regions of Israel are briefly reviewed below (Fig. 1).
3.1. **Hermon**

The higher part of Mount Hermon, on the northern end of Israel, displays distinctive alpine karst features. The elevation within Israel's border reaches 2220 m, and snow covers the higher parts several months a year. Massive Jurassic limestone, several hundred meters thick, gives rise to developed holokarst with doline fields and poljes. Agriculture was practiced in the past up to ~1500 m a.s.l. The Jordan river emerges from large springs at the foot of Mount Hermon which lacks perennial springs within its elevated parts in spite of high precipitation (>1300 mm/y).

3.2. **Galil**

The Galil mountains is the major karst region of northern Israel, developed on Cretaceous to Eocene carbonates. Mediterranean fluvio-karst terrain is common, while the upper Galil, especially around Mount Meron, displays some mature karstified areas (Gerson, 1974). Of these, Mount Peqi'in is notable for its developed doline karst landforms with highest density of limestone vadose shafts in Israel. Two ponors drain large karst areas: Me'arat Pa'ar, in the bottom of a large doline, and Zomet Meron sink.

3.3. **Carmel**

The Carmel ridge is built mainly of Upper Cretaceous carbonates. Fluvio-karst is common, while karstic closed depressions are rare. A major active fault along the north-eastern edge of the ridge seems to inhibit karst development on this side.

3.4. **Shomeron**

Karst landforms in Shomeron appear on Jurassic to Neogene carbonate rocks. The Ram'alla anticline at eastern Shomeron is dissected by large transversal faults. Large caves appear mainly on its southern part, which is structurally similar to the Judean mountains.

The limited outcrop of Jurassic limestone displays extensive surface karren features, such as rillenkarren. Most regional karst features appear on Cretaceous to Eocene limestones and dolomites. The Eocene carbonates of the northern Shomeron syncline serves as a major karst aquifer of Bet-She'an valley and Shekhem region. This region displays the largest tectonokarst feature in Israel - the Sanur polje.

Karst landforms appear rarely in Tertiary conglomerates of eastern Shomeron.

3.5. **Judea**

Karst features appear here on Cretaceous to Eocene carbonates. Much of the upper erosion surface of Judean Mountains was formed by karst denudation (Frumkin, 1993). Fluvio-karst is most common, but north of Jerusalem there are some areas of internal karst drainage (Fig. 2), and also a doline field with 12 known vadose shaft systems (Frumkin, 1986). Lack of major faults has promoted the development of long and stable subsurface flow routes in the phreatic zone, allowing the
development of the largest and most abundant limestone caves in Israel.

3.6. Negev and Judean deserts

These regions are arid, with precipitation lower than 200 mm/year. Therefore active karst processes are mostly limited to the micro scale, and agriculture is limited too. Judean desert is a product of rain-shadow east of Judean mountains. These mountains (precipitation of up to 600 mm/year) are the input zone of ground water discharging along the Dead Sea. Such circulation has probably formed the relict phreatic caves found in Turonian limestone west of the Dead Sea. Unlike Judean desert, the Negev is part of the global Saharan arid belt. Water was probably insufficient for extensive karst development even during humid phases of the Pleistocene, but agriculture was practiced in several periods.

4. Ground water and water supply

Water is recharged in the carbonate rock outcrops of the mountain ranges, and discharge to major springs along the foothills regions: (1) in the west: Kabri springs, Tanimim springs, and Yarqon springs; (2) in the east: the Bet-She'an, Jordan valley, and Dead Sea springs. Most of these springs get their water from large underground karst catchments, allowing abundant water supply the whole year round.

Within the mountain ranges proper, however, water is scarce, being the most limited resource for agriculture. Two types of rocks are distinguished here: (1) Pure karstic rocks, with <10% insoluble impurities form highly karstic permeable mountain ridges which deliver practically all infiltrated water down towards the regional aqui-
fer (Ford & Williams, 1989). In this type of terrain water resurgence typically occurs at the foot of the mountains rather than within the elevated region. (2) Where marls and chalk are incorporated within the karst rocks, they tend to obstruct water flow locally, forming aquicludes. Local aquifers are perched above these layers, giving rise to abundant springs, discharging at the contact between the karstic rock and the underlying impermeable layer. The ancient population of the Judean Mountains (and to a lesser degree, other regions) used these water sources, in addition to rain water, for agriculture. However, most of the mountain springs are characterized by low discharge (<1 litre/second) due to their relatively small catchments. Moreover, the relatively fast flow via karstic conduits and the small catchment area cause discharge to fluctuate heavily, both seasonally and annually in direct relation to precipitation.

As population increased, water supply engineers had to find ways to extract more water from the limited ground water resources of the mountain aquifers. Several solutions were utilized:

1) Large volume water storage. Reservoirs were used for retaining water from night to day, and for dry seasons.

2) Increasing the discharge of mountain springs by excavation of short sub-horizontal tunnels. This method has been used in Israel continuously for thousands of years. Excavation usually began from a spring into the mountain along the fissure supplying the water (Ron, 1966). The method was in use since the Iron Age when the monumental sub-horizontal water tunnel of El-Jib spring had probably been excavated (Pritchard, 1961). In some cases the water engineers incorporated natural karstic caves within their tunnel systems, increasing their yield with relatively little effort, e.g. Ein Wadi el-Biar of the Jerusalem water supply (Miron & Frumkin, 1986).

3) Long tunnels were excavated during the Roman period along ground water-bearing rock formations to collect their water. Shafts were used as initial points of excavation as well as for air introduction and maintenance. These tunnel systems were excavated along stream valleys, several meters below the stream channel level. This was feasible only where an aquifer is close enough to the surface, an uncommon feature in the mountains of Israel. Two major systems using this technique are known in Israel: (a) The Upper Biar tunnel, 2.8 km long, extracting water from Cenomanian dolomitic-marly rock for the Jerusalem water supply system (Tsuk et al., 1986). (b) The upper Nahal Taninim tunnels, >6 km long, utilized an Eocene chalky aquifer (Sigelman & Ravek, 1993).

4) Qanat (Foggara) systems, widely known from Iran, were used along the arid parts of the Jordan Valley and the Arava, probably during the 7-8 century C.E. (Porath, 1987). They were designed to capture mountain aquifer water by a 'mother well' before it becomes salinated within the rift valley deposits, and to convey the water to the surface through a moderately-inclined tunnel.

Local surface runoff stored in cisterns was a major water source in the whole
country. In the desert this source becomes even more important. This source shares the insecurity of discontinuous supply during droughts, but it may suffer only small damage from extreme rain events due to the small catchment of each cistern.

The Negev desert has few permanent springs. Major spring sites like Kadesh Barnea naturally attract human activity and water engineering. A more widespread way of using ground water in the Negev was digging vertical wells. This method takes advantage of the fact that much of the desert rain and runoff infiltrates through permeable surfaces or stream beds. The regional aquifer is shallow near the Mediterranean coast, becoming deeper further inland. This determined the depth of wells and the possibility to reach the water using available techniques.

In the mountain region of the Mediterranean zone agriculture depended heavily on rain. On the other hand the desert agriculture depended mostly on runoff harvesting which promoted engineering innovations.

5. Deforestation and soil use

Karst depressions of Israel are most easily cultivated, as their soils are commonly deep and fertile. These were used for farming at least since the Bronze Age. However, some depressions lack drainage (Fig. 2), and their hydromorphic conditions were unfavourable for agriculture until the 20th century, when most wetlands were drained and replaced by agriculture. Natural vegetation is almost non-existent in the intensively farmed karst depressions.

The situation is different on rocky karst slopes, where soil is generally shallow. The natural Mediterranean vegetation on carbonate outcrops consisted mostly of dense forest and maquis. The expansion of settlement in historical times resulted in deforestation which promoted soil degradation. Deforestation took place in several forms: clearing of vegetation for tillage, planned and accidental fires, and cutting timber for construction, industry and fuel. Therefore, deforestation was tightly associated with settlement expansion. After a piece of land was deforested, continuous grazing by goats and sheep inhibited the natural succession and regeneration of the forest even in periods of settlement contraction. Grazing was harmful also to agriculture, especially in years of drought, when nomads from the desert penetrated the cultivated land with their goats. The long dry and hot summers rendered the forests susceptible to fires which occurred either naturally or artificially as means for clearing the land, driving game for hunting, improving pasture for game and domesticated animals, or as an act of war.

According to the Bible, the karst surface north of Jerusalem (or possibly east of the Jordan river) was deforested at the beginning of the Israelite period (4th millennium B.P.) when the tribes of Joseph settled this area because the fertile valleys were already occupied by the Cananites:

"And Joshua said to them: If you are numerous people, go up to the forest, and there clear ground for yourselves... the hill country shall be yours, for though it is a forest, you shall clear it and possess it to its farthest borders" (Joshua 17, 15-18,
The Hebrew word 'Ya'ar' used here for a forest to be cleared appears some 50 times in the bible, with apparently two meanings (Tur-Sinai, 1965). Apart from the usual meaning of dense forest, it sometimes means a wild desolated landscape (e.g. Hoshe'a 2,14; Micha 3,12). This meaning is possibly preserved in the Arabic word 'Wa'ar' which means rugged rocky terrain. This word is used today to describe karst terrains common in the late Cretaceous carbonate outcrops of the mountains of Israel. A field survey of the usage of this word indicates that it is used to describe landscapes where soil has been partly or completely stripped from karren fields.

In spite of deforestation, the Bible includes many references to a dense forest over the karst landscape throughout biblical times, indicating that deforestation was not very intensive at that time. Archaeological evidence indicates that population density achieved its climax in the Hellenistic-Roman-Byzantine periods (24-15th century B. P.), associated with large-scale deforestation and agricultural development. Palinological studies in Lake Kinneret and the Dead Sea (Baruch, 1990) also show that during this time the natural forest was replaced by extensive fruit farming, mainly olive plantations. Olive trees were both economically important and well suited for the terra-rossa soil within the karst deforested areas (Fig. 3). Olive presses were excavated during this period not only in the soft chalk of the Shefela lowland region, but also in the hard carbonate rocks of the mountains.

Decline of agriculture and re-establishment of the forest plants occurred during the second half of the second millennium B. P., as indicated by historical, archaeolo-
Fig. 4 - Traditional-style plowing along a linear terrace. The terrace and the parallel plowing reduce soil-erosion.

6. Terracing

Linear dry field terraces were commonly built in the fluviokarst slopes of Israel. They involve the construction of a stone wall along the hill slope and creation of arable land behind it. This technique was practiced in Israel for at least 3000 years, as indicated by archaeological evidence and the Bible (Cant. 2, 14). Terraces were considered part of the 'normal system', so the prophecy of Ezekiel about total destruction of the mountain landscape includes: "The cliffs shall fall and every terrace shall tumble down" (Ezek. 38,20).

Terraces controlled runoff, reduced soil erosion, and allowed the operation of animal traction plowing (Fig. 4).

They were not level except for artificially irrigated terraces, where absolute level-
ness was needed for even distribution of water. Terraces served as shelves where soil, minerals, and organic matter could accumulate, while (rainfall or irrigation) water could infiltrate into the ground. This is important in the dry climate of Israel, both for soil water balance and for ground water recharge. Terrace walls also served as a means to dispose of stones collected from the field.

Terraces were built primarily on outcrops of dolomites with intercalations of marls, such as Giv'at Ye'arim, Soreq, and Bet Me'ir formations in the Jerusalem region. These formations assume a natural step-like morphology, so the terrace wall could be based on the hard dolomite layer, and the marl constituted part of the soil behind the terrace wall. The same marl layers inhibit karst water circulation in these formations, and promote subaerial runoff. Therefore, the construction of terraces on these formations was more important than on karstic formations, in terms of water management.

On the other hand, karstic carbonate rocks without marl intercalations, such as the 'Amminadav, Weradim, and Bi'na formations in the Jerusalem region, create a rugged karren topography promoting water infiltration into well-developed fissures and karst conduits. Consequently, terraces are less common on these karstic outcrops. Agriculture was developed in valleys and soil patches within the karren fields of these formations. Stones collected in these fields were used for building fences and watch towers, or just piled over protruding rocks (Fig 5).

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Fig. 5 - Summer view of a karst plateau over 'Amminadav Formation north of Jerusalem: A doline (foreground) where deforestation and agriculture took place in the past was invaded by Sarcopoterium spinosum (dark patches) when cultivation ceased. Wheat cultivation is still practiced at the larger karst depression filled with deep soil (background).
In some cases intentional erosion of terra rossa pockets in karren fields was induced by farmers, in order to enrich the down-slope terraces with eroded soil. This was done by clearing stones along lines perpendicular to the slope, forming channels for runoff water (Ron, 1966).

The ancient stone wall terraces are carefully built and are therefore labour-intensive. During the last centuries farmers concentrated on repairing old terraces rather than building new ones. Today another kind of terrace is replacing the ancient one. It involves heavy machinery instead of human work, and the terraces are wider, with piles of rocks along the edge of each terrace (Fig. 6).

![Fig. 6 - Modern development of a karst slope: heavy machinery uproots limestone blocks and transfers them to form arable patches of soil bordered by piles of rocks.](image)

These terraces are built of uprooted stones and rocks cleared by bulldozers from the field surface. This practice is especially effective in karren fields where subsoil and epikarst dissolution detaches the protruding rocks from the underlying bedrock. It is used mainly for growing fruit in the hills of Judea and Galil. However, this type of land use causes some soil erosion over the newly cultivated areas.

7. Conclusion

The present karst landscape of Israel is the product of several thousand years of human impact changing the natural environment. Deforestation resulted in increasing erosion rates on karst surfaces, but terracing helped in conservation of soil and water. As water is the most limited resource in this dry region, several engineering solutions were utilized to use the available water in the best way. This included using rain water and ground water, as well as limiting the amount of runoff and increasing the infiltration.
REFERENCES


LAND USE IN THE KARSTIC LANDS IN THE MEDITERRANEAN REGION

Ibrahim Atalay

ABSTRACT
Karstic lands have special importance in terms of soil formation and land-use. Soil appears only on the flat and slightly undulating karstic lands, while soils are found along the cracks and bedding surfaces between the layers on the hilly karst areas although these lands are rocky in appearance. Karstic lands in the hilly area are not conducive to cultivation. But rocky areas create a favourable habitat for the growth of forests except in an arid climate. Because the tree roots easily follow and develop along the cracks in the limestone. As a general rule soil erosion does not occur on sub-horizontal karst surfaces due to the fact that atmospheric waters easily infiltrate along the cracks. Natural generation of vegetation like the maquis-type occurs via the root suckers, but coniferous trees such as cedar, fir, pine through seed dispersal. The clearance of natural vegetation on the karstic lands leads to the formation of bare lands. That is why the slopes of the limestone hillsides have been converted into bare and/or rocky terrains in places where natural vegetation has been completely destroyed.

KEY WORDS: soil formation, land use, land degradation

1. Introduction
Parent material is one of the main ecological factors which determines the soil formation and the growth of natural vegetation. Limestone which is a chemical sedimentary rock mainly composed of calcium carbonate, produces particular topographic forms. The soil forming process and the ecological conditions of a limestone area are different than in areas with other parent materials. In order to explain the importance of the limestone on land-use it is necessary to give a brief description of the soil formation and ecological conditions that are relevant to this type of area.

2. Materials and methods
Detailed field studies have been carried on in the region since 1970. Soil profiles and parent materials were examined in different places extending from the seashore to the subalpine belt in the Mediterranean Region of Turkey and in some other Mediterranean countries. The experimental plots were selected with different parent materials and altitudes in order to observe the regeneration of vegetation with particular reference to the degraded areas. Field observations were also made in the forest fire areas.

2.1. Soil formation in the karstic lands
Limestone which is mainly composed of calcium carbonate and clay is dissolved
by water containing carbon dioxide. Karstic topographic forms such as lapiés, karstic depressions (dolines, poljes), sinkholes and ground water channels formed through the dissolving of the limestones. Soil material in the karstic areas is of clay which is the main remaining material after the removal of calcium carbonate. For this reason the soil which is found in the karstic land is of 'clayey' texture.

Tree roots easily penetrate into the deeper part of fractured rocks. This suggests the presence of favourable ecological conditions for soil formation. Root residues, producing organic acids, may also be effective in chemical weathering. Soil formation in the karstic lands, on the other hand, is mainly determined by the limestone purity, situation of the cracks and inclination of the beds.

The thin bedded limestones produce richer soils than the massive rocks. This is because these types of limestone are good water retainers (Fig.1). For instance, red Mediterranean soils (Terra-rossa or Alfisol) are abundantly found on the thin bedded and fractured limestones. While in the Taurus Mountains on massive and hard lime-

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**Fig. 1 - Soil formation on the karstic lands:**

- **A** - Development of the soils along the cracks and in the cavities between the beds;
- **B** - Formation of soils along the cracks in the rugged karstic lands and karstic depression;
- **C** - Beginning of the soil formation along the cracks on/in of the horizontal limestone layer;
- **D** - Vertical transportation of the soils with the widening of the cracks;
- **E** - Formation of the rugged karstic lands dissected by lapiés and transportation of the soil towards the deeper parts with progression of karstification.
stones the soils are thinner (Atalay, 1997b).

The dissolution of limestones along the vertical fractures leads to the widening of fractures, this process is very well expressed in the Mesozoic limestones in the Alpine mountains extending in the northern part of Mediterranean Sea (Fig. 1).

Soils which developed along the fractures, have been transported vertically by a widening of the fractures via dissolution of the limestones. Thus, the soil mass may be removed from the near surface to much deeper zones by vertical transportation with time. Such soils, in general are red and completely decalcified. This explains why soils are found in the fillings of caves and of karstic depressions.

Thin fractures and bedding planes are favourable sites for water retention. Therefore the process of weathering and soil formation take place in locations where water is held. The tree roots penetrate easily into the deeper part of the rocks through the fractures and accelerate soil formation.

Soil erosion processes generally do not occur on the surfaces of the karstic lands because of the fact that the run-off is very low and the rock has a high infiltration capacity.

The fractures in the limestones provides suitable conditions for oxidation so that through Fe oxidation soils attain a reddish colour.

Rich and thick soils are common in the places where a thin bedded stratigraphic sequence is present. Because pure limestones sometimes contain many more fractures than the 'clayey' limestones, soil formation takes a long time, and most of the soils do occur in widened fractures, even a few meters below the rock surfaces, therefore most of them are paleosoils (Atalay, 1997a and 1997b).

2.2. Ecological properties of the karstic lands

Karstic lands are where the main productive forests are found in the Mediterranean climatic region. The cation exchange capacity of karstic soils is about 40 me/100 g soil. This figure is sufficient for the growth of forests. These soils contain the required nutriments for plants. Plant roots easily develop and grow along the fractures. Water retention capacity is also high due to the 'clayey' texture of the soils. Water wastage through evaporation and capillarity is very low in the soils found in the fractures.

The inclination of the slope has no significant effect in karstic lands due to the fact that soil erosion is not always very intensive. In the virgin karstic lands the slopes are covered by natural vegetation. These areas are widespread in the Taurus Mountains. While damaged hillside areas which are composed of granite, gneiss, andesite appear as a barren areas.

The seeds which fall down into the cracks containing soil germinate easily and the plant roots follow the water seepage through the cracks. The roots reach up to about 1 meter in length in only one vegetative period (Atalay, 1987b). These properties produce favourable conditions for the growth of vegetation. Indeed the virgin karstic areas are covered by dense forest. For example in the Euro-Mediterranean belt of the Taurus Mountains the red pine (Pinus brutia) is prolific and the upper slo-
pes of these mountains are covered by cedar (*Cedrus libani*), black pine (*Pinus nigra*) and fir (*Abies cilicica*). Studies on the forest biomass on the different parent material such as limestone, marl, sandstone, schist and ultrabasic rocks, show that the karstic land is one of the most favourable for the growing areas of these forests (Atalay, 1994, 1995).

3. Vegetation in Mediterranean karstic lands

Agricultural activities and forestry on the karstic lands are governed by altitude and soil properties.

As a general rule arable lands are only found in the karstic depressions mostly within the karstic plains (poljes). These lands have reddish Mediterranean soils which have formed both in situ and alluvial and colluvial soil materials which derive from the uplands in the vicinity of karstic terrains. Arable lands are devoted to crop production. Subtropical crops such as orange, vegetables and fruits are produced in the lower belt of the Mediterranean Region. While cereals grow in the upper and/or oro-Mediterranean belt. Olive groves are also widespread on the karstic terrains. Wild olive trees which are found in the lower belt of the Mediterranean region have been grafted.

Two main tree communities grow in the karstic lands:

1- Most of the karstic lands are covered by maquis or shrub communities which are the climax species for the Mediterranean Region, in general. Maquis is accepted as a secondary succession in subhumid and humid parts of the region (Atalay, 1994). Indeed the maquis is widespread for example in places where *Pinus brutia* (red pine) forests have been destroyed.

This type of vegetation mainly regenerates via root suckers even if completely cleared. For example, the roots of maquis elements like Laurel (*Laurus nobilis*), Kermes oak (*Quercus coccifera*), Eastern strawberry tree (*Arbutus andrachne*), Pistache (*Pistacia terebinthus*), wild olive tree (*Olea europea*) etc. develop along the fractures of the limestones. It is impossible in general to dig up the roots of these shrubs. On the other hand if the roots of the maquis is cut and/or wounded, the plant regenerate easily with the young shoots. For this reason maquis vegetation is the most widespread in the karstic lands with a Mediterranean climate and the semiarid-subhumid parts of the World.

2- Some coniferous trees such as *Pinus nigra*, *Pinus pinea*, *Pinus brutia*, *Cedrus libani*, *Abies cilicica* and broad-leaved trees such as *Fagus*, *Castanea*, *Alnus sp.* etc. also grow in the karstic lands. These trees regenerate with natural seedlings. If these forest trees were completely cleared, bare or rocky areas would appear. In other words, if cedar and black pine forest had completely vanished, the karstic lands would be converted into rocky barren lands. Indeed the upper karstic part of the Taurus Mountains resembles the stony desert areas due to the destruction of the natural vegetation. Natural regeneration of the forest could only happen in the areas protected from intensive grazing in the vicinity of the forests.
Tree seeds fall down into the cracks containing soil, germinate and after one or two years, the forest commences to spread slowly. Indeed the cedar forest which is found in the protected areas has begun to spread (Atalay, 1987b, 1995; Boydak and Ayhan, 1990; Boydak, 1996). One can see these forest areas in the upper part of the Taurus Mountains. If there are no tree communities forests, karstic land remain bare land (Fig. 2). In this case the reforestation of the karstic lands is generally impossible because of the fact that there is insufficient soil on the surface for the plantation of plants. Most of the karstic bare land in the Taurus Mountains have arisen as the result of forest destruction.

One of the main reasons for the destruction of the natural vegetation in the karstic lands is over-grazing: the economic activities of the rural areas depend on both crop production and animal husbandry. The animal husbandry activities change according to vegetation belts. Evergreen maquis vegetation also provides meadow

![Fig. 2 - Erosion and land degradation in the Mediterranean vegetation in the karstic lands and marl deposits: 1 - Natural vegetation; 2 - Clearance of vegetation; 3 - Regeneration of maquis with root suckers in the karstic land and garrigue dominance on the abandoned farmland. (P= Pinus brutia, M=Maquis, G=Garrigues, F=Farmland).](image-url)
areas especially for goats in the lower belt of the region. The evergreen maquis vegetation in the karstic lands form the main grazing areas for goats.

Nomadic activities, on the other hand, are also the main reasons for erosion and land degradation. Nomadic societies, named Yörük (walking men) in Turkey, graze their animals during the winter season on the coastal belt of the Mediterranean and Aegean seas. During the summer, Yörük travel up to the Taurus Mountains in order to graze their animals.

As a result, this type of animal husbandry has led to the degeneration of the natural vegetation and the disappearance of the forests. In other words, grazing in the forest lands hinders natural regeneration since young plants are eaten by the goats. In addition, the natural regeneration of the forest in the burnt areas does not occur where the animal grazing continues. On the other hand both the upland meadow areas of the Taurus Mountains and oro-Mediterranean forest belts are also summer grazing areas for Yörük societies and the rural population. In these areas excessive exploitation of forests and animal grazing have led to the degeneration of the composition of natural forests and herbaceous vegetation. Indeed, oro-Mediterranean forests composed of Cedrus libani, Abies cilicica and Pinus nigra are replaced by the steppe and juniper communities due to human impact.

These activities which have continued for centuries have led to the degradation of the climax vegetation. Because of continuous destruction, the upper limits of the forest have shifted one or two hundred metres from the natural timber line, and most part of the oro-Mediterranean forests have disappeared. For example the oro-Mediterranean cedar forest areas have been replaced by stony barren land. Some parts of the forest areas are occupied by juniper communities which can be termed a regressive succession (Atalay and Semenderoglu, 1996). A large majority of the climax herb vegetation has disappeared due to over-grazing. For example, subalpine herbs have been replaced by the spiny cushion species such as Acantholimon, Astragalus, and bitter herbs such as Euphorbia species which are not eaten by animals. This has also caused a decrease in herb production. So the upper parts of the oro-Mediterranean forest area have been converted into stony barren lands. These lands cover an area of 1 million hectares.

4. Results

Some conclusions can be reached regarding land degradation and erosion given the particular habitats of the Mediterranean Region:

1 - Hilly karstic lands which are not favourable to agriculture are the main areas of the natural vegetation. Most of the burnt and cleared areas are covered by maquis vegetation in the semi-arid part of the Mediterranean region. Even if maquis or shrubs are cleared in karstic land, regeneration occurs due to root sucking.

2 - The regeneration of the coniferous forest trees is prevented in general if all trees have been cleared. For this reason destroyed forest areas have been converted into bare rocky land.
3 - Rocky karstic bare lands have arisen as the result of forest destruction and over-grazing.

4 - It is necessary to protect the area from over-grazing and excessive forest exploitation in order to maintain the natural equilibrium and a sustainable development of the karstic hillside areas.

Fig. 3 - Land degradation in the karstic land of the upper belt of the Taurus Mountains: A - Natural vegetation (Cedrus libani forest); B - Complete clearance of cedar forest; C - Formation of bare land.

REFERENCES


ENVIRONMENTAL VULNERABILITY AND AGRICULTURE IN THE KARSTIC DOMAIN: LANDSCAPE INDICATORS AND CASES IN THE ATLAS HIGHLANDS, MOROCCO.

Brahim Akdim and Mohammed Amyay

ABSTRACT
After the brief presentation of the major karstic areas in Morocco, the article focused essentially on the Atlas mountains to investigate the impact of the agriculture on the natural systems equilibrium. Socio-economic changes (demographic pressure, escalation of the landscape use, utilisation of new techniques in water harvesting, etc...) have sometimes fathered mechanisms of degradation. Many indicators seem to reflect these mechanisms. The pedologic indicators, soil erosion, the hydrologic and geomorphic indicators, are apprehended to demonstrate existent correlation between different variables and the often negative impacts of land over-use in the karstic domain of the Middle Atlas.

KEY WORDS: Morocco, Karst, Atlas, agriculture, impact.

1. Introduction
The karst landforms are dominating over the Atlas mountains because of the high occurrence of the Mesozoic and Cenozoic carbonate rocks. These are mainly forming in the Liassic limestone and dolomite, folded and elevated by Tertiary tectonic events and neotectonics. Densely populated, the Atlasic domain is progressively under stress as human needs are exceeding natural resources. The perpetual adaptation to intense human economic needs determine net landscape vulnerability as most Atlasic natural systems are fragile.

The relative equilibrium of the system, acquired from previous adaptations of the traditional human communities (the extensive farming and cattle-breeding), is disturbed in the present-day context. Humans degrade portions of the environment while doing intentional alterations (creative destruction) and may contribute unintentionally to land degradation (Johnson and Lewis, 1995). Regarding the progressively dense settlement of tribes and the intensively engaged agricultural activities, the natural resources in the Moroccan karstic domain are under stress. The vegetation, land and water uses are obviously affected by such activities. Consequent system's imbalance, then, appears.

Multiple disequilibrium indicators were observed while studying the geomorphic dynamics recently developing within this area. The human-induced sediment erosion and sediment transport along artificial streams, the fluctuating discharge due to damming of streams and tributaries "seguias", the abusive irrigation and water supply due to modern crop types, the deforestation, the multiple boreholes managed within the
karstic plains and water pollution due to domestic sewage and soil chemical fertilisation are indicators of such environmental degradation initiated by human action. In environmental geomorphology and resource conservation, these processes may reach catastrophic thresholds (non reversible) if the present-day trends are maintained in the future.

The main topic of this contribution is to apprehend the relationships between some active geomorphic, environmental aspects and the anthropic action in the karstic domain of the Moroccan Atlas mountains. This is a relevant question, as sustainability is becoming a respectable concept and a priority in local development and rural management. A brief description of the main Moroccan karst fields is presented, and followed by the discussion of the human context and anthropisation. The land use - landscape disequilibrium interface is studied in terms of indicators analysis to show trends in the landscape degradation.

2. The most typical karst of Morocco (fig. 1)

A bibliographic review related to the Mediterranean karsts (including the Moroccan ones) have been published by Julian et al. (1978). But more works were done ever since. The surface karstic forms of the Atlas mountains have been studied and well known following works of geomorphologists such as Couvreur (1981), Weisrock (1980), Martin (1981), Ghazi (1987), El Khalki (1990) and Perritaz (1995) for example.

Large numbers of karst features were developed in the Middle Atlas plateaux, in the folded Middle Atlas and in many areas of the elevated plateaux of the High Atlas such as Ait Abdi, Assif Melloul, Assif Ahansal and Imadghas. The high karst of Ait Abdi plateau is situated at an elevation of 2200 m to 3000 m and it is named "a perched karst" by Perritaz (1995). The snow action is predominant so that most karst forms on such elevation are nival. Large to small dolines, uvalas, poljes, lapiez (karren), blind and dry valleys, incised canyons, plains, rock-fans, and diverse surface solution sculptures were reported in many areas of the Atlas.

Tennevin (1978) reported that the karst topography of North East Middle Atlas "shows highly diversified forms: the plateaux of Ahermoumou, where it takes on superficial forms and activity is reduced; the rocky cones, giant sink-holes and snow wells of Jbel Bou Iblane; the regions of Chara and Ademmane, riddled with sinkholes and full of underground rivers". He emphasised its complex genesis as karstification was guided by tectonics, fluctuating hydrology and paleoclimatology.

The underground karstic morphology and processes in Morocco are less apprehended even if their study begun many decades ago. The "Speleological Society in Morocco" has been set up in February 1948 following efforts of individuals who contribute to the Moroccan speleologic research. Deepest holes were located and mapped in the Rif and the Atlas heights. More than 330 subjacent karst phenomena (caves, caverns, holes etc...) were listed within the Atlasic domain (D.H., 1981). However, the most developed caves are the Toghbeit cave in the south of Chefchaoun (900 m depth), the Wine Tmadouine (Wit Tamdoun) underground river
(6 km long) in the western High Atlas, at the north west of Agadir, the Friouato and Chiker underground system in Taza region were discovered early. More recently the caves of the central High Atlas, such as Akhiam cave in the high Assif Melloulun were explored (Calandri and Ramela, 1990).

The physical context controls landscape and environmental equilibrium. The climate is diverse due to complex factors (topography, exposition, elevation, air dynamic masses, etc...). Some increase in aridity from the West to the East and from the median summits to the South is a common characteristic in the Atlas. The subregions vary from humid (Azrou - Ifrane Region), to sub-humid, sub-arid and arid areas (steppic southern flanks). Even in the median Atlas, local depressions could be dried
by the foehn or the south-eastern dry winds (Chergui) blowing from the desert. The southern flanks of the Atlas are more affected by the present-day climate conditions with low rainfall and high evaporation.

Considering the main role of hydrology and climate in karst processes, some major landforms indicate a changing and episodic genetic history. The paleo-karst processes are apprehended basing on the quaternary chronology of terraces and links between karst landforms and related carbonate deposits (tufa and travertine). The Pliocene is for example an episode of intense carbonate solution in the Middle Atlas as major amounts of exported travertine were precipitated in the surrounding lower pediments "Dir" at Sefrou, Imouzzer Kandar and El Hajeb regions for example (Martin, 1981). This is in agreement with Nicod's assumption (1994) confirming paleo-karst processes in more than one case in the mediterranean area. The tectonic events have been considered among explaining factors of various lakes in the Atlas highlands. In the median High Atlas, Couvreur (1981) reported sedimentologic indicators of a mid-quaternary lake in Tizi-n-Tghza due to the Ait Bougmez valley obstruction, following tectonically destabilised slopes. After El Fellah (1994), the lake Tamda in the Middle Atlas (upper Melloulou, Guercif) fit in a similar explaining model (karst processes activated by tectonic effects). Debris flows and mud flows could also obstruct valleys and generate lakes' formation as observed on the Djbel Izourki flanks, where the lake Izoughar has been formed (Couvreur, 1981).

Current carbonate dissolution rate, as estimated from water analysis, is seemingly slow. It is approximately above 25 mm/1000 years as calculated for the upper basin of Oued Sebou, Middle Atlas (El Khalki, 1990). It is presently a very localised and less perceptible dynamic.

3. The human context and anthropisation

3.1. The favourable context of change

Agents of landscape transformation are of physical and anthropogenic kind. The human and socio-economic factors are however more efficient in the changing processes during the last two decades. The Atlas mountains were subject to two basic driving forces: the local population increase and the national market vegetable needs, commercialisation and investments (external forces). Human settlement is ancient in the Moroccan highlands as indicated by human neolitic traces in caves (e.g. El Hajeb and Imouzzer Kandar). Very important sites of paleolitic instruments and silex pebble presenting human sculptures have been observed in the vicinity of Aguelman Sidi Ali (Middle Atlas) and on the plateau of Azrou.

In most areas, the natural resources abundance provided an ideal environment for human settlement within a peculiar adapted system of nomadism (seasonal movements between the summits "Almou" and the borders "Azaghar") and traditional farming and cattle-breeding (Table 1).

The fact that the Moroccan highlands were until recently less populated is noticeable. Rural population density in the Middle Atlas for example is generally under
Table 1 - An outline of land-use in the Middle Atlas at the century beginning (after Chahhou, 1992).

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<tr>
<th>seasons</th>
<th>farming works</th>
<th>breeding activities</th>
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<tr>
<td>autumn</td>
<td>labour, seeding wheat and barley</td>
<td>Herd / to &quot;Azaghar&quot;</td>
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<tr>
<td>spring</td>
<td>maize seeding in &quot;Azaghar&quot;</td>
<td>Herd / back to &quot;Almou&quot;</td>
</tr>
<tr>
<td>summer</td>
<td>harvesting</td>
<td>Grazing / forests</td>
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</table>

20 persons per square kilometre. Many mountainous parts are still human deserts. The most important villages are grouped along valleys, rivers and springs. The rural landscape shows typical adaptation to karst landforms in several cases. As reported from other Mediterranean karst areas (Nicod, 1982), the farmers seek the best potential soils, the low platforms and topographies of the karst depressions and manage adapted parcels called "Jardins du Karst", "doline-champs", "doline à terrasses" and so on. Their flat bottoms are generally cultivated (Fig. 2). However, this is the first step of land use in the karst areas. It proceeds what is seeming to be the new tendency as characterised by soil reclamation even on the rocky degraded surrounding flanks (Fig. 3).

However, the three last decades witness considerable population growth and an urbanisation process is presently active in the area as observed from examples given in Tables 2 and 3.

The valleys where traditional agro-pastoral activities were practised and the sum-
Fig. 3 - On the Ifrane plateau, the land reclamation process consists of enlargement of arable land areas, either on behalf of forests or by managing uncultivated lands using techniques of crusts' dislocation and karren substrates levelling out. The dislocated blocks are used to build long walls on the fields' limits.

Table 2 - Population increase of some rural districts in the Atlas mountain area. Source: based on the results of the general censuses of population (1971, 1982, 1994).
expansion. Among them are the following factors:

1) the abundance of water resources. The Atlas, particularly the Middle Atlas was considered to be the natural "Moroccan water reservoir" with regulated and permanent rivers and springs discharge flow. However, the advantage issued from this hydrologic factor is presently shifting as resources are already over exploited in some cases;

2) the fertile soils, mainly in the karstic depressions, where thick soil profiles are acquired from a long term carbonate dissolution and humus accumulation;

3) the population growth due to the demographic "explosion" and emigration;

4) the economic factors attributed to the higher added-value issued from modern activities. The profits resulting from modern agriculture in some mountainous areas attracted more considerable investments;

5) the increase in demand of foodstuffs due to the demographic growth and the new cultural attitudes which intensified needs to foodstuffs;

6) the commercialisation network and market development;

7) the government's encouraging acts. Many decisions oriented to support agriculture and rural development have been adopted in terms of credits, financial aid, exemption from taxes, technical assistance, etc...

3.2. Rural development and landscape change processes

Developing actions sponsored by the government, the communes and private individuals contribute intentionally to the landscape structure and change in the Atlasic karst domain. They consist of multiple irrigation projects, drinking water providing program for rural communities (The P.A.G.E.R. program), rural electrification (The P.E.R.G. program: Programme National de l'Electrification Rurale), rural disen-
clavement (rural roads network) etc... However, the most important change process appears in agriculture. Even the traditional agriculture (which is a production system evolving when the marginal productivity of labour is very low) is still dominating in the upper lands and summits of the Atlas, it is, however, gradually shifting in the western and northern Middle Atlas as intensified land use becomes a main fact.

Uncultivated lands are reclaimed and underutilised lands are subject to growing productivity actions. The last two decades have witnessed an unparalleled revolution in development, dissemination and adoption of new agricultural technology. These actions aim to develop high yield crop varieties and more efficient agriculture.

Apple trees, pear trees and peach trees are the dominant trees adopted in recent plantations. Badidi (1995) shows that within the last three decades (1964 - 1994) their area have been considerably enlarged (Table 4). Their allocated surface is approximately 22400 hectares in the province of Sefrou (including an important proportion of olive trees plantations), more than 4100 hectares in Ifrane province (fig. 4) and 9000 hectares in the Province of Khenifra. A peculiar landscape changing process has been linked with the farming development as land reclamation, crusts dislocation and resources waste took place.

Such agriculture is a highly water consumer and becomes inadequate without irrigation. Most farms are irrigated either by turned aside waters from rivers, springs, or

Fig. 4 - The main fruit trees planted areas in the Northwest of the Middle Atlas.
even by wells lowering progressively the underground water table. Such a problem is seasonally emerging in several regions (Guigou, Amekla plateau etc...), generating occasionally severe social conflicts.

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<tbody>
<tr>
<td>Immouzzer Kandar</td>
<td>200</td>
<td>926</td>
<td>1236</td>
<td>1700</td>
</tr>
<tr>
<td>Irklaouen district</td>
<td>450</td>
<td>778</td>
<td>1450</td>
<td>1882</td>
</tr>
<tr>
<td>Amekla</td>
<td>36</td>
<td>82</td>
<td>389</td>
<td>450</td>
</tr>
<tr>
<td>Ait Oumghar district</td>
<td>14</td>
<td>223</td>
<td>846</td>
<td>1400</td>
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</table>

Table 4 - Evolution of the planted area by fruit trees between 1964 and 1994 (in ha) in some districts of the Middle Atlas mountain (Badidi, 1995).

3.3. The impact of social stakes on karstic landscape degradation.

Social facets of land degradation are generally accepted in environmental studies (Blaikie and Brookfield, 1987; Johnson and Lewis, 1995). The historical and socio-political factors are important in environmental change of the Moroccan mountain including the karstic areas. A fragile land property status has been acquired from a long term history of tribes' struggles, dramatic events and sometimes agreements on landscape cuts and commons definition. However many sites of social tension are presently still existing in the marginal areas and borderlines between tribes and local communities. They are vulnerable and witness environmental adjustments depending on the historical events and acquired social equilibrium either horizontally (between different ethnic groups) or vertically (within the same tribe). In most cases, ecosystems disequilibrium is setting off as natural resources are over exploited by individuals or even groups in the absence of any governance of the community. Either agreements and conflicts on lands appropriation and land use have complex effects in terms of environmental equilibrium, leading sometimes to what investigators call the "tragedy of the commons" (Bencherifia and Johnson, 1991; Johnson and Lewis, 1995).

Several examples of such situation have been observed within the Atlas mountains. They illustrate how further the social impact may be in terms of environmental equilibrium. The case of Skoura - Mdez management project may be presented here as a typical example.

The project aimed to create a modern irrigated agriculture in Skoura depression (Province of Boulemane, Middle Atlas) at the expense of the forest domain (an area of approximately 1400 hectares). Series of enactments have been decreted since 1953 (Dahir of January the 28th, 1953; followed by a ministerial decision in June the 25th, 1959 which brought precision on criteria and procedures of land distribution). A systematic deforestation began and a network of irrigation canals have been built across the depression. The project blockage emerged soon when the conflict started between the neighbouring tribes (Aït Seghrouchem and Aït Youssi). The list of beneficiaries was prepared among retired resistants and military servicemen from Aït
Seghrouchene. That fact was not allowed by Aït Youssi who plead common rights on a land they considered to be theirs. Consequent deterioration of equipments, land degradation, soil erosion and bad-lands forming are presently active processes in the area.

4. The land use - landscape disequilibrium interface: indicators of landscape degradation.

4.1. The pedologic aspects

1. Soil types, soil scarcity and land reclamation

The physical framework of the Atlas mountains induces a noticeable soil scarcity. Most calcareous semi-arid flanks are initially without any soil cover except in fractures and local depressions. Due to climatic conditions, the geomorphic factors and the hydro-karstic activity, the thick soils are generally concentrated in the bottom of karst depressions.

On the calcareous and dolomitic Atlas flanks, most surfaces are rocky or covered by rock-debris soils, over rock layers at depths of 10 to 50 centimetres. Only in collecting topographies (karst depressions) and valley terraces, full profile soils with A, B and C horizons of more than one meter thickness can be observed.

The existing soils in the Moroccan Atlas highlands are several types. In general, the upper zone (> 2200 m in elevation) is composed of steppic soils. The middle zone (1800 - 2200 m) is mainly composed of brown forest soils and locally red-iron soils. The Terra-rossa and typical red-soils widespread however in the lower mountain and on the Atlas borders (locally known as "Dir"), due to soil erosion / deposition from the upper zones and the locally karstic activity. Such processes generate clays and red specific soils known in the Mediterranean area as "Terra Rossa", called "El Hamri" in most regions of Morocco. Their favourite locations are generally valley - terraces, topographic micro and macro depressions, diaclases, fractures, karren, lower pediments and plains forming a surrounding belt of the Atlas mountains.

The links between karstic hydrology, topography and sedimentation allow sometimes a diversity in pedologic processes. The white coloured soils observed locally in the "Dir" and on the Atlas flanks are in fact soils enriched in carbonates. Tufa and travertinous deposition, caliches and the carbonate enriched waters affect soils' colour. When dominating within the profile, such material allows the genesis of white (carbonate enriched) soils locally named "Biada".

Studies of terraces and valley deposits (eg. Couvreur, 1981; Martin, 1981) argue that most of them are either Holocene or Wurmian in age (Rharbian or Soltanian in the Moroccan nomenclature). Soil types and soil allocation in the Atlas reveal, therefore, a fragile and vulnerable equilibrium.

The present day land use and land reclamation process affect the acquired fragile equilibrium. The land reclamation consists of enlargement of arable land areas, either on behalf of forests or by managing uncultivated lands using techniques of crusts' dislocation and lapiaz substrates levelling out (Fig. 5). Such operation has been
encouraged by the government at the beginning of this decade.

The soil scarcity over the Atlasic flanks is subsequent of the initial system's dynamics within the karst areas. The genesis of irregular topography (lapiaz, dolines, uvalas, polje, etc...) tends to concentrate residual and detritic material and therefore soils in the lower sites. In order to reach the hollow sites, to reduce the field's surface roughness and to adapt it to the use of modern agricultural instruments, the surface blocks are often broken and carried out to fields borders (Fig. 3). The topography tends to be more homogenous and covered by soils recuperated from above and below destroyed rocks. Hypothetically, new basis of equilibrium should be sought by the system because new landscape, new hydrologic conditions and new human context have been imposed.

2. Soil destructuration, soil erosion and swallowing

Two directions have been observed in soil erosion and sediments transfer. An horizontal transfer from the upper to the lower areas in the drainage basin, and a vertical transfer of sediments following the infiltration and underground geomorphic networks. Concerning the first direction, it is noticeable to observe the intense soil erosion on the Atlasic flanks and in the lowest silty terraces (the Holocene terrace) along karstic high valleys. The upper Oued El-Atchane for example, in the north-east
of Boulemane city, illustrates a case where such terrace is intensely degraded. The seasonal turbid waters of the Guigou river are fed by materials of the terraces destruction. Agradation, sedimentation and pedogenesis are generally observed in the lower sites on different scales. The change in soils forming factors is registered in profiles and traced either in their texture or in their structure and their chemical components.

The vertical direction of transferred sediments is most typical of the karstic domain. Soil swallowing through ponors and fissures is becoming threatening process. The karst depressions are submitted to a vertical soil loss as they allow material transportation when surface waters infiltrate through ponors to the underground systems.

The impressive case of Dayet Chiker (Northern Middle Atlas) in the south of Taza illustrates this problem. Soil loss by erosion and swallowing, activated by the developed underground karst system (the Friouatou cavernous system) is considerably reducing areas of rain fed agriculture of the Bni Warrayn and Ghyata tribes in the polje of Chiker (Fig. 6). Even the reclaimed arable surfaces are important on the polje's borders, the evidence of the land degradation increase is given by gullies enlargement, generating degrading land mass movements on ponors' vicinities. Gullies of 200 to 300 centimetres width and 100 to 200 centimetres depth appeared during the last two decades showing the recent severe trend of soil loss. The phenomenon is accelerated by soil sliding (mainly near ponors), when the mass movement

Fig. 6. In the karst domain, the vertical soil erosion following ponors and underground networks is important. In Dayet Chiker, such erosion activates gullies enlargement and tends to generating bad-lands on ponors’ vicinities.
is conditioned by the vertical attraction of the underground karst system. Surprisingly, few farmers try vainly to maintain and conserve soil by continuous obstruction of ponors, as we viewed during our field survey in spring 1998. However the landfill and blocks piling up on the ponors did not stop soil transfer as the involved disturbance was huge and connected to the karst hydrogeology and underground karst. Land degradation is thereby controlled by a hazardous mechanical down transfer of sediments to the caves and developed underground karst forms.

Land degradation on the other hand, may be controlled by chemical processes deteriorating soil fertility. Acidified water issued from rain and surface hydrology is enriched in carbon dioxide from vegetation roots, soil organic matter or bacterial respiration. It becomes a factor of dynamic erosion and crypto-corrosion of limestone while percolating. The solution rate is enhanced and progressive enlargement of karst depressions took place. The resulting clays and soils tend to fill low topographies but further cut-down mobilises soils sink.

Most caves of the Atlas mountains have sedimentary infillings showing surface land use and soil erosion. Generally iron oxides are transported into caves as suspended particles and take the form of red wall coatings, internal alternating concentric thin layers within speleothems and clay or sandy layers on caves' bottoms. Land clearing, farming and poor forestry management have had direct effects on soil erosion - deposition in caves where red infilling materials could be more or less significant indicators of settlement and human factors.

4.2. The hydrologic indicators

The hydrologic indicators of desertification and environmental vulnerability are complex indicators (Sharma, 1998). They combine the surface water (runoff, infiltration, evaporation, turbidity changes in water flow, sediment load etc...), the ground water (sequential changes in depth to water and water quality) and the human use of the resource.

The modern agriculture that progressively developed in several points of the Atlas affects most of these indicators. It is a highly water consumer because it is not generally adequate without irrigation. As mentioned above, most farms are irrigated either by derived waters from springs, rivers or even pumped waters from wells lowering progressively the underground water table. Such a problem is seasonally emerging in several regions as in the Guigou basin and the Ameakla plateau in the Middle Atlas, where wells excavation is intensively becoming spectacular. The results of a research program we have developed in the Guigou Basin (AI-1005/95), show an important discharge decrease from the upper parts to the lower parts of the basin. The explaining factor is the agriculture use of water. In June 1998, the measured discharge in Foum Kheneq (south-east of Timahdit) was 386 litres per second (the input discharge to Guigou depression). It became 517 l/s at Titzil springs and have been entirely consumed in agriculture through the basin. No water flow have been observed in its lower parts (at Aït Khebbach hydrologic station). Comparatively, the measuring campaign of the October 1997 shows that in absence
of the agriculture activities, a general discharge increase have been observed as the
input discharge was 329 l/s in Foum Kheneg, 522 l/s at Titzil and 543 l/s at Aït Khebbach hydrologic station. Agriculture's effect water flow is, therefore, evident in spring.

The coincidence of climatic variability, droughts and human overpressure on the
resource generates sudden draw-down of the piezometric level affecting the dischar-
ge of springs and even the level of karstic lakes (Fig. 7). The Dayet Aoua lake

![Dayet Aoua lake](image)

**Fig. 7. Dayet Ifrah. The recurrent droughts and water use affect the lake level. The consequent temporal lake retreat provides fertile soils for intensive agriculture.**

(Imouzzer) dryness in 1995 illustrates such catastrophic event. It is in fact a rare
event as it is unique in the history of the lake during the century. Most springs fee-
ded by the Atlas aquifers were also affected. Some of them dried before announcing
the crisis in perspective. Aïn Chgag spring on the "Dir" for example dried up since
1985 and several indicators of a sustained hydrology have been preserved along its
valley. A series of built equipment such as non functional water mills, water dykes
(used to keep back water and prevent flooding), traditional irrigation channels
(séguias) are indicators of the intense socio-economic activity which took place in
the Aïn Chgag valley before 1985.

Under the Mediterranean climatic conditions, springs discharge variability in the
karstic system may be attributed to the physical conditions as aquifers recharge fol-
lows rain falls and snow melting. However, water use for agriculture on the plateaux
and the domestic needs should be considered because they affect the magnitude and
the frequency of the hydrologic fluctuations.

The karstic hydrologic system is also complex because the underground reser-
voirs are not linear, nor regular. They follow the underground cavernous network of conduits, joints and fractures. As soil erosion is progressively active on the surface as evoked above, the transferred soils and sediments from the surface to the underground conduits network may cause their sudden obstruction locally. Consequently a sudden dryness of its connected springs occurs, hence frightening the human communities they feed. Such explaining model has been adopted to understand the Ribaa and Ain El Atrous springs' sudden dryness in June 1981 (El Faskaoui, 1994).

Finally, the agriculture impacts on karst systems equilibrium is reflected in water quality facets. It is obvious that modern agriculture focus on productivity is based on chemical nutrients and pesticides. No apprehension has been issued for the phenomenon; but seemingly chemical degradation, sewage and fertilisation are locally potential problems of the karstic areas in the very near future.

4.3. Deforestation, quarries and karst-systems equilibrium

The Atlas highlands vegetation has been the main forest of the country. It is composed of diverse species (Cedar, Oak, *Quercus ilex*, etc...) and supports populations' life in the past. For many years, it was widely assumed that the forests never fall below an optimal level and their exploitation has grown continually for multiple purposes.

The Atlasic forests were used as summer pasture lands since several centuries. They have been the source of winter fodder for cattle. Fires, heating wood collection, charcoal making and building activities contributed also to forests degradation.

Consequently, the vegetation and its environmental equilibrium have been altered in several sites. An advanced stage of cedar degradation has been observed in the Jbel Habri and Timahdite areas (regions of Ifrane and Azrou). Even the government's program of plantation (the National Program of Reforestation), planting efforts are still unable to re-establish lost equilibrium in most areas.

The continuing growth of urban centres in the Atlas and its surrounding areas creates additional needs of lands and earth materials. The Atlasic substrates, especially the limestone and dolomite formations interested by tectonic activity are convenient for gravel mining to manufacture concrete and building materials.

In the vicinity of Sefrou city for example, the number of operational quarries exceeds presently 15, notably in the Oued Aggay drainage basin and on the Sefrou-Bhalil transect.

Quarrels expansion is becoming a considerable phenomenon and even locally a hazardous factor in terms of environmental equilibrium. In addition to the frequent atmospheric dusts coming from rock crushing, the quarries are becoming factors of deforestation and soil erosion agents, and landscape changing factors. As soon as the extraction ceases, the artificial depressions, generally left without any maintenance, become sites of waste deposition and consequently vulnerable sites of chemical contamination. Within this context, the natural environmental equilibrium and vegetation are in progressive transformation.
A strong conversion of forest areas to matorrals is observed on forest limits. The resulting matorrals are in turn degraded and submitted to reclamation for agriculture. The vegetation, forming a basis of natural defence of soils against erosion, therefore, disappears and phenomenal gully erosion becomes intensive.

4.4. Some geomorphic indicators

1. Alluvial deposits of anthropic origin: "alluvionnement anthropique"
   The alluvial deposits are settled out when the speed of water flow is no longer sufficient to carry them. Their fundamental cause could be physical or anthropic. In the last case they could be named human-induced alluvial deposits as they are attributed to the human action either in their source (origin) or at their sedimentary environment. Two types of human-induced alluvial deposits were recognised. The deposits coming from slopes' erosion as a result of land overuse and deforestation and those spreading through farms, irrigation channels (named seguia or tagua in the local dialect) and river tributaries due to artificial drainage and modern management. They are called anthropogenic as the human action is their initial forming factor. They are transported by running water from slopes and upper parts and accumulate over managed surfaces, terraces, irrigation channels and farms. They occasionally contribute to soil fertilisation when enriched in organic matter but in most cases they are rather negative in their effects. They damage irrigation substructure, equipment and agriculture land. Such negative effects are observed in the Guigou basin (Middle Atlas) for example (Akdim et al., 1998).

2. Badlands genesis in the Middle Atlas large basins
   The bad-land landforms are not directly linked to the karstic processes as their genesis is mainly controlled by the surface runoff of sufficient magnitude and duration, the substrates features, and the topographic conditions. However, their recent occurrence on a large spatial scale through the Middle Atlas evokes the question of their evolution within a present-day changing environment.

   The cleared forest and matorral resulted from land reclamation for agriculture, overgrazing by nomadic sheep and goat herds is generally an area of occurrence of rill channels and great erosion rates following rainy seasons. Human removal of natural vegetation reduces the resistance of soils to erosion and consequently reinforce the dynamics of bad-lands genesis, as observed in the Middle Atlas. In the Guigou basin for example, a spectacular bad-land is forming in the fan of Oued El Maleh and its abandoned thalweg, where several geomorphic agents act on rill erosion, material removal and deposition. The artificial canal built near the village of Aït Said attracted water drainage on its sides. The vertical erosion of its multiple tributaries contributes to the bad land formation along the canal.

   In the Skoura depression, such a change has been fundamental. In connection with the Skoura - Mdez management project failure evoked above, bad-lands are presently forming as natural equilibrium has been disturbed by deforestation and soil erosion.
The soft impermeable substrates exposed to rapid fluvial erosion is a favourable conditions of badlands formation (Campbell, 1989). As soon as the vegetal cover was eliminated, the marly substrates in Skoura depression have been exposed soil erosion. The erosion processes are, therefore, a direct natural response to the man-created deforestation.

These processes have been assessed on the basis of their nature, their location and their magnitude. The operating degradation in Skoura depression is complex. Its most important process is the seasonal sheet floods, which gradually shifts to rill erosion as incision develop. The concentration of water drainage activated rill erosion and gullies formation. The deflation is seemingly an active process in the presence of susceptible substrates, deforestation and wind velocity. No quantitative data is obtained on the aeolian process, but we observed a frequent dust-raising activity in the area, during dry periods. We assume that wind erosion, clearly contributes to particles' transfer and combine its effects to explain the geomorphic landscape genesis and evolution.

5. Conclusion

Population growth and economic factors are argued to be the dynamic factors of landscape change, and are considered decisive and causal variables of land use intensification and land reclamation in the karst domain of the Moroccan Atlas.

The karstic areas in the Atlas mountains are progressively exploited and intensively used but the equilibrium and environmental thresholds are reached and seemingly threatened in many subregions, considering their hydrologic and resources' shortage. The production capacity may be in a cascading loss whenever such thresholds are overpassed and the consequent degradation could be non reversible.

The social stakes are potential factors of environmental disequilibrium in the mountains and karst areas. They should be managed to insure optimal conditions for local development, land use, resources exploitation and environment.

At the present stage of our research efforts, land degradation and karst changing landscapes are apprehended basing on general assumptions and field observations. This provides an initial assessment. Even we note that a more detailed and systematic research is needed to find clear indicators, measure processes and develop estimation methods.

Considering recent environmental changes in the Atlas mountains, it is paramount to parallel the present day rural development and a sufficient reflection on the mountains' future status in a national framework. The mountains' latent capacities and natural constraints should be addressed to outline the limits and opportunities of the sought sustainable development.

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REFERENCES


EL FASKAOUI M., 1994 - Problèmes d'aménagement des eaux en milieu karstique: cas du Moyen Atlas. Table ronde sur la dynamique des milieux karstiques, Département de Géographie (Sâïs), Université de FES.


Th. 3e C., Toulouse 2.


NICOD J., 1982 - Paysages ruraux et formes karstiques. Mélanges offerts en hommage à Jean Miège. Université de Nice.


SUSTAINABLE DEVELOPMENT OF AGRICULTURE IN KARST AREAS, SOUTH CHINA

Song Linhua

ABSTRACT
The exposed carbonate rocks aged from Sinian to Mid-Triassic Periods cover an area of 500,000 km² in south-west China. In karst areas with spectacular landscapes characterized by magnificent tower karst and conical karst, rare surface drainage systems and prevalent sub-surface drainage systems, the environment is ecologically very fragile. The rapid increase of population, over deforested and cultivated lands, worsened the ecological system, causing a higher frequency of drought, flood and various disasters, backward economic development, low living standard of the people.

In order to improve the sustainability of the agriculture the experience shows that the following operations should be adopted: (1) serious control of the population increase, emigration, extra labours and improvement of the environmental education of the local inhabitants; (2) terracing of the slopes (shijala di) as to improve the cultivated land quality, to preserve the water, soil and fertiliser and ameliorate the effective utilisation of the land; (3) development of new rural energies such as the solar energy and gas energy, and expansion of the saving-fuel stoves to reduce the load of bio-energy; (4) reforestation and bounding the hills and mountains; the ecological, economic and fuel forests model has been developed in fengcong-depression areas: the tree species with high ecological, economical and energetic characteristics, should be chosen, such as the bamboo, wild grapes, Sapixium rotundifolium etc.; (5) better utilisation of the rain water and karst water resource to solve the water supply problems.

The karst landscape is well developed in the 500,000 km² carbonate terrain in Yunnan, Guizhou, Guangxi, west Hunan and south Sichuan provinces in south-west China, where 100 million habitants live (Song, 1997). The large population and its high density, serious deforestation, over-cultivation and fragile ecological system make the environmental problems very serious and about 30,000,000 people are now very poor.

This paper describes the measures to improve the ecological and sustainable development of the agriculture in the karst areas.

KEY WORDS: South China, human impact on karst, sustainable development.

1. Geomorphological characteristics

The karst region of South China, 500,000 km² large, is situated in the tropical and subtropical monsoon zones; its annual average temperature is 15-20°C, with a maximum of 22°C. The annual mean precipitation ranges from 1000 to 1600 mm, the
maximum being 2500 mm. Under the effect of monsoon climate, the regimes of temperature and precipitation are synchronous, hot and wet in summer, cool and dry in winter.

The carbonate rocks, with a thickness ranging from 5000 to 7000 m (Zhou Huixian, 1965), aged from Sinian to Mid-Triassic Periods and have been intensively faulted and folded by different tectonic phases. The SN, EW, NE, NNE and NW sets of faults and fractures are well developed and control the hydro-geomorphology framework.

The main types of complex karst features are the "fenglin plain", "fenglin basin", fengcong depressions", "fengcong basin", "fengcong canyon". The individual features are tower, column and conic hills, stone forest, stone teeth, karren, depression, polje, basin, sinkhole, funnel, solutional pot, top window, cave, speleothem, spring, underground river etc. (Chen Suopeng, 1954; Zeng Caoxian, 1960, 1964). In the area the three outstanding karst monuments are the Guilin tower karst, the Fengcong type deep depressions in Qibailong, Dahua, Guangxi, and the Lunan Stone Forest in Yunnan (Ford, 1997).

The intermittent intensive tectonic movement caused not only the uplifting of the Himalayan chain, but also revived the old faults in the southern China and stimulated the karst development also in a vertical dimension. Series of rejuvenated geomorphologic features have been created (Song, 1986). The geomorphologic sequence from the water divides to the main surface river (Wujiang River that is the local drain base) in a belt of 0-15 km which consists of fenglin basins, fenglin depressions, fengcong depressions including the normal and rejuvenated depressions and the hanging depressions; valleys and streams often appear by the river (Fig. 1) (Yang et al, 1976; Yang, 1988).

In the geomorphological profile from the Tibet plateau at the altitude 4000-5000 m above the sea level (a.s.l.) to the Guangxi basin about 100-300 m a.s.l. four main

![Fig.1 - Karst geomorphological series in Guizhou Plateau.](image)
Geomorphological levels are recognisable: the Tibetan-Qinghai plateau, the Yunnan plateau (1500-2500 m a.s.l.), the Guizhou plateau (900-1500 m a.s.l.) and the Guangxi fenglin and residual karstic hill plain. The conical karst landscape (conical fenglin) developed on the Yunnan and Guizhou plateaux, the fengcong – depression including the normal and rejuvenated depressions are distributed in the slope zones between the last two plateaux.

On the karstic plateaux, the surface rivers and ground water drainage systems generally with the hydraulic gradient of I-5° are well developed. The groundwater is very close to the ground surface. The natural karst lakes are well developed on the plateaux such as Puheizhai lake, 10 km² large, in Qiubei, Yunnan (Fig. 2).

![Fig. 2 - Puzhihei karst lake on the Yunnan Plateau, Qiubei.](image)

In the fengcong-depression region, the surface and rainfall waters quickly flow into the underground drainage system through the sinks and solutional fissures. The vadose zone is very thick, generally, the groundwater is tens meters beneath the bottoms of the shallow depressions and hundreds of meters under the deep depressions. Each depression constitutes an independent system. The water is collected from the conical peaks and swallowed in the depressions. Simple underground channels are developed between the depressions along the hydraulic gradient direction. In flood conditions some springs originate creeks flowing from the upstream side to the downstream side of the large depressions. In the region, the ground surface water is very rare if there is no the relative aquiclude. The natural resources are lacking and the environmental problems become more and more serious in the region.
2. Ecological and environmental problems

In the karst areas, the population is increasing by the annual natural growth rate of 1.3-2.0%. The average population density reached 159p/km², with a maximum of 280 p/km². The ratio between the population and the cultivated land becomes very high. In the “fengcong” depression region in Dahua County, the cultivated land per capita is now less than 0.007 ha (including the land with a slope >15°). The shortage of cereals and income forced the farmers to enlarge the farmland on the steep slope (Table 1). The farmland seems hanging on the steep slope of karst peaks. The forest coverage rate decreased from 30-40% before 1949 to less than 5% even 1.2% on the exposed karst hills at the present (Su Zhongming, 1993).

<table>
<thead>
<tr>
<th>Slope</th>
<th>&lt;6°</th>
<th>6-15°</th>
<th>15-25°</th>
<th>25-35°</th>
<th>35-45°</th>
<th>&gt;45°</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cultivated area (ha)</td>
<td>81.3</td>
<td>372.2</td>
<td>15968</td>
<td>39333</td>
<td>37972</td>
<td>20377</td>
<td>114037</td>
</tr>
<tr>
<td>% of the total lands</td>
<td>0.013</td>
<td>0.326</td>
<td>14.00</td>
<td>34.49</td>
<td>33.30</td>
<td>17.87</td>
<td>100</td>
</tr>
</tbody>
</table>

Table 1 - The slope of cultivated lands in Dahua County, Guangxi.

The investigation in 26 counties in Guizhou shows a serious soil erosion that took place in an area of 13,500 km², about 20% of the total surface. The accelerated soil erosion in Heizhang, Shuicheng, Wangmou, Ziyun and Leishan counties is affecting the 47% of the total area. In Heizhang county, accelerated soil erosion involves the 57.6% of the total area; erosion rate reaches 2.1 mm/a. In the period of 1957-1981, the rocky land increased 467 ha per year. In 70% of the farms in Ziyun County the cultivated fields are on steep karst hills and the soil erosion area covers 59% of the total. 17,300 ha of the rocky land, about 51% of the total area, increased from 1974 to 1982. Now the farmland is mostly degraded and rocky desertified.

After a heavy rain, the surface runoff transports soil, debris and organic materials down to the depressions and basins. The soil flow on the slope often damages the farmland in the basins and large depressions. In 1988, near 0.8 ha of rice field was covered by 1-1.5 m of debris from the hills near Xinjie, and 10% of rice and corn field have been risked by the mudflow during the rainy seasons in Bangguo, Xizhou County. In the county, the storage capacity of reservoirs has been reduced about 30-50%, and some of them have completely lost their capacity. There are 375 depressions flooded 15-90 days each year. The frequency and intensity of the flood and draught hazards have been increased (Table 2 and table 3).

<table>
<thead>
<tr>
<th>Periods</th>
<th>Serious flood</th>
<th>Serious draught</th>
<th>Serious flood &amp; draught</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Times</td>
<td>Freq. (%)</td>
<td>Reap.(a)</td>
</tr>
<tr>
<td>1957</td>
<td>8</td>
<td>1.022</td>
<td>82</td>
</tr>
<tr>
<td>1958-1979</td>
<td>6</td>
<td>2.727</td>
<td>4</td>
</tr>
<tr>
<td>1980-1986</td>
<td>3</td>
<td>42.48</td>
<td>2.5</td>
</tr>
</tbody>
</table>

Notes: Freq. = Frequency; Reap. = Reappearance.

Table 2 - The frequency and reappearance of natural hazards in Xichou County, Yunnan Province.
The storage capacity of the karst aquifer has been greatly reduced. For example, the designed capacity of the Nanquo irrigation system was 0.8 m$^3$/s with the lowest discharge of Nanquo spring in 1958. With the decrease of forest coverage from 40% to 3.8% in the karst terrain, the lowest discharge of Nanque spring has been reduced to 0.18 m$^3$/s in early 80's and 0.15 m$^3$/s at present. By the 90's, 75% of 120 pumping stations built in early 60's has lost their functions as the ground water level fell down or the springs completely dried out in the dry seasons. In Qibailong Fengcong-depression region, there were a lot of fissure springs around the depressions in the 40's early 50's when the forest coverage was over 40%. After several serious tree clearings, the forest coverage reduced to 4%, and most springs have disappeared since 80's. The depressions became very dry. At present, 12,000 of a total of 16,500 people are short of water supply.

It is very difficult to build reservoirs and develop other water projects in the depressions also because the subsoil karst and epikarst are well developed. Since 1958, in Guangxi province 1252 reservoirs have been built in the karst basins and depressions, but over 60% are dry (Table 4).

### Table 4 - The leakage reservoirs in depressions and basins in Guangxi.

- **Regions**
- **Reservoir Numbers**
- **Designed Capacity** ($x10^6$ m$^3$)
- **Designed irrigating** ($x10^3$ ha)
- **Practical irrigating** ($x10^3$ ha)
- **Practical Capacity** ($x10^6$ m$^3$)
- **Leakage reservoir (N)**

<table>
<thead>
<tr>
<th>Regions</th>
<th>Numbers</th>
<th>Designed Capacity</th>
<th>Designed irrigating</th>
<th>Practical irrigating</th>
<th>Practical Capacity</th>
<th>Leakage reservoir</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nanning</td>
<td>658</td>
<td>16.4</td>
<td>193</td>
<td>143</td>
<td>211</td>
<td>447</td>
</tr>
<tr>
<td>Liuzhou</td>
<td>279</td>
<td>7.8</td>
<td>80</td>
<td>52</td>
<td>191</td>
<td>88</td>
</tr>
<tr>
<td>Hechi</td>
<td>147</td>
<td>3.8</td>
<td>25</td>
<td>16.0</td>
<td>99</td>
<td>48</td>
</tr>
<tr>
<td>Baice</td>
<td>64</td>
<td>4.4</td>
<td>23</td>
<td>15.0</td>
<td>46</td>
<td>18</td>
</tr>
<tr>
<td>Wuzhou</td>
<td>45</td>
<td>1.1</td>
<td>12</td>
<td>9.0</td>
<td>29</td>
<td>16</td>
</tr>
<tr>
<td>Guilin</td>
<td>33</td>
<td>1.0</td>
<td>13</td>
<td>9.8</td>
<td>20</td>
<td>13</td>
</tr>
<tr>
<td>Yuejin</td>
<td>26</td>
<td>0.9</td>
<td>10</td>
<td>5.7</td>
<td>12</td>
<td>14</td>
</tr>
<tr>
<td>Total</td>
<td>1252</td>
<td>35.4</td>
<td>356</td>
<td>250.5</td>
<td>608</td>
<td>644</td>
</tr>
</tbody>
</table>

3. Improvement of ecology and sustainable development in karst areas.

The improvement of ecological system in the karst areas is the key factor for a sustainable development of the economy. The principal measures should be taken as follows:

3.1. Reduction of extra population and increase of the population quality

The over growth of population is overloading the fragile ecological system in the karst fengcong - depression areas, for instance in Qibailong, Dahua county. 16525
people live on 14030 $mu$ of farmland, in which, 13867 $mu$ are dry land with the mean specific cereals yield of 96 kg/$mu^{(2)}$. Each person only gets 81.5 kg grain per year. Based on the living standard, the grain pro capite must be 200 kg/a, that grain capacity of 14030 $mu$ land might feed about 6500 people, the rest 9000 people will be the extra. To improve the ecological system and help the people to reduce the poverty, the government must control the family planning and favour the emigration of the extra-population; now 500 people have moved to Guangdong, Hainan and east Guangxiand, 963 people to the developing region near the county town.

The population education is very low; for example, the number of the illiterates and semi-literates older than 12 years represents 50% or more of the total population in karst area. The farmers are very reluctant to accept the new knowledge and cultivation techniques and to improve the rural economy; they prefer to keep their traditional technology. The investigation shows that the annual income of educated farmers is 2 times or more higher than that of the uneducated farmers. In order to promote a sustainable development of the agriculture, it should be made a great effort to increase the number of educated people.

3.2. Establishment of different forest models on bare karst hills

To improve the ecological system on the bared karst hills, a reforestation model has been developed for the fengcong - depression region in Xichou County, Yunnan (Fig. 3).

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$^{(2)}$ The $mu$ is the basic and traditional area unit in China, $1 mu = 666 m^2$ or $1 mu = 0.0667 ha$ ($1 ha = 15 mu$).
The *Sapium rotundifolium* Hemsl is the best economic and ecological tree species (Zhang et al, 1993). It can grows 1 m a year on the bared karst with less soil in the fissures and can be used as fuel, the leaves as pesticide, the fruits as raw materials for chocolate, the wood is also good for the ship building.

Bamboo and wild grapes are good shrubs to be planted on the Fengcong hills in Guangxi. Bamboo may grow in the fissure with soil, later the roots will hold the rock and grows on the rock. It may fix leaves and sediments on the rock blocks by the roots. The bamboo is good material for processing and building industries, bamboo shoots are good food. The wild grapes are not only for ecological improvement, but also the material to make wine and drinks.

3.3. Improvement of the land quality and return of high slope land to forest

Table 5 shows that the terrace lands are much better than other types of lands, while it only can be built on the gentle slope. The *Shi Jala di* land has a high content of organic matters, may conserve the soil, water and fertiliser and benefit to management of farm in comparison with steep slope lands. If it possible "Shi Jala di" should be enlarged also in form of small terraces (Fig. 4). If the land is sloping 25° or less, it is better to arrange it as terrace land (Fig. 5); when the slope is steeper than 25°, the land should be reforested.

<table>
<thead>
<tr>
<th>Land types</th>
<th>Flat lands</th>
<th>Terrace lands</th>
<th>Slope lands</th>
<th>Shi Jala di lands</th>
</tr>
</thead>
<tbody>
<tr>
<td>CaCO₃ content (%)</td>
<td>1.0035</td>
<td>1.3269</td>
<td>1.9945</td>
<td></td>
</tr>
<tr>
<td>pH value</td>
<td>7.60</td>
<td>7.63</td>
<td>7.71</td>
<td></td>
</tr>
<tr>
<td>Organic contents (%)</td>
<td>3.1416</td>
<td>4.2158</td>
<td>5.3583</td>
<td></td>
</tr>
<tr>
<td>N Total (%)</td>
<td>0.1275</td>
<td>0.1696</td>
<td>0.2356</td>
<td></td>
</tr>
<tr>
<td>Alkalinity (%)</td>
<td>0.0109</td>
<td>0.0128</td>
<td>0.0192</td>
<td></td>
</tr>
<tr>
<td>P Total P₂O₅ %</td>
<td>0.0901</td>
<td>0.1062</td>
<td>0.1012</td>
<td></td>
</tr>
<tr>
<td>Valuable ppm</td>
<td>9.2654</td>
<td>7.5957</td>
<td>4.3385</td>
<td></td>
</tr>
<tr>
<td>K Total K₂O%</td>
<td>0.8026</td>
<td>0.9276</td>
<td>0.6016</td>
<td></td>
</tr>
<tr>
<td>Valuable ppm</td>
<td>89.0551</td>
<td>81.9100</td>
<td>63.0495</td>
<td></td>
</tr>
<tr>
<td>Slope</td>
<td>&lt;8°</td>
<td>&lt;8°</td>
<td>8-25°</td>
<td>25-45°</td>
</tr>
<tr>
<td>Soil thickness (mm)</td>
<td>&gt;100</td>
<td>40-100</td>
<td>40-100</td>
<td>10-40</td>
</tr>
<tr>
<td>Exposed rocks</td>
<td>&lt;10%</td>
<td>&lt;10%</td>
<td>10-40%</td>
<td>40-60%</td>
</tr>
<tr>
<td>Soil erosion</td>
<td>very low</td>
<td>light</td>
<td>medium</td>
<td>medium</td>
</tr>
<tr>
<td>Corn yields (Kg/μaín )</td>
<td>&gt;250</td>
<td>&gt;250</td>
<td>150-250</td>
<td>&lt;150</td>
</tr>
</tbody>
</table>

Table 5 - Land and properties of farmlands in karst fengcong-depression area of Xichou County, Yunnan

3 Shi Jala di is the local name, means the small piece of farmland surrounding by the stone walls or the fissure and the space filled with soil among the rocks may be farmed and also named as the Shi Jala di.
The strong filtration makes the land in karst depression very poor and short of some elements like P, B, Mn, Sand Cu, and the corn dies during the blossom period. In 1990 some experiments to feed with multi-elements the corn land have been carried on; the feed corn grew very well and the yield increased 25% than before.
3.4. Change of the rural energy system

The traditional rural energy is from the trees on the karst hills. The annual rural fuel requires 108,000 m$^3$ of wood, but the annual products of the forests in Xichou karst is about 60,000 m$^3$ of wood. So it is clear that the farmers over-cut 48,000 m$^3$ of wood resource as fuel. Therefore it is necessary to improve the ecological system by reducing the fuel consumption. If the wood resource consumed as fuel has to be decreased to less than 60,000 m$^3$, the ecological system will improve year by year. There are several ways to reduce the consumption of wood fuel: by reforming the traditional stoves to energy-saving stoves; by using electric energy from small scale hydropower stations; by developing gas energy; by distributing to the local people fossil chemical energy like the natural gas and the coal.

3.5. Scientific development of water resources

The "fengcong" landscape areas are usually short of water resources for irrigation for agriculture and water supply for human and livestock. In order to promote a sustainable development of agriculture and to solve the water supply problems the following techniques may be adopted:

3.5.1 - Construction of water tanks or pools

This is an efficient solution to accumulate the rain water and the runoff water, if it is possible to store the water of the temporary springs of the epikarst. This technique has been spread in the karst areas. By storing the runoff water during the rain period in double level tanks it is possible to separate the clear water in the second tank for water supply.

3.5.2 - Construction of underground reservoirs in suitable sites along the subsurface river or conduit flow

A dam may be built to seal or block the conduit or river flow; a semi-closed reservoir or complete closed reservoir is then obtained. If there are no flood problem for farm land and villages in the upper stream, a closed reservoir may be considered. For example, a 6 m high dam with a base 9 m long and 3 m thick and a top 1.8 m thick was built on the Yuezai subsurface river near the outlet. It floods 3 depressions on the upper part. About 40,000 m$^3$ of water are collected and 200 ha of rice field have been irrigated. The rice output per mu rose from 200 kg before 1975 to 600 kg after 1996.

3.5.3 - Construction of pumping stations

A pumping station may be built above underground river and karst ponds. On account of the strong fluctuation of the karst water level, the pump may be installed, e.g., on a boat. A pump was installed on rails into the karst water occurrence of Disu Subsurface Drainage in Lengguo, Duan, Guangxi. If the water level rises above a given value, the pump station may be moved into a sealed pump house.

3.5.4 - Construction of surface reservoirs

Surface reservoirs suffer commonly of leakage problem. If a cement curtain is
made around the dam, it is possible to obtain reliable reservoirs in karst basins and large depressions. In Dushan County, Guizhou 181 pumping stations were installed up to irrigate 17,940 mu of rice field.

REFERENCES


LU Y., 1976 - Karst in China (Picture album). Shanghai Scientific and Technical Publisher.


KARST AND AGRICULTURE IN AUSTRALIA

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ABSTRACT
Much of the development and degradation of karst lands in Australia has occurred in the last two centuries since European settlement. Recent prolonged El Nino events add further climatic uncertainty and place real constraints on sustainable agriculture. The lower southeast of South Australia is perhaps the one area in Australia where karst, and particularly karst hydrology, impinge on the daily lives of the community in that pollution and overexploitation of the aquifer are readily apparent to the local population. Effluent from intensive dairy farms, piggeries and cheese factories enters the karst and has caused concern over pollution of water supplies. Human impacts on the Mole Creek karst of Tasmania have been well documented. The principal recent impacts on the karst are associated with land clearance for farmland, forest cutting for timber, road building, refuse disposal and associated hydrological change. There is similar evidence of agricultural impacts on karst in central New South Wales, with clear evidence of vegetation clearance and soil stripping on the limestones at Wellington, Orange and Molong.

KEY WORDS: Australia, human impact on karst, water pollution, soil erosion.

1. Introduction

Forest clearance in the extensive karsts of Europe and Asia has been undertaken to obtain land for agriculture from Mesolithic and Neolithic times to the present. The process of extreme land degradation known as rocky desertification thus has some antiquity (Williams, 1993). In contrast, much of the degradation of karst lands in Australia has occurred in the last two centuries since European settlement. Karst only occupies about 4% of the land area (Fig. 1; Jennings, 1975; Gillieson & Spate, 1998), with four main groups being present:
- Impounded karsts in Ordovician, Devonian and Silurian rocks of the Eastern Uplands and Tasmania;
- Karst plains on Precambrian and Cambrian limestones and dolomites of northern Australia;
- Karst on Quaternary and late Tertiary dune limestones of the coastal fringe of southern Australia;
- The Nullarbor karst developed in Oligocene to Miocene limestones of the Eucla basin.

In this account we will concentrate on those karsts which have been most subject to agricultural land use.
1.1. Eastern Uplands

Although both the Chillagoe and Mount Etna areas properly belong to the Eastern Uplands, both areas stand up out of the surrounding landscapes as residual towerkarst and mogote forms. The remainder of the one hundred-odd cavernous karst areas of southern Queensland, New South Wales and eastern Victoria are karst barees - small impounded karsts mostly recessive in the landscape. The limestones are Palaeozoic, chiefly Silurian or Devonian, and are the remnants of limestone deposits emplaced during a number of orogenies in the Tasman Mobile Zone. However, it appears that carbonate deposition was limited in extent and the cycle of uplift, deformation and dissection has both removed and revealed small patches of limestone (Osborne & Branagan, 1988).

These impounded karsts are amongst Australia's best known and studied areas and include well-known areas such as Jenolan, Wombeyan, Yarrangobilly and Cooleman Plains, all in New South Wales, and Buchan in eastern Victoria. This depth of study is largely the result of the peculiar population distribution in which the vast majority of Australians live southeast of a line between Newcastle and Adelaide.

The Tasmanian karsts, largely in Ordovician rocks, also belong in the Eastern Uplands. There are over 150 karst areas recorded (Kiernan, 1996). Tasmanian caves
are particularly well developed due to the larger range of local relief, more effective and greater amounts of rainfall and the fact that dolerite sills have protected the limestone high on the valley sides. Many of the caves there bear witness to the effects of multiple glaciations (Kiernan, 1984a). The extensive karst of Mole Creek in the north has been cleared for farms as well as for forestry, while the Junee-Florentine karst is still mostly forested (Eberhard, 1994).

1.2. Southeast South Australia

Horizontally bedded Oligocene to Pleistocene limestones underlies the southeast of South Australia and a small portion of western Victoria. These limestones are highly permeable and possess a wide array of karst features including some highly spectacular cenotes (Grimes, 1994). Although the land use is radically different, the area is broadly similar to the karst of the Yucatan peninsula. Much of the cave development appears to have taken place at times of lower sea levels and scuba divers are now discovering faunal remains and well decorated caves dating to the last glaciation. The lower southeast is perhaps the one area in Australia where karst, and particularly karst hydrology, impinge on the daily lives of the community in that pollution and overexploitation of the aquifer are readily apparent to the local population (Emmett and Telfer, 1994). Effluent from intensive dairy farms, piggeries and cheese factories enters the karst and has caused concern over nitrate pollution of water supplies. The area also produces some of Australia’s finest red wines from grapes grown on the terra rossa soils at Coonawarra and Padthaway.

In common with most areas of Australia, these karsts are characterised by a low rainfall and a high level of climatic variability (Fig. 2). While the continental core can experience coefficients of variability (C.V.) of rainfall of up to 50%, even the coastal karsts experience 20-30% C.V. Droughts of up to six months are common, depressing groundwater levels by several metres, while high summer temperatures stress vegetation and fauna. Recent prolonged El Nino events add further climatic uncertainty and place real constraints on agriculture.

Previous work on the impact of agriculture on karst in Australia is limited. Kiernan (1984b, 1989, and 1996) has made by far the greatest contribution for the karsts of Tasmania, while Gillieson (1989) has provided a brief overview of land use impacts on mainland karst. Grimes (1994) has described the nature of the syngenetic karst of Southeastern South Australia, while Emmett and Telfer (1994) have provided details on water pollution in karst in that region. But much of the record is anecdotal and data are few. The conference proceedings of the Australasian Cave and Karst Management Association also provide some examples of specific impacts.

2. Changes to water quantity and quality

2.1. Surface water impacts

The removal of natural vegetation cover causes changes in karst hydrological
regimes, particularly by disrupting storage and release mechanisms in the regolith. Fire associated with hazard reduction in agricultural areas can cause sealing of the epikarst, reducing infiltration capacity, so that surface waters may pond, and runoff may carry high sediment loads, eventually impacting on groundwater quality (Holland, 1994). In Mole Creek, Tasmania, mobilisation of sediments after clearing has meant that conduits become choked, so that flooding of pastures during the winter months has rendered these areas unusable for many months of the year (Kiernan, 1989).

Recharge rates are affected by removal of the native vegetation cover and replacement with crops, plantation forests and pastures. In the Southeast of South
Australia there is quantitative evidence that areas under mature pine plantations have no significant recharge, whereas recharge, probably in excess of that which occurred before European settlement, does occur under pasture (Allison & Hughes, 1972; Colville & Holmes, 1972). Speleothems at both Jourama and Yarangobilly, NSW have been damaged by dehydration and/or re-solution since the planting of pines above caves, pines having greater evapotranspiration and canopy interception than native vegetation. At Naracoorte in South Australia, thick mats of pine roots from a 90 year old plantation had intercepted cave air space, and many decorations had dried. Logging of these pines resulted in a regeneration of speleothems, and refilling of rimstone formations (Kiernan, 1988).

Irrigation dams have been built on or adjacent to karst, drowning many features and completely altering hydrological regimes. A large, shallow irrigation dam was built to supply tobacco farmers on the New South Wales/Queensland border, completely drowning the Texas Caves system (Gillieson, 1989). These caves are now only accessible by divers, or during long periods of drought when falling water levels expose some cave entrances, but even then, many of the caves and their surviving contents have been damaged by thick coatings of mud. Similarly, the caves beneath Burrinjuck Dam, New South Wales are now drowned and largely inaccessible (Jennings, 1983).

The most spectacular example of agriculture impacting on surface drainage at a large scale can be found in the Southeast of South Australia. This area was first settled in the 1840s, however, settlement was typically scattered into isolated pockets on high ground. This settlement pattern was a direct result of the karst topography. Natural drainage is impeded by extensive strandlines running parallel to the coast, the water table occurs close to the surface, and rainfall is relatively high. This resulted in between half to three-quarters of the land surface in any given area being seasonally waterlogged or flooded, and water was reported to pond in vast sheets, up to a maximum of 3-4 m deep, behind the dunes. The early settlers felt isolated and forgotten, and their cries for a drainage scheme to improve the productivity of the land apparently went unheard by the South Australian government. So strong was the despair of the settlers, that they soon proposed secession from the rest of the State (Williams, 1974).

In 1863, the South Australian government, eager to prevent the loss of potentially valuable lands from their estate, began a piecemeal approach to drainage, firstly to improve road access, but later to open up grazing land. A combination of administrative ineptitude, poor financial management, technical difficulties and general apathy meant that for nearly 80 years a series of ineffectual drainage programs were undertaken, most without significant improvement, except in localised areas. It was not until the late 1940s, that effective drainage took place (Fig. 3). Drainage has uncovered 53% of formerly flood-prone lands and has resulted in the alteration of surface flows, allowing agricultural improvement to the detriment of the wetland ecosystems that once were so widespread.

Jones (1978) reports that since the completion of the drainage scheme, only 11.2
% of the original wetlands remain and of these only 1.3% are reserved. Along the southern coast, approximately 1800 hectares of swamps, characterised by lines of spring lakes and surrounded by peat fens, were drained, burnt and ploughed for soldier settlement schemes following the Second World War. The two largest remnants, Piccaninnie Ponds and Ewens Ponds are now reserved. Since the swamps have been cleared, there has been a change in the composition of the dominant aquatic plants. Exotic plants such as *Rorippa nasturtium-aquaticum* have been introduced and these are out-competing the native species, with at least one species now locally extinct. Nutrients levels are steadily increasing in the ponds, while chemical sprays are being used to control plant growth in associated drains. Water levels at Ewens Ponds have been permanently lowered by at least 1.5 m from original survey levels. Given that these wetlands are recognised as having high natural heritage values, the negative impacts of agricultural development are of continued concern.

### 2.2. Groundwater impacts

Karst aquifers are highly susceptible to groundwater pollution. This is because pollutants can easily and rapidly pass into and through the aquifer with minimal filtration, and with insufficient time for natural degradation (Tranter et al., 1997). Even where contamination sources are localised (point source pollution), the impact of these pollutants are often widespread. This is due to the interconnectedness of the flow paths in karst which allows pollutants to spread across the aquifer. Thus it is possible to detect pollutants in areas of the aquifer far removed from the initial source (Pasquarell & Boyer, 1991). The speed at which contaminants can pollute a karst...
aquifer are highly variable, and depend on vegetation and soil cover, as well as rainfall patterns and the nature and extent of water transmission through the aquifer.

Blockage of cave and doline entrances are a common occurrence in agricultural lands on karst. For property owners, these openings and depressions represent a potential hazard to stock, and reduce the value of grazing land. Regrettably, in many instances this has lead to the deliberate infilling of these features with agricultural and domestic waste. There are numerous examples of refuse sites being located within karst depressions, and causing point source pollution. At Wee Jasper, in New South Wales, the entrance to Dip Cave has served as a rubbish dump for the local community (Jennings, 1983), while the Heywood municipal tip in western Victoria is located on, and completely infills Dyes Cave (Davey & White, 1986). At Borenore Caves also in New South Wales, dolines have been used as rubbish dumps and an old grike has been used as a sheep dip, the latter probably releasing arsenic into the groundwater (Holland, 1991). Farm refuse has also been dumped in numerous sinkholes in the Mole Creek area, including drums of the chemical 2,4-D, prompting the site to be named 2,4-D Cave by local cavers (Kiernan, 1989).

Coliform counts in excess of 30,000/100 ml have been recorded at Mole Creek in Tasmania, which is well above standards for human contact. Preliminary investigations indicate that livestock are the main source of this contaminant. Cattle also have unrestricted access to surface waters in some areas of Mole Creek, causing degradation of the stream banks as well as adding faecal contamination. (Kiernan, 1989). There is also anecdotal evidence that the groundwater pollution at Mole Creek has lead to abnormal rates of human health problems in the local area (Lichon, 1993). Thousands of sheep carcasses were dumped into Earl’s Cave in Southeast South Australia, following a major bushfire in 1959. Over 20 years later, putrefied remains were still present, and the water in the pool was still highly polluted and considered hazardous to human health (Horne, 1993).

The incident at Earl’s Cave is regrettably not an isolated event, and rubbish and wastewaters have been disposed directly into the unconfined aquifer of the Southeast karst for over 100 years. Waterhouse (1977) reported that nitrate is the most significant contaminant of the area, and the sources include derivatives of animal wastes and dairy industry wastes. He developed a contour map of the nitrate concentrations which showed the highest concentrations to be around the city of Mount Gambier, and in the coastal plains to the south, but the entire aquifer is essentially contaminated to some degree (Fig. 4). Levels of nitrate in the groundwater appear to be generally increasing and it has been suggested that point source pollution has played a minor role with as much as 89% of the nitrogen load coming from diffuse sources (A. G. Consulting Group, 1990).

There are thought to be hundreds of contamination plumes in the Southeast, varying in size, nature and range of contaminants. The Mil-Lei cheese factory used an old well as a liquid waste disposal site for over 80 years (Emmett & Telfer, 1994). Groundwater monitoring at the site shows that a pollution plume about 1.5-2 km in length is present downstream of the factory (Fig. 5), and that it has migrated at a rate
Fig. 4 - Contours of nitrate concentration in karst groundwater, South East District, South Australia. From Waterhouse, 1977.

of 40 m/yr. A cheese factory at Mount Schank, closer to the coast, also disposed of liquid wastes down excavated pits, exposed solution joints and wells (Emmett & Telfer, 1994). Gas and polluted groundwater was evident some distance from the factory and have moved rapidly through karst voids, presumably forming another pollution plume.
From the 1970s, agriculturally based industries in the Southeast, including the Mil-Lel cheese factory, adopted waste-spreading techniques in an attempt to reduce loadings of contaminants likely to leach or drain directly into the groundwater. Wastes from some intensive animal industries, dairies, piggeries, saleyards and abattoirs are now disposed of by spreading them on agricultural land. While in some instances the desired effect has been achieved, there are numerous instances where waste-spreading has continued to add to the pollution problems of the Southeast by contaminating the groundwater with nitrates and faecal bacteria. However, these contaminants are currently not migrating far from the point source, and are undoubtedly causing further pollution plumes to develop within the aquifer.

At the Mil-Lel cheese factory, several monitoring wells show nitrate concentrations between 20-60 mg/l, while another within the original plume shows levels up to 300 mg/l still present. At the Naracoorte, Millicent and Mount Gambier saleyards and at a piggery near Padthaway, waste spreading systems are causing contamination leading to escalating nitrate levels, with some sites having levels well above recommended limits. At a piggery near Myora waste-spreading is occurring over a pine
plantation, where there is essentially no recharge to the aquifer. While this appears to be a successful method of waste disposal in this instance, the effect of harvesting when the pines mature is uncertain.

Livestock farming and plantation forestry are not the only agricultural activities to directly impact on karst groundwaters in Australia. Of all the groundwater extracted from the unconfined aquifer in the Southeast, more than 75% is used for crop irrigation. In the Padthaway region, there is concern that these supplies are being overutilised and salinity problems are occurring (Smith 1989). The Murray-Darling basin, which includes a carbonate aquifer sequence from which groundwater is being extracted, is also suffering from widespread salinity problems. A burgeoning viticulture industry in the Southeast and around the western tablelands of New South Wales, and the Margaret River region of Western Australia are placing heavy demands on groundwater supplies. Evidence is only just coming to light to suggest that groundwater supplies in these regions are being significantly depleted.

Agricultural impacts on the karst hydrology of the southeast of South Australia have now been recognised for some time, and local authorities are now working towards protecting and restoring the aquifer. While conditions appear not to have significantly worsened in recent years, there are still many problems to overcome. Generally landholders in both the public and private sector are becoming more aware of the implications of living on karst, but the pollution plumes still remain and are likely to do so for many hundreds of years.

3. Increased sedimentation on karst and caves

The residual soils of limestone areas in Australia have accumulated over long periods of earth history, where climatic conditions suitable for soil development have been short and the droughts leading to soil profile reduction have been the norm. The episodic nature of landscape processes on this dominantly dry continent produce pulses of sedimentation separated by long periods of minor reworking. The limestone soils are shallow, nutrient poor and that nutrient reserve is inextricably bound to soil humus. Simple clays and sesquioxides with little surface charge dominate the residual soils. Thus any erosion will lead to severe depletion of the edaphic properties of the soil.

Apart from these residual soils, many karsts have partial cover of transported soils due to a variety of geomorphic processes including fluvial transport, aeolian processes, mass movements, and cold climate conditions. In Tasmania the legacy of multiple glaciations is seen in the mantles of periglacial deposits and alluvium covering karsts (Kiernan, 1984a). These are often coarse textured, being derived from dolerite. Deep Tertiary weathering mantles overly many mainland karsts, and are very susceptible to erosion once their stabilising vegetation cover is disturbed. The development of subjacent collapse dolines in such deposits (Fig. 6) is widespread. There is thus a crucial link between landscape stability and vegetation cover on karst in Australia. Richards and Ollier (1976) record up to one metre of sediment deposi-
tion in a cave in the Florentine Valley, Tasmania following clearfelling. At Jenolan Caves in NSW, Murray et al. (1993) have used fallout radionuclides to determine the origins and rates of sedimentation in the karst hydrological system. Following clearance of native forest for pine plantations in the early 1950s, sedimentation rates increased to $35 \pm 14\text{mm/a}$ from an estimated post-1939 rate of $10 \pm 3\text{mm/a}$. Much of this increase can be attributed to the effects of intense rainstorms eroding newly established road networks in the plantation.
Human impacts on the Mole Creek karst of Tasmania have been well documented by Kiernan (1989). The area is used for dairy cattle and sheep grazing, forestry, and quarrying of limestone for agricultural lime. The principal recent impacts on the karst are associated with land clearance for farmland, forest cutting for timber, road building, refuse disposal and associated hydrological change.

The principal impact on the karst at Loatta has been the clearance of natural vegetation and conversion to pasture over a large area of the polje floor and the nearby terraces of the Mersey River. There is abundant evidence of increased sinkhole development (Fig. 4) since clearance occurred. Kiernan (1989) considers several relevant factors. First, removal of the forest has reduced evapotranspiration leaving more soil water. Secondly, removal of tree stumps has reduced the binding agency of tree roots that stabilise the regolith overlying the limestone. Thirdly, increased soil water flow has abstracted soil fines and led to partial infilling of solution cavities and some caves. After heavy rain or the passage of a large animal, sudden failure of the ground has occurred. Runoff from impermeable road surfaces has also accentuated sinkhole development. The combination of increased runoff and impeded drainage has led to flooding of sinkholes and winter loss of available pasture on nearby flooded areas. Recent deliberate attempts to impede sinkhole drainage, and the use of allogenic irrigation water, have also changed the water balance. On steeper ground land clearance has increased soil loss, leading to some localised stripping and exposure of subsurface karren on sites such as the Dogs Head area.

There is similar evidence of agricultural impacts on karst soils in central New South Wales. Gillieson (1989) briefly described clear evidence of soil stripping on the karsts of central New South Wales, at Wellington, Orange and Molong. At Wellington rabbit bones in deep colluvium suggest a deposition date after 1865, when the animals were introduced. Frank (1972) noted the presence of an historic hearth at a depth of 40 cm in cave sediments at Arch Cave, Borenore, and NSW, suggesting significant deposition in the last century. There is also evidence of widespread alluvial deposition in nearby Tunnel Cave. Holland (pers. comm.) has noted the exposure of subsurface limestone pinnacles and grikes by soil erosion on cleared land at Borenore, whilst under relatively undisturbed eucalypt woodland no such soil stripping is evident. This relationship between exposed subsurface solution forms and land clearance is evident at other karst areas in central and southern New South Wales (Gillieson, 1989).

At Moore Creek, near Tamworth in the Northern Tablelands of New South Wales, Holland (1990) has recorded agricultural impacts on karst. The land has a long history of cattle grazing. Solution runnels exposed by soil surface lowering are widespread, as are terracettes on the cleared limestone hill. Solution pipes at grike intersections are infilled with soil. Other recorded impacts include the removal of limestone for lime burning, rubbish dumping and weed establishment on the cave reserve. Within Moore Creek cave, extensive pits occur due to exploration for guano deposits, and a bat colony has declined to the point of local extinction. This is also the case at the Ashford Caves near Glen Innes (Eberhard and Spate, 1995) as well as
inwashing of large volumes of surface soil from nearby irrigated tobacco crops.

Australian limestone soils are nutrient poor in comparison to those of the younger continents (CSIRO, 1983). In most cases nutrient concentrations decline exponentially with depth, with the highest proportion in the surface 1-5 cm. Thus the nutrient reserve is easily and severely depleted by modest erosion, and in many karst areas that erosion occurred in the nineteenth century with initial clearance and intensive use prior to the introduction of artificial fertilisers. Thus many karst areas are in a state of vegetation recovery with depleted soil resources and depauperate soil seed banks. In many karsts, the open forest or woodland dominated by species of Eucalyptus has an open understorey of grass or scattered shrubs. Continued grazing creates compaction, minor rill erosion and few seedlings survive to maturity due to grazing. This is especially true for understorey shrubs, which provide an important habitat for native birds. Native perennial grasses, such as *Themeda australis* and *Danthonia caespitosa*, are displaced in favour of exotic grasses such as *Phalaris aquatica*, *Briza maxima* and *Lolium perenne*. These ruderal species provide dense cover but can prove less resistant to drought, leading to periodic cover reduction and accompanying erosion. Rabbits are also a key factor in vegetation cover reduction, and the recent introduction of Rabbit Calici Virus (RCV) by the CSIRO has led to spectacular declines in their populations, especially in less humid areas. The long-term effectiveness of this biological control is unknown, and it has not spread with maintained virulence in the humid areas such as eastern New South Wales and Tasmania.

Fire management on limestone areas is a contentious subject, especially when severe wildfires have previously caused loss of life or property. In many areas fire has been widely used as a vegetation clearance tool. Most karsts have a low natural fire frequency due to the shielding effects of limestone outcrops, reduced ground cover and often a denser canopy with rainforest elements in the flora. In some karsts of eastern Australia, natural fire frequencies are poorly documented but the fire interval may be 35 to 50 years or greater (Williams & Woinarski, 1997). Under these conditions relict vegetation types may survive, for example the rainforest understo- reys of karsts in central NSW. In these karsts sediment transport only occurs immediately after fires, with minimal soil erosion in the intervening periods.

Hazard reduction burning is widely used by land managers, but may have deleterious effects on karst areas. In Australia for example many authorities aim to burn individual areas on a five to seven year cycle. This increased frequency reduces the fuel load but often promotes more fire tolerant vegetation, or changes the vegetation understorey. Thus there is potential for changes to the hydrology of the underlying karst particularly if highly organic surface soils or peat are burned. Although there may be a management prescription to avoid burning limestone outcrops, unplanned escape of fires into sensitive areas occurs due to weather changes. Increased stream siltation and cave sedimentation may result. A careful zoning of fire management, aided by mapping of past fire boundaries with buffers around karst areas, may help
to reduce these impacts. Historical fire records using mapped data and oral histories are another valuable resource in this regard. The study of fire histories using sedimentary charcoal in caves is a promising avenue for research (Holland, 1994).

Fire is also a potent geomorphological process on limestone areas. The direct heating effect of a fire on limestone causes the removal of the rock surface as shards, which may be incorporated into the soil profile as a stone line (Holland, 1994). In tropical Australia repeated firing, on an annual basis, has caused the blunting of rillenkarren edges and the accumulation of a talus at the base of limestone bluffs. At Bendethera, NSW, fire tolerant Acacia covenyi thickets on the limestone concentrate heat close to the rock surface promoting spalling. At Mount Schank, South Australia, extensive karst pavements due to soil stripping are the products of an extensive and intense bushfire in 1939 (Holland, 1994).

4. Cave and karst ecosystem degradation

In Australia, the study of karst ecosystems has been slow to progress in all but a few cases, and for many areas, baseline surveys have not yet been undertaken. This poses a problem in many agricultural areas in that little is known of the nature of the ecosystems prior to European settlement, and consequently, many species may have already been lost or populations altered without prior knowledge. However, evidence is steadily building to suggest that present-day karst ecosystems are being adversely impacted by agriculture. The main processes that have been identified as having actual or potential impacts include:

- clearance of native vegetation and replacement with exotic species which alters food supplies and may cause alterations to cave climates such as desiccation;
- changes to hydrological regimes including altered flood regimes and changes to water table levels, and
- changes to water quality including increased turbidity, nutrient enrichment and the introduction of chemical pollutants.

These processes are thought to have impacted on fauna by causing losses of taxa, declines in the geographic distribution of cave communities, alterations to community composition, and alterations of community processes (Eberhard & Spate, 1995; Eberhard & Hamilton-Smith, 1998).

With the exception of guano from bats and cave-dwelling birds, caves ecosystems are largely dependent on external food sources. As cave environments are slow to change and relatively predictable, these ecosystems are highly vulnerable to external events, even those occurring at some distance from the cave. Clearance associated with agriculture has caused disturbances to surface environments that have affected the type and amount of food entering caves (Clarke, 1997). Clearance has either been followed by deliberate planting of exotic vegetation, or has created disturbance regimes encouraging the invasion of weedy exotics. This may mean that favoured food types are no longer available, and the new alternatives may not be palatable to the
The loss of leaf-litter input by conversion from forest to pasture may also be detrimental to some cave fauna. Organic inputs into the cave systems may be increased in runoff from pastures, which may favour some species, but not others. Clearing for pasture may also reduce foraging habitat for bats, causing them to abandon roosting sites and consequently decimating guanophilic communities, while causing an increase in surface insect populations, which may then have implications for the land users and their crops. There is also the potential for the dispersal opportunities of terrestrial cave species to be severely reduced, if not completely severed by conversion from forest to pasture. (Eberhard, Richardson & Swain, 1991). Changes to cave microclimates may be brought about by vegetation clearance by altering moisture regimes. Water pollution can also impact on the gas content of the air. For fauna dependant on a particular climatic regime within a particular microhabitat, this can have devastating effects (Kiernan, 1988). Exotic pine plantations in South Australia have been found to cause dramatic changes in the level of the local water table and in cave climates. Spate (in NPWS, 1983) found qualitative evidence that caves under pines at Yarangobilly, New South Wales, have less recharge, and that cave fauna diversity and abundance are reduced in comparison to areas under native vegetation cover. These factors undoubtedly alter the environmental factors governing the location and extent of various cave fauna communities.

Changes to the hydrological regimes of karst areas have also been detrimental. When the Pike Creek Dam flooded the Texas Caves, one of the two known species of troglobitic silverfish was lost, reducing the known diversity of these animals by half (Eberhard & Spate, 1995). Flooding of Burrinjuck Dam has also wiped out terrestrial communities, causing the abandonment of the caves by bats, which has impacted guanophilic communities and caused a reduction in biodiversity.

Changes to stream flows whether an increase or decrease in flow rate and timing, are also of concern. Doran et al (1997) suggest that changes to natural flood regimes are potentially catastrophic to associated fauna when relatively minor floods occur at unusual times, or there is an absence of floods at the expected time. Root-mat fauna of the Leeuwin-Naturaliste Ridge, Western Australia, are under threat from watertable lowering, which is due to groundwater extraction for irrigation, stock watering and consumption by rural communities (English & Jasinska, 1998). As a consequence, these Leeuwin-Naturaliste communities which are amongst the most species-rich in the world and which contain species with Gondwanan affinities, have been listed as critically endangered.

Increased turbidity in the recharge waters of disturbed karst catchments can lead to the deposition of clays into gravel-floored cave streams. This has presumably lead to a loss of the interstitial habitat and the decline or extinction of species which were adapted to living there. Scouring of organisms with increased sediment yields is also likely during flood events. These impacts have been recorded from plantation areas in Tasmania and in caves downstream of mine sites (Clarke, 1997) and so are likely to also occur in areas under pasture.
Clearing and fire cause the release and leaching of nutrients from the surface, leading to elevated nutrient loading in karst streams and contamination of groundwaters. This encourages bacterial multiplication, fungal growth, and in surface waters, algal blooming. Such abnormal growth situations generate high pathogen and toxin concentrations. This may cause localised extinction or reductions in species richness and biodiversity, particularly amongst highly specialised stygobionts. High nutrient levels will favour opportunistic 'polluted' water species, which may out-compete the endemic fauna (Pasquarell & Boyer, 1991).

Eutrophication is the single greatest threat to the groundwater communities of the Southeast of South Australia. Extant stromatolite communities have been found on the walls of cenotes (water-filled sinkholes) south of Mount Gambier. These communities of great significance, particularly because an exceptionally high diversity of morphological types have been recorded, and also because of the associated stroma-

tolite-building microbial communities, which are essentially unique to each location (Thurgate, 1996). As mentioned previously, nitrate levels in the groundwater have been increasing for some time, causing an increase in the abundance and persistence of planktonic and benthic algae, especially cyanophytes (blue-green algae) which compete with the stromatolites for resources.

In the cenote known as The Sisters (Fig. 7), phytoplankton blooms are so intense in the first few metres of water during summer months that visibility is extremely

Fig. 7 - Aerial view of The Sisters cenote near Mount Gambier.
poor, and at depth, no detectable light penetrates. Undoubtedly this interferes with photosynthetic processes in the microbial communities, and may have caused significant changes to species composition on the stromatolite surfaces. It is also possible that depositional processes, which are responsible for the ‘growth’ of the stromatolites, are halted during these times. In other cenote lakes, phytoplankton blooms in the water column may not be as intense, however, in Gouldens Hole and many other cenotes, thick sheets of filamentous benthic algae drape over the stromatolites and this probably has the same effect. Run-off laden with agricultural fertilisers has also caused eutrophication in Lake Clifton, Western Australia, producing algal blooms that are reducing available light levels and directly smothering the stromatolites (Eberhard & Hamilton-Smith, 1998).

Apart from the impacts of high nutrient levels, chemical pollutants such as insecticides and herbicides (Kiernan, 1989) can also adversely affect groundwater ecosystems. The chemical control of weeds on the surface of the karst may introduce undesirable compounds into the soil, surface waters and groundwater. This may change or destroy the balance of the natural faunal communities. Using baits and poisons on the karst surface to control feral animal populations could also potentially impact on cave populations if these materials seep underground.

5. Conclusions

The evaluation of the impacts of agriculture on Australian karsts needs more work, for at present few empirical studies have been made. With the exception of southeastern South Australia, little monitoring of karst groundwater has been carried out. Two major areas of change have long term implications for this issue:

5.1. Implications of changing land use and agricultural restructuring

Australian agriculture is in the throes of major change, necessitated by increased environmental awareness and changing international markets for the commodities that have been the mainstay of the national economy. This is manifest in several key areas:

• The introduction of “smart farming” techniques, including minimal tillage, laser levelling of fields, more efficient water use, and limited use of fertilisers and herbicides, are all factors that in the long term will reduce the pressure on karst resources.

• The growth of Landcare groups in most rural areas can be viewed as a very positive move to promote a responsible, informed “grass roots” approach to land management. Such groups frequently seek the advice of qualified karst managers for training and specific advice, for example at the Borenore karst in NSW.

• The increased use of irrigation to produce high value crops is equivocal. Many new operations use flood irrigation within large bunds. These use more water and evaporation can be high. However a move away from traditional dryland farming may reduce the erosional impacts of drought conditions. Catchment management officers have now been appointed in many areas, and their monitoring programs will
ultimately reveal the effects of these changes on karst hydrology.

- There has been a profound demographic change in rural areas, with an ageing population and widespread amalgamation of farms. More properties are owned by companies who appoint managers and are better capitalised. Such operations are more likely to innovate and seek the advice of professional karst managers.

5.2. Implications of climatic change

Australia is climatically a very variable continent. Even in the relatively well-watered coastal regions, the coefficient of variability of rainfall is often as much as 20%. For karst areas, this means quite dramatic fluctuations in water levels on a seasonal or annual basis. Increased extraction of karst groundwater for irrigation may severely impact on cave fauna, as well as promoting increase sediment transfers underground. Drought-breaking rains are often of high intensity, producing a pulse of sedimentation from catchment areas that have reduced vegetation cover. Predictions of net primary productivity under global warming by Henderson-Sellers & Blong (1989) suggest that coastal areas in southwestern Australia and the coastal fringe of southeastern Australia may experience reduced or more variable vegetation growth, which may exacerbate the problem. Increased bushfire risk under dry conditions may also destabilise the land surface resulting in increase erosion. It is therefore imperative that catchment management is undertaken with this future uncertainty in mind, so as to minimise the effects of increased climatic variability on altered karst geomorphic regimes.

REFERENCES


KIERNAN K., 1996. An atlas of tasmanian karst. Tasmanian Forest Research Council,


LAND USE IN THE TROPICAL KARST - THE CASE OF PERUAÇU, JANUÁRIA AND JAIBA; SE BRAZIL

Heinz Charles Kohler, Sergio dos Anjos Ferreira Pinto and João Francisco de Abreu

ABSTRACT
The karstic regions of the municipalities of Peruaçu, Januária and Jaiba present a variety of soil uses which are a function of the organization of the karstic relief. This relief system forms a rift, which received fluvial sediments deposition from the São Francisco River. The horst of the Peruaçu plateau is developed on limestone rocks of Late Proterozoic age with a high concentration of calcium carbonate. The South American Surface was formed on this and is today occupied by cattle ranching. In the graben, due to easy irrigation from underground karst waters and because of the nearby drainage system of the São Francisco River, a mechanized and specialized farming system has developed. The change in the management of cattle breeding and in traditional farming methods has had a substantial impact on the economic structure of the community and also on the karst itself.

KEY WORDS: Brazil, land use, human impact

1. Introduction
Brazil’s continental area of approximately 8.5 million square kilometers, between the parallels 6° 16' lat. N and 33° 45' lat. S, presents different karstic systems due to lithological and hydrological differences (over a wide climatic range). Because of their extent and importance, the karstic scenarios which developed over calcite and dolomite rocks of Late Proterozoic are prominent. The main karstic landscapes are located on Craton de São Francisco, in the surrounding areas in the states of Minas Gerais, Bahia and Goiás, and also in the Arc of Borborema, in the states of Mato Grosso do Sul and Mato Grosso.

The limestone outcrops make up approximately 5% to 7% of the total area of the country (Karmann, 1994). If covered karst is included, this percentage would increase considerably. In areas of superficial karst, there is a variation between fluviokarstic scenarios, sink hole plains, raised plateaus, residual hills, poljes, and large fluvial plains.

1 This research was supported by FAPEMIG (Fundação de Amparo à Pesquisa do Estado de Minas Gerais) Grant – CEX 230596.
2. The Karst

The municipal districts of Peruaçu, Januária and Jaiba, are located in the extreme north of Minas Gerais State, about 620 km away from the state capital, Belo Horizonte. The region is drained by the São Francisco River and its medium sized tributaries.

Climatic analysis done over a period of thirty years (EPAMIG et al., 1976), shows an average precipitation of 876 mm per year, concentrated in the months of November to April while there are six almost dry months, from May to October. Rainfall is variable and can range from 1400 mm to 450 mm, depending on the season. The month of October is the hottest (34°C) and the coldest is July (16°C), with a thermal average of 24°C.

The karst has developed in a lens of sub-horizontal meta-sedimentary limestone approximately 350 m thick, from the Late Proterozoic Bambui Group (Dardenne, 1981). Dissolved carbonate hardness, ranges between 135 ppm and 140 ppm (Piló, 1989):

The regional stratigraphic column reveals six main units. The mineralogical analysis from X-ray diffractometry and their relative percentages, were obtained by Campos et al. (1992):

1) Pink yellowish dolomite limestone;
2) Light grayish calcite;
3) Pinkish dolomite (calcium carbonate = 30%; dolomite = 65.8%);
4) Yellowish sublitographic dolomite;
5) Siltstones and argillites;
6) Black limestones (calcium carbonates=90%; dolomites= 7%).

Cretaceous silicified sandstones have reworked the rocks from the Late Proterozoic.

Piló (1989) studied the Karst of the Peruaçu River region, a tributary of the left margin of the São Francisco River: there are six principal morphological units.

A. Covered karst constituted of two surfaces:
   a) residual hills of a Cretaceous surface with a duricrust, above the level of 780 m and reaching 800 m.
   b) The South American Surface covered by deep lateritic soil, where a "cerrado-caatinga" vegetation has established itself, with scrub savanna characteristics. On this surface remains of a lateritic duricrust occur.

B. One karstic unit, formed by the exhumation of small hills between altitudes of 750 m and 615 m, with a vegetation of pastures and remains of a dry thicket, sub caducifolia, with elements of "caatinga".

C. The fluvi-karst of Peruaçu, with its blind valleys, canyons, and subterranean paths, with perennial vegetation predominating.

D. A sinkhole land unit between the altitudes of 750 m and 615 m, covered with artificial pastures and dry forest "mata seca".
E. A rocky escarpment, covered by a field of lapiés, between the altitudes of 700 m and 500 m where some cactuses are established.

F. The São Franciscan depression characterized by its fluvial plains, between altitudes of 500 m and 400 m, with its dissolution sinkholes, along the São Francisco River (440 m) and its floodplains with their channel sands and temporary lagoons, between the altitudes of 440 m and 438 m. Over the alluvial soils established originally a caducifolia forest, today this has been partially replaced by pastures and agricultural enterprises.

3. Farming - cattle breeding scenario.

A TM-Landsat image, (WRS 219-70, 1997, Fig. 1), has been produced with a multispectral false-color composition (bands 4, 5 and 3 – RGB) and a panchromatic band 4 enhancement, at a scale of 1:1,000,000. This provides the best visual separation of the main geomorphological regions, compatible with the scale. The image has made it possible to delineate three geomorphologic units and their respective land use from the highest lands to the plain:

I. Covered karst, represented by the remains of the Cretaceous surface, where duricrust and sandy soils derived from silicified sandstones dominate, preserves traditional extensive cattle breeding (1 animal per ha.). On the South American Surface, over lateritic soils, great areas of savanna were replaced with artificial pastures. This allowed the implementation of large cattle farms, directly irrigated from the Rio Peruaçu and its tributaries.

II. In the karstic region, only the declivities that link the South American Surface to the karst and to the region of large sinkhole plain allowed an extension of the areas of pasture. In the fluvio-karst, outcropping limestone, and in the rocky escarpment, towards the São Francisco plains, farming and cattle breeding activities are insignificant.

III. In the vast valley of the San Francisco River a development of great agricultural undertakings began, together with the establishment of cattle ranches. The semi-arid climate, a limiting factor for agriculture in the past, was kept under control by great irrigation projects, using ground water irrigated by central pivot sprinklers and distribution through channels. The Landsat image (Fig.1) clearly illustrates these two irrigation techniques.

4. The impacts of farming and cattle breeding over karst (table 1)

The environmental impact on the region studied have their origins in the 17th century, when the people of the region, the Portuguese and the “paulistas bandeirantes” (defending the crown) conquered the back-country along the São Francisco river to secure navigation privileges. The vegetation clearance began, and continues to the present, together with installation of open-cut coal mines, to obtain space for farming and cattle breeding.
GEOLOGICAL, GEOMORPHOLOGICAL
AND LAND USE DATA

COVERED KARST
< 780m - Cretaceous Planation
Surface, sandy soils, lateritic
duricrust, savana, extensive
cattle farms.
750-780m - South American
Surface (Oligocene-Miocene),
lateritic soils, duricrust, savana,
pasture, semi-intensive cattle
farms.

SÃO FRANCISCO KARST
PLAIN
440-500m - Dissolution dolines,
irrigation systems (channels-river
water; aerial-groundwater),
agroindustrial settlements and
semi intensive cattle farms.

KARST
615-750m - Fluviokarst,
doline landscapes karren
fields, restricted land use.
500-700m - Escalonated
escarpment, karren fields,
no land use.

SÃO FRANCISCO FLOOD
PLAIN
440-444m - Marginal dique, sand
banks, marginal lakes, no land
use.

Fig. 1 - Landsat image of the examined area.

<table>
<thead>
<tr>
<th>Main Agriculture Products in Minas Gerais - North Region (1996)</th>
</tr>
</thead>
<tbody>
<tr>
<td>JANUARIA</td>
</tr>
<tr>
<td>Soybeans (4000 ha)</td>
</tr>
<tr>
<td>Beans (4100 ha)</td>
</tr>
<tr>
<td>Manioc (2500 ha)</td>
</tr>
</tbody>
</table>

Table 1 - Table of land uses, in the North Region of Minas Gerais, with areas of land involved.
The ease of obtaining karstic waters and the utilization of irrigation systems through the central pivot sprinkler, transformed the area at the end of the 1970’s. The traditional systems (extensive cattle breeding and cotton cultivation) were transformed into semi intensive cattle breeding, great mechanical fieldwork and farming and cattle breeding projects, as well as small-holdings with their familiar diverse farming. The impact caused by changes in economic structure and management leads, as geographer Dr. Maria Aparecida dos Santos Tubaldini\(^1\) points out, to the small farmer selling their small-holdings or gleba. These have been transformed into medium or large properties.

Today, the outcome of this land use change, some implemented with no previous environmental impact research, has led to bankruptcy for some landowners. They have exhausted the karstic wells by water pumping, and no study has been made of the rate of natural replenishing of these wells. This has resulted in salinization and compaction of the soils. The hydro-geologist, Mr. Fernando Jardim\(^2\), regrets the lack of research done on the behavior and dimension of the karst underground water, as well as the hydraulic flow of the São Francisco river and tributaries.

Another impact of the karstic underground waters that has yet to be studied is that caused by water pollution by toxic compounds and bacteria. We live in a period of global warming, which could also be catastrophic to the region.

Karstic land use in the intertropical region, with farming and cattle breeding dominant (e.g. the valley of São Francisco) should be periodically monitored so that prompt corrective measures can be taken to prevent irreversible damage.

The creation of APA - Peruaçu (an area of environmental protection for the basin of the Peruaçu river) by the Federal government in 1992, was received with great optimism by conservationists and regional inhabitants. However there are still no economic and ecological zoning definitions, which disadvantages the ongoing management of the APA.

REFERENCES


\(^1\) pers. comm.

\(^2\) pers. comm.
AGRICULTURAL USE AND WATER QUALITY AT KARSTIC CUBAN WESTERN PLAIN

Juan Reynerio Fagundo Castillo, Patricia González Hernandez

ABSTRACT
In the paper some results of studies on the karstic aquifers of the western plain of Cuba are presented and discussed. The intensive exploitation of these aquifers for agriculture use and drinking water supply induces an increase of marine water intrusion, water salinisation and a progressive increase of chemical corrosion with a greater dissolution of carbonates. During the period of study (1983-1998) a trend in the deterioration of water quality was observed by means of a chronological series of hydrochloride content.

KEY WORDS: karts aquifers, marine water intrusion, Cuba

1. Introduction
Carbonate aquifers are dynamic geochemical systems in which rock - water interactions occur continuously (Hanshaw and Back, 1980). The belt formed at the mixing of fresh and sea water is the chemically most active part of the system.

The intrusion in the fresh karst water of salt water from the sea causes a mixing process of the two waters, which differ in their chemical and physical behaviour. Among the more significant changes which occur when two waters of different nature are mixed, there are the following: incongruent dissolution of mineral caused by common ion effect, precipitation of ferric minerals caused by the formation of more oxidizing mixture, increase or decrease of the solubility caused by changes in pH, increase of carbonate solubility caused by saline or ionic strength effect, increase of chemical dissolution of carbonates caused by mixing corrosion effect, dolomitization or de-dolomitization and ion exchange processes.

The kinetics and geochemical aspects of the coastal fresh-salt water systems in the particular case of the karstic aquifers at different regions under different climatic conditions were studied: Florida and Yucatan (Back and Hanshaw, 1981; Back et al., 1986; Plummer, 1975); Apulia, Italy (Cotecchia; 1979); Mallorca and Menorca, Spain (Herman, Back and Pomar, 1986); Western Cuba (Arellano et al., 1989, Fagundo et al., 1993; 1996, 1998; Morell et al., 1997 and González et al., 1996; 1998).

In all the above mentioned cases human impact affects both hydro-dynamical processes and calcite dissolution-precipitation processes.

Although apparently slow, these undesirable changes in processes on the karst coastal aquifers have irreversible effects on the water quality used for the plant irrigation and drinking water supply.
The aim of this paper is to show the rapid changes of water quality and of chemical corrosion processes in the karstic coastal aquifers of western Cuba, caused by human impact.

2. Geochemical process in coastal karstic aquifers

2.1. Carbonate dissolution-precipitation process

A detailed explanation of the conditions of saturation, subsaturation and oversaturation with reference to dissolved calcite, and the basis of the changes in the equilibrium of dissolution-precipitation of carbonates were given by Custodio (1986) as a function of the following effects:

a) common ion effect: Ca\(^{2+}\) contributions to the carbonate dissolution allow a medium, previously saturated with calcite or dolomite, to exceed its solubility product, thus giving rise to carbonate deposits.

b) Ionic change effect: the Ca\(^{2+}\) and Mg\(^{2+}\) concentrations affected by clay exchanges originate Na\(^{+}\) and other elements. This effect can be appreciated only in slow flow conditions.

c) Ionic strength or saline effect: an increase of the ionic strength (μ) due to the mineralization increase cause a decrease of the calcium ion activity coefficient (γ) and an increase of carbonate solubility

\[ K_c = \gamma_{Ca} \mu_{CO_3} \mu_{CO_3} \]
\[ K_d = \gamma_{Ca} \mu_{Mg} \mu_{Mg} (\gamma_{CO_3})^2 \]

d) Temperature changes: temperature affects the dissolution-precipitation equilibrium constants and activities.

e) Mixture of waters with different composition: the mixture of two saturated waters with respect to calcite, both with a different chemical composition, produces a water that can be subsaturated or oversaturated.

The dissolution and precipitation of calcite and dolomite can be summarized in the following equilibrium:

\[ CO_2 + H_2O + CaCO_3 = Ca^{2+} + 2 HCO_3^- \]
\[ 2 CO_2 + 2 H_2O + CaMg(CO_3)_2 = Ca^{2+} + Mg^{2+} + 4 HCO_3^- \]

The dolomitization can be a common process in a coastal karstic aquifer by the higher Mg\(^{2+}\) contents of the seawater. This process can be written as follows:

\[ 2 CaCO_3 + Mg^{2+} = CaMg(CO_3)_2 + Ca^{2+} \]

2.2. Redox process

There is much reduction-oxidation processes in nature. The oxygen consumption in a karstic aquifer may react with any reduced substance in the aquifer sediment, such as organic matter or Fe\(^{2+}\) bearing minerals like pirite. For the oxidation of orga-
The above process increases the dissolution of calcite in natural condition of the aquifer. By human impact (organic waste disposal) this effect is much more emphasised.

Another interesting redox process in coastal karstic aquifers is the sulphate reduction. Sulphate from the sea can be reduced by organic matter by means of biogeochemical process catalysed by anaerobic bacteria of the genus *Desulfovibrio* (Bitton, 1994) according to the overall reaction:

\[
2\text{CH}_2\text{O} + \text{SO}_4^{2-} = 2\text{HCO}_3^- + \text{H}_2\text{S}
\]

Where: \(\text{CH}_2\text{O}\) represents the organic matter. The \(\text{H}_2\text{S}\) produced can react with the \(\text{Fe}^{2+}\)-oxides in the sediment and form iron sulphate minerals (Appelo and Postma, 1993). This type of geochemical process is very common at the southern karstic plain of the western of Cuba where lagoons and swamps exist along the coastal line (González et. al., 1998).

2.3. Adsorption and ion exchange

Although this process is more common in alluvial aquifers, adsorption and ion exchange occurs also in karstic aquifers (Custodio, 1986; Pulido-Bosch et. al., 1993). The reaction can be expressed as:

\[
\text{R}_2\text{Ca} + 2\text{Na}^+ = \text{Ca}^{2+} + 2\text{NaR}
\]

Fresh water in coastal terrain is dominated by the \(\text{Ca}^{2+}\) and \(\text{HCO}_3^-\) ions, as a result of dissolution of calcite, while in sea water, \(\text{Na}^+\) and \(\text{Cl}^-\) are the dominant ions. Sediments in contact with sea water often adsorb \(\text{Na}^+\) for large part (inverse exchange).

3. Geographical, geological and hydrogeological framework

Western karstic plain (Fig. 1) is an example of the more widespread morphological landscape throughout the territory. It is developed on Paleocene - Pliocene carbonate terrigenous and transgressive limestone packages. On such sequences there is a Pliocene - Quaternary developed karst, with great capacity and high transmissivity aquifers, with open seaward discharge.

According the karstification degree of the limestone, the transmissivity of the aquifers change from 5000 m³/d to 50,000 m³/d to. The storage coefficients change from 0.03 to 0.2. Such high transmission capacity is due to the high primary porosity of the rocks, the increasing of the fracturing and the intense karstification, specially in terms of the accelerated corrosion as a consequence of the mixing of fresh and sea
Fig. 1 - Karsts areas of Cuban according to Nuñez Jiménez (1984).

waters in the coastal belt. In such aquifers the marine intrusion usually reaches long distance inland.

According to Nunez Jiménez (1984) there are five plain karstic type in Cuba: 1) naked karst, 2) karst covered by soils, 3) littoral karst in marine terraces, 4) thick fluvi- vial and lateritic sediments and 5) coastal swamp karst (Fig.1).

The wells chosen for this study were: Lopez Peña (L-1) and Los Palacios (P-1), at the southern plain of Pinar del Rio Province; P158 and P165 (South Basin of Havana Province), and P224, P225 and P226, at the Varadero-Cardenas hydrogeologic sector (Matanzas Province), all located at the western portion of the Cuban karstic plain.

4. Increase of the groundwater salinity in function of agriculture and population water supply demand

The groundwater extraction for agricultural purpose in some regions of the Cuban karstic plain is of the order of 3.5 m$^3$/s, while for population supply is of 3.2 m$^3$/s (Jiménez et al., 1997).

Table 1 shows the exploitation in the period 1983 - 1995 at the Havana South basin. This territory reach the maximum values of exploitation in 1984 (188.8 hm$^3$) and 1991 (202.5 hm$^3$). The yearly mean precipitation is of 1375 mm, but in the period 1983-1999 the value has been lower.
<table>
<thead>
<tr>
<th>Year</th>
<th>Precipitation (mm)</th>
<th>Exploitation (Hm³)</th>
<th>Year</th>
<th>Precipitation (mm)</th>
<th>Exploitation (Hm³)</th>
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<tr>
<td>1984</td>
<td>983</td>
<td>188.8</td>
<td>1992</td>
<td>1465</td>
<td>140.7</td>
</tr>
<tr>
<td>1985</td>
<td>1139</td>
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<tr>
<td>1986</td>
<td>1266</td>
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<td>1994</td>
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<td>140.1</td>
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<td>1997</td>
<td>1466</td>
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<tr>
<td>1990</td>
<td>1269</td>
<td>164.1</td>
<td>1998</td>
<td>1064</td>
<td></td>
</tr>
</tbody>
</table>

Table 1 - Precipitation (mm) and exploitation (Hm³) at the P 165 well (Havana South basin).

As a result of combined effect of the rain deficit and the increasing of water exploitation, the NaCl contents increased in the groundwater (Fig. 2).

Similar overexploitation with poor precipitation was produced in other places of the plain (Pinar del Río, La Habana and Matanzas).

![Temporal variation of precipitation, exploitation and hydrochloride contents at P165 well (Havana South basin).](image)

5. Chemical corrosion in the aquifer by mixing fresh and saline waters

Mixing two waters with different CO₂ and ionic contents will result in subsaturation. The renewed aggressiveness in mixed waters may cause calcite dissolution,
effect which has been called “mischungskorrosion” in German literature (Bögly, 1978).

With the aim to evaluate the effects of mineralization and ion strength (μ) on the decrease of the calcium ion activity coefficient (γ) and increase of carbonate solubility (table 2), a mixture of different proportions (0-100%) of fresh and sea water was prepared in laboratory. The fresh water came from the Jaruco-Aguacate basin, located at great distance from the coast, in an aquifer developed on Miocene limestone. The sea water was sampled in the Atlantic Ocean.

<table>
<thead>
<tr>
<th>Sea water (%)</th>
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<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
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<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>HCO₃⁻ (mg/L)</td>
<td>270</td>
<td>266</td>
<td>268</td>
<td>260</td>
<td>258</td>
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<td>250</td>
<td>246</td>
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<td>252</td>
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<tr>
<td>Cl (mg/L)</td>
<td>17</td>
<td>200</td>
<td>389</td>
<td>568</td>
<td>761</td>
<td>938</td>
<td>1120</td>
<td>1314</td>
<td>1498</td>
<td>1680</td>
<td>1863</td>
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<tr>
<td>SO₄²⁻ (mg/L)</td>
<td>12</td>
<td>34</td>
<td>66</td>
<td>83</td>
<td>111</td>
<td>140</td>
<td>159</td>
<td>196</td>
<td>214</td>
<td>246</td>
<td>262</td>
</tr>
<tr>
<td>Ca²⁺ (mg/L)</td>
<td>60</td>
<td>66</td>
<td>69</td>
<td>72</td>
<td>74</td>
<td>79</td>
<td>84</td>
<td>86</td>
<td>89</td>
<td>92</td>
<td>96</td>
</tr>
<tr>
<td>Mg²⁺ (mg/L)</td>
<td>15</td>
<td>32</td>
<td>41</td>
<td>52</td>
<td>66</td>
<td>73</td>
<td>89</td>
<td>101</td>
<td>115</td>
<td>123</td>
<td>139</td>
</tr>
<tr>
<td>Na⁺ (mg/L)</td>
<td>13</td>
<td>118</td>
<td>220</td>
<td>320</td>
<td>426</td>
<td>525</td>
<td>632</td>
<td>728</td>
<td>835</td>
<td>938</td>
<td>1042</td>
</tr>
<tr>
<td>K⁺ (mg/L)</td>
<td>1</td>
<td>5</td>
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<td>12</td>
<td>16</td>
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<td>24</td>
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<tr>
<td>EC (µS/cm)</td>
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<td>1230</td>
<td>1850</td>
<td>2596</td>
<td>3306</td>
<td>3850</td>
<td>4470</td>
<td>5080</td>
<td>5672</td>
<td>6270</td>
<td>6850</td>
</tr>
<tr>
<td>γCa²⁺</td>
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<td>0.64</td>
<td>0.60</td>
<td>0.57</td>
<td>0.54</td>
<td>0.52</td>
<td>0.50</td>
<td>0.48</td>
<td>0.47</td>
<td>0.46</td>
<td>0.44</td>
</tr>
<tr>
<td>γHCO₃⁻</td>
<td>0.92</td>
<td>0.89</td>
<td>0.87</td>
<td>0.86</td>
<td>0.85</td>
<td>0.84</td>
<td>0.83</td>
<td>0.82</td>
<td>0.81</td>
<td>0.81</td>
<td>0.80</td>
</tr>
<tr>
<td>TSS (mg/L)</td>
<td>388</td>
<td>721</td>
<td>1061</td>
<td>1367</td>
<td>1712</td>
<td>2031</td>
<td>2358</td>
<td>2699</td>
<td>3034</td>
<td>3362</td>
<td>3693</td>
</tr>
<tr>
<td>√μ</td>
<td>0.08</td>
<td>0.12</td>
<td>0.14</td>
<td>0.16</td>
<td>0.18</td>
<td>0.20</td>
<td>0.21</td>
<td>0.23</td>
<td>0.24</td>
<td>0.25</td>
<td>0.27</td>
</tr>
</tbody>
</table>

Table 2 - Ion concentrations, electric conductivity (EC), total soluble solids (TSS), ion activity coefficients and square root of the ion strength (μ) at a fresh water (Jaruco Aguacate basin) and at different proportions of seawater mixture (Atlantic Ocean).

The ions contents (in terms of TSS and EC) increase with the percent of see water in the mixture, while hydrocarbonate (γHCO₃⁻) and calcium (γCa²⁺) activity coefficients decrease. The chemical corrosion ([Ca²⁺]_chem) in terms of calcium (mg/l) removed from the aquifer by the waters has been calculated by the following equation:

\[
[Ca^{2+}]_{\text{chem}} = [Ca^{2+}]_s - [Ca^{2+}]_m \quad (1)
\]

Where:
- [Ca²⁺]ₘ: Calcium contents determined with analytical methods
- [Ca²⁺]ₙ: Calcium contents calculated from the conservative mixture.

The above parameters have been calculated using the relationships between the hydrochloride contents and the fresh water percent in the mixture (Pₚ), as well as the
calcium contents relationships. The resulting equation is the following:

$$P_m = 0.1812 [Cl^-]_s - 0.09 \quad (2)$$

Where $[Cl^-]_s$ is the hydrochloride concentration of the sample (mg/l). The slope represents the $Cl^-$ concentration at the 0 percent of the mixture and the intercept is the $Cl^-$ contents of the groundwater without salinization. Then, the calcium contents supplied for the mixture $[Ca^{2+}]_m$ is:

$$[Ca^{2+}]_m = 0.2 P_m + 3.0 \quad (3)$$

Which can be calculated as a function of the mixture percent from the corresponding relationships (table 1). Combining (1), (2) and (3) the equation can be written:

$$[Ca^{2+}]_{chc} = [Ca^{2+}]_s - 0.03824 (Cl^-) + 2.982 \quad (4)$$

The $[Ca^{2+}]_{chc}$ values can be expressed in terms of $CaCO_3$ hardness (mg/l) as the following:

$$[CaCO_3]_{chc} = 50 [Ca^{2+}]_{chc} \quad (5)$$

This magnitude can be used to compare the corrosion developed in the different sites of the basin or in the aquifers located in different places.

With the aim to test the above calculations two pairs of wells from different aquifers representative of waters with lower and higher salinity in the same basin at Pinar del Rio, Havana and Matanzas Provinces were chosen. The different behaviour of the wells is due to the local differences of the limestones composition, porosity and fissuration, to the location with respect to the coastal line and to the degree of water extraction for agricultural and population supply purpose. In the following tables (3-5), the mixture percent ($P_m$ %) and the chemical corrosion ($[CaCO_3]_{chc}, \text{mg/l}$) are shown for the studied period in the karstic aquifer open to sea at Pinar del Rio, Havana and Matanzas Provinces respectively.

In general, the quantities of $CaCO_3$ removed from the limestones in the three studied places of the western Cuban karstic plain are different, and a major increase of the chemical corrosion can be appreciate in those aquifers which have larger percent of sea water.

While the quantity of $CaCO_3$ removed from the limestone is similar in the Pinar del Rio and Matanzas wells, it doubles in the Havana karst, maybe due to the different lithological and tectonic characteristics of the aquifers.

The different $CaCO_3$ magnitudes in the Havana aquifers and in the Pinar del Rio Province aquifers can be related with the different nature of their catchment areas. In Havana area the runoff comes directly from precipitations, and the $CaCO_3$ is dissolved in an open system (with free $CO_2$), while in the area of Pinar del Rio the aqui-
<table>
<thead>
<tr>
<th>Year</th>
<th>L-1</th>
<th></th>
<th></th>
<th>P-1</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>$P_m$</td>
<td>$\text{CaCO}_3 \text{ eq (mg/L)}$</td>
<td>N</td>
<td>$P_m$</td>
<td>$\text{CaCO}_3 \text{ eq (mg/L)}$</td>
</tr>
<tr>
<td>1974</td>
<td>1</td>
<td>0.07</td>
<td>24</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1975</td>
<td>5</td>
<td>0.10</td>
<td>21</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1976</td>
<td>5</td>
<td>0.02</td>
<td>17</td>
<td>5</td>
<td>0.70</td>
<td>69</td>
</tr>
<tr>
<td>1977</td>
<td>11</td>
<td></td>
<td></td>
<td>11</td>
<td>0.69</td>
<td>53</td>
</tr>
<tr>
<td>1978</td>
<td>8</td>
<td></td>
<td></td>
<td>8</td>
<td>0.69</td>
<td>61</td>
</tr>
<tr>
<td>1979</td>
<td>1</td>
<td>0.03</td>
<td>40</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1980</td>
<td>1</td>
<td>0.01</td>
<td>47</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1982</td>
<td>3</td>
<td>0.03</td>
<td>41</td>
<td>9</td>
<td>0.85</td>
<td>71</td>
</tr>
<tr>
<td>1983</td>
<td>7</td>
<td>0.03</td>
<td>36</td>
<td>8</td>
<td>0.87</td>
<td>66</td>
</tr>
<tr>
<td>1984</td>
<td>7</td>
<td>0.04</td>
<td>33</td>
<td>2</td>
<td>1.04</td>
<td>57</td>
</tr>
<tr>
<td>1985</td>
<td>7</td>
<td>0.03</td>
<td>33</td>
<td>2</td>
<td>1.04</td>
<td>59</td>
</tr>
<tr>
<td>1986</td>
<td>4</td>
<td>0.03</td>
<td>41</td>
<td>2</td>
<td>1.02</td>
<td>86</td>
</tr>
<tr>
<td>1987</td>
<td>3</td>
<td>0.03</td>
<td>32</td>
<td>2</td>
<td>1.16</td>
<td>99</td>
</tr>
<tr>
<td>1988</td>
<td>1</td>
<td>0.03</td>
<td>28</td>
<td>2</td>
<td>1.16</td>
<td>90</td>
</tr>
<tr>
<td>Mean value</td>
<td>0.04</td>
<td>32</td>
<td></td>
<td>0.81</td>
<td>66</td>
<td></td>
</tr>
</tbody>
</table>

Table 3. Mixture percent and chemical corrosion magnitude at the Pinar del Río southern karstic plain.

<table>
<thead>
<tr>
<th>Year</th>
<th>Pozo 158</th>
<th></th>
<th></th>
<th>Pozo 165</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>$P_m$</td>
<td>$\text{CaCO}_3 \text{ eq (mg/L)}$</td>
<td>N</td>
<td>$P_m$</td>
<td>$\text{CaCO}_3 \text{ eq (mg/L)}$</td>
</tr>
<tr>
<td>1984</td>
<td>6</td>
<td>0.06</td>
<td>78</td>
<td>4</td>
<td>0.21</td>
<td>67</td>
</tr>
<tr>
<td>1985</td>
<td>4</td>
<td>0.08</td>
<td>80</td>
<td>2</td>
<td>0.30</td>
<td>92</td>
</tr>
<tr>
<td>1986</td>
<td>10</td>
<td>0.11</td>
<td>88</td>
<td>9</td>
<td>0.43</td>
<td>85</td>
</tr>
<tr>
<td>1987</td>
<td>3</td>
<td>0.53</td>
<td>145</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean value</td>
<td>0.09</td>
<td>83</td>
<td></td>
<td>0.38</td>
<td>92</td>
<td></td>
</tr>
</tbody>
</table>

Table 4. Mixture percent and chemical corrosion magnitude at the Havana southern karstic plain.
The low values obtained at Matanzas where the aquifers are also open to the precipitations, as Havana, can be explained referring to the different characteristics of the limestone, that, in Cardenas -Varadero sector of Matanzas, is very dolomitized. The dissolution of dolomite at the groundwater temperature of Cuba (25 °C) is lower than that of the pure limestone.

The additional role of the CO$_2$ contents in the chemical corrosion can be illustrated by the example of the P222 well at the Varadero-Cardenas hydrogeologic sector (table 6). In this place, a sugar cane factory spills its wastes directly through a ponor into the karst and therefore CO$_2$ contents are high.

The kinetics experiment carried out in laboratory (Table 7), are coherent with the water underground behaviour.

<table>
<thead>
<tr>
<th>Year</th>
<th>N</th>
<th>CaCO$_3$ eq (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1983</td>
<td>2</td>
<td>1.21</td>
</tr>
<tr>
<td>1984</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1985</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1986</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1987</td>
<td>3</td>
<td>6.34</td>
</tr>
<tr>
<td>1988</td>
<td>1</td>
<td>7.79</td>
</tr>
<tr>
<td>1989</td>
<td>1</td>
<td>3.95</td>
</tr>
<tr>
<td>1990</td>
<td>4</td>
<td>5.26</td>
</tr>
<tr>
<td>Mean value</td>
<td>4.18</td>
<td>133</td>
</tr>
</tbody>
</table>

Table 5. Mixture percent and chemical corrosion magnitude at the hydrogeologic sector of Varadero-Cardenas (Matanzas Province)

<table>
<thead>
<tr>
<th>Province</th>
<th>POZO</th>
<th>N</th>
<th>CaCO$_3$ eq (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pinar del Rio</td>
<td>L-1</td>
<td>15</td>
<td>30</td>
</tr>
<tr>
<td>Habana</td>
<td>158</td>
<td>7</td>
<td>69</td>
</tr>
<tr>
<td>Matanzas</td>
<td>226</td>
<td>7</td>
<td>30</td>
</tr>
</tbody>
</table>

Table 6. Relation among the basical chemical corrosion removed from selected places at the Pinar del Rio, Habana and Matanzas Provinces with a mixture percent on the order of 0.04-0.05 %.

<table>
<thead>
<tr>
<th>NaCl Concentration (mg/L)</th>
<th>0</th>
<th>2</th>
<th>6</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>CaCO$_3$ eq (mg/L)</td>
<td>0</td>
<td>144</td>
<td>269</td>
<td>344</td>
</tr>
</tbody>
</table>

Table 7. Variation of the chemical corrosion in the interaction CO$_2$-H$_2$O-CaCO$_3$ with different percent of NaCl in the water.
The results discussed above allow to realize how drastic are the changes resulting from human impact in the karstic coastal aquifers of Cuba. These changes bring both to water quality deterioration and to increasing of secondary porosity of the carbonates, especially as a result of the aquifer overexploitation and of the organic wastes spill.

6. Conclusions

By means of the study of chronological series of hydrochloride contents, significant differences of the magnitude of chemical corrosion in the karstic coastal aquifers of western Cuban were found. The aquifers show an intense chemical corrosion, which is function of the sea water percent in the mixture and of different types of human impact. These aquifers are submitted to great exploitation for agricultural and water supply purpose, and occasionally are affected by the sugar cane waste spill.

REFERENCES


Influencia de la reducción de sulfatos en los procesos de disolución y precipitación de carbonatos en un acuífero carsico costero. In Memorias del XII Seminario Internacional del CIRA y XII Seminario Internacional sobre Gestión y Tecnología de Suministro de Agua Potable y Saneamiento Ambiental. ISPJAE, La Habana.


IN MEMORIAM

ANTONIO NUÑEZ JIMENEZ (1923-1998)

For more than 20 years I have been a friend of Antonio Nuñez Jimenez, the speleologist and scientist who, more than anyone else, has contributed to the speleological development, first in his birthplace Cuba and then in all Latin American countries.

Born in a middle-class Cuban family, Nuñez Jimenez began his speleological activity very early when he was just 16 by exploring his first cave, “Cueva de la Candela” in 1939.

The exploration activity wasn’t enough to satisfy him completely; from the very start in fact he felt the need to expand his passion by involving other people. So in 1940 Antonio founded the “Sociedad Espeleologica Cubana” and he remained president until his death.

The speleological interests however didn’t cause him to forget his studies as he took a degree in Letters and Philosophy at La Habana University in 1951 and then a PhD in Geographic Science at the Lomonosov University in Moscow, finally becoming Professor of Geography at the Academy of Science of La Habana.

It was the Cuban Revolution that really marked his life as, from the very beginning, Antonio was first in line, winning the grade of Captain under the command of Che Guevara. During the revolution his capability and speleological knowledge were of great use to Castro, so much so, that when Castro became “Leader Maximo”, he compensated Antonio by nominating him Vice Minister for Culture and bestowing power, even political power, to the Cuban Speleological Society, something unique in the whole world.

In more than 50 years of his life as a speleologist Antonio has not only explored caves in Cuba and in many other countries in Central and South America, but has also published more than 100 scientific and monographic works of speleological interest. These arguments range from speleogenesis to mineralogy and from geomorphology to archaeology.

It is all due to the absolute merit of this person who fought all his life in order to spread the speleological activities if many countries from Venezuela to Brazil, Argentina to Costa Rica, and Mexico to Peru have their speleological organisations operating.

Following this line of thought, he succeeded in founding the Federacion Espeleologica de America Latina y del Caribe (FEALC) which today counts 22 participating nations. Nuñez Jimenez was the first president and remained so for a long time until his health permitted it.

Antonio was one of the major supporter of the International Union of Speleology
from its very foundation and for 30 years has been the UIS Official Delegate of his country.

Though speleology was most certainly his greatest interest, his culture and tireless activity have given him the opportunity for other themes; the mesoamerican archaeology above all, where he organised systematic studies of the petroglifs in Peru, publishing an exceptional monograph in 3 volumes. He organised also some geographic exploration, following the epic waterways by using an identical copy of an antique canoe from the springs of the Amazon River down to Cuba.

During his long travels Antonio has met thousands of speleologists from all over the world, many of whom became his friends and have been guests at his splendid house at Miramare. On his death, Antonio left this house in his will as a patrimony to the Nation that contains collections of finds and souvenirs of his adventurous life. Today this house is a really exceptional ethnographic speleological museum not to mention the vast library that, considering the size and variety is certainly not less than the greatest National Speleological Libraries.

The speleologists, not only Cubans, have inherited a series of organisations, he thought of and realised, that have helped in the past and will in the future help generations of young people to come into contact with the fascinating cave world more easily and safely.

There will remain a memory of a unique personality who tempered his frenetic disposition and decision maker with an exquisite education and a sincere love of discussion for those who have known him.

Paolo Forti
ALFRED BOEGLI (1912-1998)

He was born in Bern and studied Geography, Geology, Petrology and Mineralogy from 1931 to 1937 qualifying as a teacher in a secondary school in 1935 in Bern and in 1937 in Luzern. In 1939 he took a degree in Geography in Friburg.

During that time he studied the glacial morphology of Alps and, also, the morphogenesis, hydrography and karst morphology entering in 1945 the Group for geomorphological research of the Swiss Alps. Since 1962 he started his participation to the elaboration of the geomorphological maps for the Swiss Atlas.

In 1965 he was charged with the courses of Geography, Karst Geomorphology and Hydrography at the University of Frankfurt becoming in 1967 honorary professor. Since 1969 he deliverd courses of Physical Geography at the University of Zuerich.

Just after the 2nd World War he begun the first researches in the Hoelloch by devoting there most of his activity: by the way, in 1969 he spent in the cave more than 5400 hours, i.e. about 2/3 of the hours within one year!

In 1949 he co-operated as a geologist with the Research Group of the Swiss Alpine Club. After having been appointed in 1951 scientific director of the Speleological Group of Hoelloch, in 1959 he became general director of the cave. The explorations lead by him covered much more than one hundred kilometres of the cave which were mapped.

With the experience achieved with these researches, Boegli became an expert of the karst phenomena at an international level. He was entrusted with relevant tasks, e.g., as a member of the Commission for Karst Phenomena of the International Geographical Union, first foreign member of the Cave Research Foundation (USA), member of the Commission for Karst Terminology of the Union Internationale de Spéléologie. He carried out also many researches in the USA and Jamaica.

Nevertheless, the most important contribution that brought Boegli among the VIPs of speleology was the formulation of the mixture corrosion theory published for the first time in 1964.

In a paper I delivered at the 5th International Congress of Speleology in Stuttgart in 1969 I had reported my regret because such a theory was held in poor consideration. In particular, I added that the importance of the mixture corrosion theory in speleology was comparable with that of the Einstein's relativity in physics.

My friend Boegli, too grateful for the comparison, asked me to cancel such a passage from the text to be published in the proceedings because he considered it exaggerated and possible source of criticism from other colleagues. To his regret I didn't succeeded to modify my text so that the original one with my great appreciation for Boegli's theory was published in the proceedings.
I never got aware of any censure to him on account of my words and therefore, yet with my regret to have caused perhaps a displeasure to him, I cannot but rejoice now at what happened.

In fact I have always been convinced that the concept of the mixture corrosion was the first example of a fundamental theoretical contribution to explain a whole series of effects observed in karst phenomenon. The lack of a prompt acknowledgement which he deserved was due to a mentality widely spread among cavers brought to base themselves exclusively on the observation of nature and excluding any quantitative check requiring a mathematical formula.

Later only, when the old generation disappeared, young cavers more open to accept formulae and symbols appeared on the stage and, consequently, our great Boegli got the success he deserved. Obviously this doesn’t mean that the mixture corrosion theory describes everything happens in the karst phenomenon. Many things depends on other factors, some already known and some totally unknown.

But, after the first observation that the corrosion of some rocks is due to the carbonic acid, any quantitative evaluation would have easily shown that such a corrosion could not occur, in practice, deeper than a few centimetres from the surface.

No one ventured to investigate this fact notwithstanding an evident contradiction between the role of carbonic acid which was confirmed by many experimental results and the theoretical impossibility of an underground karst phenomenon since the percolation water attains saturation after a very short path.

The subtle mind of Boegli solved the problem by settling two observations which appeared to be incompatible.

All the community of cavers and of persons interested to karst regret to-day the loss of a great colleague and a good friend who opened to us new views with his teaching.

In particular we express our sympathy to the Boegli family.

Arrigo Cigna
FRANCE HABE (1908 - 1999)

Last 12 October 1999 France Habe died in Postojna, Slovenia, just three months before his 92 birthday. He was born in Vrhnika which is near to the Karst-springs of the river Ljubljanica and, at that time the region was part of the Austrian-Hungarian monarchy. Successively he studied history und geography at the University of Ljubljana finishing in 1932 and becoming a teacher in different highschoos.

During the 2nd World War he was taken into the concentration camp of Dachau. After the war he resumed his activity as a teacher.

He started as a caver in 1926 in Vrhnika under the guide of Ivan Michler and in 1952 he founded the Caving Club of Postojna. From 1967 to 1971 he became President of Caving Association of Slovenia; from 1970 to 1976 he was President of Speleological Association of Yugoslavia and Vice-president from 1976 - 1980. From 1972 to 1982 he was Chairman of the Commission for cave protection and cave tourism within the Speleological Association of Yugoslavia. From 1977 to 1986 he was member of the UIS Bureau and, from 1984 to 1996, Chairman of the UIS-Commission for the protection of karst and caves. During his speleological career he performed 184 first explorations of caves, published about 200 papers and got 15,000 pictures concerning the karst phenomenon.

In 1964 he got his doctorship at the University of Ljubljana with a thesis entitled: "Morphological, hydrological and speleological development of the Northern part of the Pivka basin with special emphasis on the karst system of Predjama". In 1965 he became scientific collaborator of the Karst Research Institute at Postojna and in 1975 he was promoted higher scientific collaborator; two years later, in 1977, he retired.

His career confirm that he was not only one of the most outstanding persons of the Slovene speleology but he had also an important role in an international framework. Among many peculiar characteristics he was particularly independent from any constraint either political or due to other reasons and therefore he was a real friend much appreciated by everyone.

During his career he produced a lot of work and published, also in the very last years, papers quite relevant and with a great interest. Still few years ago, when he was over eighty years old, he was quite fit and during a visit to a karst site the students he was leading were amazed by professor Habe who climbed a fence since he forgot the key of the gate!

Beyond the scientist and the caver, we must remember his qualities. France knew a somewhat large number of languages that used fluently: sometimes he switched abruptly from one to another without getting aware of the change and his friends had hard efforts to stop him and bring again to the previous language.

In September 1979 in Wien, Austria, an International Symposium was oragni-
zed to celebrate the first centennia of the first caving club in the world, the "Verein für Höhlenkunde" which was active in many parts of the Austrian Hungarian Empire. At that time a group of old cavers gathered in Wien and one evening the atmosphere of a pub together with some pints of beer were instrumental in the foundation of the Imperial Royal Absburgical Speleological Society; obviously only persons belonging to the territories of the Empire, or in some way connected to it, could be admitted as members.

Consequently Hubert Trimmel entered the Society with the title of Prince Metternich, Fritz Oeld as Archbishop of Salzburg, Victor Caumartin (since his name was not Louis !) as Victor XIV and me as Prinz Eugen of Savoy. Of course such a Society had to be managed by a "Kaiser" and not by a president, as usually happens, and therefore our unforgettable France Habe was elected Kaiser by one consent since he was the only one to be borne under the Austrian Empire!

Afterwards we always addressed France as Kaiser: for each of us it was a way to acknowledge his great qualities and express our appreciation.

During the 13 International Congress of Speleology in La Chaux-de-Fonds, Switzerland, a more serious recognition was attributed to him (who was unable to participate for health reasons) when he was elected Honorary President of the UIS Commission for the Protection of Karst and Caves. But he received also a large number of awards and honours: the last and the highest was the "Silver Honour Award of Freedom" delivered to him on 29 January 1999 by the President of the Republic of Slovenia.

On behalf of many colleagues within the UIS we express our heartfelt sympathy with his Wife and the whole Family.

Arrigo Cigna
ALBERT ANAVY (1910-1999)

Albert Anavy died December 3, 1999 in Tucson, Arizona (USA) where is resided for a long time. He was born in Beirut, Lebanon, on February 28, 1910. From the very beginning he had an education quite international. In fact he had his Primary and Secondary Schools in French institutions in Egypt, Liban and Greece; successively he entered the Preparatory School and the American University of Beyrouth where he graduated with courses of physics, mathematics, chemistry, astrophysics, theoretical physics, physical chemistry, etc. At the Sorbonne University in Paris in 1949 he got two “Certificats de License” of mathematics and physics. Since 1931 he started his career as a teacher both at the International College and at the American University of Beirut. He was not only engaged in teaching but also in management and in athletics. He was very fluent in English, French and Spanish and could speak Arabik, Italian, Greek and Hebrew.

Greatly interested in speleology, in 1944 he explored the cave of Jeita as a leader of a group of cavers from different countries. In a short time he became one of the pillars of the Lebanese speleology together with Lionel Gorra. In fact, Gorra was the first Lebanese caver (he started in 1940 within the Clan Lyaueteve associated with the Scouts of France), in 1951 he founded the Spéléo Club du Liban together with Albert Anavy and Sami Karkabi. Since 1954, when Gorra left, Albert Anavy was always active, a true friend and a reliable counsellor who assured the further development of the Spéléo Club until 1975 when, he also retired and moved to the USA on account of the difficult situation in Lebanon.

In the meantime the reputation of his activity and management qualities spread out outside the borders of Lebanon because he also participated to the International Congresses of Speleology in Paris (1953) and Vienna (1961). Therefore when in 1965 the Union Internationale de Spéléologie was founded in Ljubljana, Albert Anavy was elected General Secretary: given his qualities as caver and polyglot, no better choice could have been made!

However this task was rather heavy because a totally new structure had to be established. Therefore Anavy accepted willingly the election on condition to be substituted at the next congress. In order to keep this promise without loosing his valuable contribution, in 1969, in Stuttgart, Anavy was substituted by Hubert Trimmel and an enlargement of the Board of UIS was agreed and Anavy became the first Adjoint Secretary. He kept this position until 1977 when he withdrew; at the same time he chaired also the Commission of Statutes, and in 1981 was elected Honorary Member of UIS.

His whole life can be summarized by his same words: "Speleology, teaching and my family have been my support and my good luck".
Another great representative of the international speleology disappears and the whole group of the old cavers will never forget his amiability and the role he paid for speleology both in Lebanon and within UIS.

His friends, from any country of the world, join to express their sympathy to his Family and his Lebanese colleagues.

A fund for the Albert Anavy Fellowship has been established at the Collège International, 850 Third Avenue, 18th Floor, New York, NY 10022 USA or at the Boîte Postal 11-0236, Beyrouth, Lebanon.

Arrigo Cigna
BOOK REVIEW

SOME RECENT MONOGRAPHIES ON KARST

J. Choppy


Cette these débute par l'étude comparative des émergences normales, hydrothermales, et des trop-pleins dans la région du Crowsnest Pass, à l'extrémité sud des Montagnes Rocheuses karstiques canadiennes. On remarque notamment qu'une proportion très importante du débit annuel est lié à la fonte des neiges, avec les intermittences quotidiennes classiques. Les duretés sont importantes, dépassant fréquemment 100 milligrammes de CaCO₃ par litre. Utilisant des données venant des régions karstiques du monde les plus connues, suit le « développement d'un nouveau modèle conceptuel pour l'écoulement de l'eau dans le karst, dans lequel l'écoulement Hagen-Poiseuille » (on sait qu'il s'agit d'un écoulement laminaire) « détermine le développement et la position des conduits dans l'aquifère. Le modèle explique pourquoi la plupart des conduits sont en équilibre dynamique avec l'apport de sédiments, pourquoi les exsurgences du karst tempéré sont pour la plupart vauclusiennes, quel est le temps moyen pour la spéléogénèse » (1.000.000 années avant qu'une circulation en régime turbulent puisse parcourir un nouveau conduit), « comment plus de 98% de la dissolution du calcaire se fait dans la zone épikarstique... Le modèle permet de prédire la vitesse d'écoulement entre la perte et l'exsurgence, la profondeur des conduits sous la nappe phréatique, le rapport des plans de stratification et des fissures utilisés par les conduits, l'espacement entre divers étages de conduits, et la profondeur des exsurgences vauclusiennes » [extraits du résumé français très légèrement modifiés]. Assez surprenant au départ, cet inventaire à la prévert est une approche du creusement du réseau de fentes, mais l'analyse détaillée des 80 pages correspondantes ne saurait trouver place ici.

Les derniers chapitres concernent à nouveau l'hydrogéologie de la région du Crowsnest Pass, les bassins d'alimentation des émergences, les circulations et leur rôle géomorphologique.

* * *

L’ouvrage débute par un historique des hypothèses essentiellement américaines concernant l’origine des cavités et de celles dans les zones terrestres envahies par l’eau de mer.

L’inception (= le «début») est le plus ancien stade de la karstification, correspondant à la période suivant l’absence de creusement karstique (no speleogenetic activity) et précédant le début de circulations laminaires et de la «gestation concomitante des conduits». Un inception horizon est essentiellement la limite de lits selon laquelle se produit cette karstification initiale: suit donc un historique des travaux sur l’influence des joint de stratification dans le karst. Dans le principe, cependant, un «inception horizon» est «tout élément de la séquence carbonatée, contrôlé lithostratigraphiquement, qui en raison d’une différence physique, lithologique ou chimique par rapport au faciès carbonaté prédominant à l’intérieur de la séquence, favorise activement ou passivement le début de l’activité de dissolution».

Viennent ensuite des chapitres consacrés aux «inception horizons» dans diverses régions, des paléokarsts, dans le cas d’intervention d’acides forts, en liaison avec des surfaces de discontinuité géologiques, dans le cadre de zones hydrographiques. Tout ceci illustré par des exemples dans des cavités, mais dans quelle mesure les cavités actuelles sont-elles un témoin d’un stade de karstification aussi initial ?

***

MICHIE N.A. - 1997, An investigation of the climate, carbon dioxide and dust in Jenolan Caves, N.S.W.; thèse, Macquarie University, N.S.W., Australie, 298 p.

C’est un véritable défi que s’est proposé Neville Alexander Michie: la grotte de Jenolan, à 200 kilomètres de Sidney, en Australie (citée de loin en loin dans les ouvrages de Martel) est un réseau à plusieurs entrées, reliant trois vallées, et à étages. De plus, de longs parcours sont aménagés pour des visites touristiques. Dans ces conditions, faire la part des processus climatiques réellement souterrains est évidemment difficile. À l’inverse, cela fournit une approche de l’impact de la fréquentation touristique, souvent étudié isolément.

L’ouvrage débute par un bon résumé des processus climatiques souterrains. Puis l’auteur étudie le réseau par des expériences ponctuelles généralement liées à des particularités morphologiques. Un chapitre novateur est consacré au dépôt de poussières, qui ternit les concretions: la poussière est recueillie dans une boîte de Petri, pendant une durée mise en relation avec le nombre de visiteurs. La quantité de poussière est appréciée par la réduction de transmission de la lumière.

Dans l’étude du gaz carbonique, une attention particulière est également accordée à l’influence des visiteurs, via leur bilan énergétique.

La liste des mesures porte sur 150 stations mesurées le plus souvent mensuellement (température et humidité relative) d’avril 1994 à mai 1996, auxquelles s’ajoutent 150 mesures spéciales de poussière.

L’ouvrage s’achève par la présentation des matériels utilisés.

La spéléologie et la morphologie karstique sont en relation avec des sciences extrêmement diverses. De sorte que nous sommes tous confrontés à de nombreux termes spécialisés.

Le dictionnaire qui nous est proposé recouvre donc d'abord les termes relatifs à l'activité sportive spéléologique, au domaine souterrain (y compris les noms des cavités les plus célèbres, notamment celles visitées par les touristes), au karst de surface, ainsi que les termes dialectaux. Mais encore plus nombreux sont les termes les plus courants relatifs à la géologie et l'hydrogéologie, à la géographie, à l'archéologie, à la biologie souterraine, à la protection de l'environnement, etc.

Au total ce dictionnaire compte environ 2500 entrées; et nul ne peut dire qu'il n'apprendra pas quelques termes nouveaux.

C'est dire que cet ouvrage peut être utile à tous. La volonté d'exhaustivité et la qualité des collaborations que Claude Viala s'est assuré sont le gage de la fiabilité de l'ouvrage. Certes, et l'auteur l'évoque dans son avant-propos, chaque spécialiste aurait facile de critiquer telle ou telle définition, la jugeant souvent trop courte... C'est le grand mérite de ce dictionnaire de faire la part belle à chacun des aspects de la pratique spéléologique et karstique dans un volume finalement restreint.

Merci Claude; c'est une bonne action.

***

JEANNIN Pierre-Yves - 1996, Structure et comportement hydraulique des aquifères karstiques; thèse de doctorat, Université de Neuchâtel, 237+10 p., résumé anglais et français


Sa thèse est divisée en deux grandes parties: «Le comportement hydrodynamique des aquifères karstiques» et « La géométrie des réseaux karstiques», car «l'étude de la géométrie des réseaux est... indispensable pour évaluer l'allure des systèmes d'écoulement ».

La première partie reproduit 5 articles parus dans le Bulletin d'hydrogéologie de Neuchâtel n° 14 (1995) et deux autres, donnés au Congrès national suisse de 1995, puis au Congrès international de spéléologie de La Chaux de Fonds (1997); plusieurs de ces articles sont en collaboration; les exemples de terrain concernent la grotte de Milandre et le réseau du Hölloch. La conclusion de cette partie confirme la «nécessité de l'existence d'un épikarst (*) et son important rôle de stockage. Dans la zone

(*) j'ai dit ailleurs que ce mot est étymologiquement un contresens.
de transfert, l’écart est considérable entre la conductivité hydraulique des conduits (> 0.1 m/s) et celle des volumes peu perméables (de l’ordre de 10^{-6} m/s). «La densité des conduits verticaux reliant l’épikarst au réseau basal n’a pas pu être estimée sur la base des observations indirectes effectuées». Cette zone «basale» comprend la zone noyée du karst, plus ce que l’on nomme d’ordinaire le «collecteur», lorsqu’il circule plus bas que le niveau de l’eau dans la zone noyée; sauf éventuellement durant les crues. Lors de celles-ci, l’existence de trop-pleins modifie la transmissivité du réseau, la relation entre charge et débit n’étant plus quadratique. Dans les conduits, la distribution hétérogène des vitesses d’écoulement provoque des retards sur la partie descendante des courbes de restitution des traçages, qui augmentent avec la distance entre point d’injection et point de restitution. Dans tous les cas, «les écoulements sont conditionnés par la structure spatiale du champ des perméabilités et en particulier par celle des conduits karstiques».

C’est donc à l’étude de ce champ de perméabilités qu’est consacrée la deuxième partie de la thèse. Une vision tri-dimensionnelle de la géométrie des réseaux, liée à l’apparition récente d’outils informatiques, fut particulièrement précieuse. Cette étude s’articule en deux grands chapitres.

L’auteur étudie d’abord la géométrie et la genèse du système Schrattenfluh, Sieben Hengste, Bärenschatz, Beatushöhle. Les conclusions, au demeurant relativement peu nouvelles, ne sont guère généralisables hors des grands réseaux de montagne. On retiendra cependant que la genèse du système «apparaît comme une succession discrète de réseaux plutôt que comme un réseau en évolution progressive».

Puis sont examinées les approches possibles de la géométrie des réseaux karstiques. L’approche déterministe est celle qui vise à relier certaines caractéristiques des écoulements et les transports qui en résultent; il apparaît que l’ouverture initiale des surfaces de discontinuité joue peut-être un rôle plus important que leur fréquence. L’approche analogique utilise des modèles pour simuler le creusement karstique.

L’«approche déterministe inverse» vise à déduire, des valeurs hydrauliques, certaines caractéristiques du réseau (c’est notamment l’approche de Mangin); elle permet d’évaluer le volume des réserves écoulables. La statistique de valeurs spéléométriques cherche à les relier à d’autres critères (fracturation, lithologie). Comme les fractales décroissent de manière satisfaisante les caractéristiques géométriques des objets, «des générateurs fractals de réseaux karstiques pourraient être» déduits «de la structure du réseau, de la tortuosité des conduits et de leur diamètre qui tous trois affichent des caractéristiques fractales»; ce ne sont pas encore «des outils réellement utilisables», et générer un réseau ressemblant au réseau réel n’apprend rien en ce qui concerne les processus.

Cette fort utile mise à jour de nos connaissances montre aussi quelle prudence est encore nécessaire pour relier les réalités de terrain, les mesures et les extrapolations par modèle que l’on peut tenter; et que chaque approche a ses limites.
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2. Papers should be written preferably in English. Other allowed languages are French, German, Italian and Spanish. Authors using a language not their own are urgently requested to have their manuscripts checked for linguistic correctness before submission. SI system should be used. Dates should be in the form "5 February 1975".

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