

About a peri-Gondwanan - North African enlarged acceptance of the Caledonian Orogeny

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ABSTRACT. The notion of "Caledonian Orogeny" is restricted by most authors to the Ordovician-Devonian thermotectonic events that are associated with the Laurentia-Baltica-Avalonia suturing. However, some views consider an orogeny as the sum of tectonic, metamorphic, and magmatic events accompanying an entire supercontinent assembly or Wilson cycle. Following this line of thinking, the Caledonian and Variscan orogenies successively assembled Pangea. During the Ordovician Period, rifting, collision, deformation, metamorphism, and magmatism took place within the Gondwana margin. All these events are known today in the basement of the Cadomian terranes from Iberia through the Alps up to the Romanian Carpathians and Balkans. We plead here for the enlargement of the "Caledonian Orogeny" terminology to these events and places, under the name of the "Caledonian North African orogenic event" or "Caledonian North African orogen".

Key words: Gondwana, Caledonian orogen, North African orogen, Ordovician, Carpathians

INTRODUCTION

Some authors define the "orogeny" as the sum of events and processes taking place between disruption and assembly of a supercontinent. Thus, Rino et al. (2008) for example, see the "Grenvillian Orogeny" as the sequence of events leading to the assembly of the Rodinia supercontinent and further, the "Pan-African Orogeny" leading finally to the assembly of the Gondwana supercontinent, or Pannotia, according to Winchester et al. (2002). Regarding the Paleozoic Wilson cycle, the Pangea supercontinent assembled through the Caledonian and Variscan orogenies (e.g., Krawczyk et al., 2008; Kroner et al., 2008). According to McKerrow et al. (2000), the Caledonian Orogeny comprises all the Cambrian to Devonian tectonic events associated with the development and closure of those parts of the Iapetus Ocean, situated between Laurentia, Baltica and Avalonia. Rino et al. (2008) extend the term "Caledonian foldbelt" to all the Asian early Paleozoic orogens. Since the rifting of the Avalonian terranes from Gondwana through their drifting and docking to Laurentia and Baltica, roughly between 485 and 450 Ma (Nance et al., 2010), within or adjacent to the North African Gondwana margin, some orogenic events also occurred and the question arising is whether these events should be treated under the general "Caledonian Orogeny" term. This is what the present paper argues about. These events have not a name and in our opinion they should be described as "Caledonian", following the Rino et al. (2008) philosophy.

Caledonian thermotectonic events along the North African Gondwana margin will be mainly discussed based on the literature referring to the Cadomian terranes in the European Variscan and Alpine basement and data from the Romanian Carpathians.

TECTONIC SETTING ALONG THE GONDWANA MARGIN DURING ORDOVICIAN

After the Early Ordovician rifting and then drifting of the Avalonian terranes toward Laurentia and Baltica, easterly of their original position along the Gondwana margin, Cadomian and Minoan terranes (Zulauf et al., 2007) were identified as components of the Galatian superterrane (von Raumer and Stampfli, 2008). According to Nance et al. (2010), Cadomia remained attached to that margin or close to it. All these terranes located today south of the Rheic suture, within the Variscan and Alpine basement, were intruded by Ordovician granitic magmas in connection with an Ordovician orogenic event as highlighted in the literature reviewed below.

According to von Raumer et al. (2002) at about 490 Ma the eastern extension of the Rheic Ocean separated the Cadomia terrane from Gondwana. Cadomia terrane consisted of the following crustal units: Ossa Morena, Cadomia *s. str.*, Saxothuringia, Serbomacedonian, Ligerian, Helvetic, Moldanubian, Penninic, and Austroalpine. Between 480 and 470 Ma the eastern Rheic aborted and Cadomia docked to Gondwana. The Ordovician orogenic event can be circumscribed around 470 Ma. Paleotethys

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Ocean that separated the Hun superterrane from Gondwana, opened post 450 Ma. The Hun superterrane formed as a collage of previous Cadomia terrane constituents and the following former Gondwanan crustal units: Alboran, Adria, Armorica, Apulia, Aquitaine, Cantabria, Dinarides-Hellenides, intra-Alpine, and Iberia. Because of this reason, within the composite Cadomian terranes as parts of the European Variscan and Alpine basement, sutures, ophiolites, granites, tectonic structures, and metamorphic mineral assemblages, all of Ordovician age can be encountered.

In Stampfli and Borel's view (2002), many terranes were detached from Gondwana through the opening of back-arc basins, following the subduction of the Prototethys Ocean ridge. An initial back-arc basin was the Rheic Ocean. At its early stages the back-arc basin had an eastern continuation along the North African Gondwana margin, in the region of the future Cadomia and intra-Alpine terranes. Subduction of the Prototethys oceanic ridge triggered the break-off of Avalonia, whereas toward east, the contraction of the active rift triggered the amalgamation of volcanic arcs and continental ribbons with Gondwana. This is the Ordovician orogenic event, connected to an abandoned Rheic branch.

The same model is adopted by Stampfli et al. (2002). The following fragment from their paper entirely expresses their opinions: "*In the eastern continuation of Avalonia only embryonic stages of the Rheic rifting may have existed. Drifting was hampered by the still-existing mid-oceanic ridge of the Prototethys, the collision of which with the detaching terranes triggered the consumption of this embryonic eastern Rheic Ocean. The amalgamation of volcanic arcs and continental ribbons with Gondwana occurred in a short-lived orogenic pulse. The resulting cordillera started to collapse during the late Ordovician, leading to the opening of the Paleotethys rift. Mid-oceanic ridge subduction during Ordovician, in the former prolongation of Avalonia triggered ... the intrusion of many Ordovician granitoids ...*" (p. 266).

According to von Raumer et al. (2003) the European Variscan and Alpine basement elements may contain relics of volcanic islands with pieces of Cadomian crust, relics of volcanic arc settings and accretionary wedges which were separated from Gondwana during initial stages of Rheic Ocean opening. After a short-lived Ordovician orogenic event and accretion of these elements to the Gondwana margin, the ongoing Gondwana-directed subduction triggered the formation of Ordovician Al-rich granitoids and the latest Ordovician opening of Paleotethys.

Carrigan et al. (2005) reported Ordovician zircon core ages from some Balkan granites and Putiš et al. (2008) mentioned Ordovician magmatic events from Western Carpathians but they attributed these events to some extensional processes.

In a plate-tectonic model, different than the previous one, von Raumer and Stampfli (2008) and von Raumer et al. (2009) preserve the idea of a mid-Ordovician tectonic phase along the North African margin of Gondwana.

Schulz et al. (2008) show that in the Austroalpine domain south of the Tauern window there are many Ordovician 480 to 450 Ma acid plutonic and volcanic rocks, now orthogneisses and metaporphyrroids. Their geochemical signatures are more or less influenced by a subduction process and they can be assigned to an active margin setting.

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Thus the Ordovician metamagmatites involve a full range of continental arc granitic magma to entirely anatectic continental collision granitic magma.

Meinhold et al. (2009) document Ordovician orthogneisses in the Vertiskos terrane basement from the Serbomacedonian massif in Greece.

All these events and their products unquestionable represent orogenic phenomena no matter whether they were extensional or contractional, because they were parts of a sequence leading to the assembly of Pangea supercontinent.

THE ORDOVICIAN OROGENIC EVENT IN THE ROMANIAN CARPATHIANS

Beginning with Pană et al. (2002) paper, it became evident that within the pre-Alpine Carpathian basement the granitic Ordovician magmatism played a crucial role. The age dataset was substantially enriched by Balintoni et al. (2004, 2009, 2010a, b) (Table 1). At the same time, Balintoni et al. (2009, 2010a, b), argue the Cadomian provenance of the Carpathian pre-Alpine terranes, more precisely, their northeastern African origin (except the Danubian domain of the Southern Carpathians) by using detrital and inherited zircon ages models.

Ordovician orthogneisses and metagranitoids are described so far in the Someș, Baia de Arieș, and Biharia pre-Alpine terranes from Apuseni Mountains (Balintoni et al., 2010b), in the upper Cumpăna metamorphic unit of the Sebeș-Lotru terrane from Southern Carpathians (Balintoni et al., 2009, 2010a), and in the Tulgheș and Bretila terranes from Eastern Carpathians (Pană et al., 2002). Balintoni et al. (2010b) suggested an extensional tectonic setting in Romanian Carpathians since late Cambrian until around 470 Ma, followed by a contractional setting between 470 and 450 Ma. During the extensional period a ribbon of continental crust split out from the Gondwana margin. Initially, between this ribbon and Gondwana motherland, a rift accompanied by bimodal magmatism developed, which further evolved to an oceanized back-arc basin (aborted Rheic). During the contractional evolution, a double subduction took place: the aborted Rheic lithosphere under the Gondwana margin and the Prototethys lithosphere under the continental crust ribbon. Continental arc granitic magmas have been generated in relation with the subductional processes intruding both the continental ribbon and the Gondwana margin. This large magmatic event was accompanied by some volcanic eruption. This model is illustrated by Balintoni et al. (2010b). Granites emplacement has been accompanied by metamorphism and deformation. Such events can be called orogenic without any doubt.

Discussion and conclusion

The widespread Ordovician granitic magmatism in the Romanian Carpathians greatly extends the similar processes known in the Alpine and Variscan basement of the Europe. In this way it becomes clear that the Ordovician granitic magmas intruded all the future Cadomian terranes. In agreement with von Raumer et al. (2002, 2003, 2009) and Schulz et al. (2008) such widespread phenomena should be attributed to an orogenic event. We also mention that Condie et al. (2008), observe a significant granitic magmatic pulse around Gondwana at 450 Ma.

Table 1. Distribution of Late Cambrian-Ordovician ages in the basement of the Romanian Carpathians.

Pre-Alpine terranes and their metamorphic units	Protolith type	U/Pb age	Method
Southern Carpathians¹			
Sebes-Lotru terrane			
Cumpana metamorphic unit	Capalna augen gneiss	458.9+/-3.5 Ma	LA-ICP-MS
	Latorita orthogneiss	466.0+/-4.2 Ma	
Apuseni Mountains²			
Somes terrane			
Somes metamorphic unit	Iara Valley orthogneiss	459.8+/-2.7 Ma	LA-ICP-MS
Baia de Aries terrane			
Baia de Aries metamorphic unit	Pociovalistea augen gneiss	470.8+/-5.0 Ma	LA-ICP-MS
	Lupsa porphyroid	467.8+/-3.8 Ma	
	Mihoesti metagranite	467.8+/-4.7 Ma	
	Muncelu metagranite	467.1+/-3.9 Ma	
Biharia terrane			
Biharia metamorphic unit	Lunca Larga metagranites	495.0+/-2.1 Ma	LA-ICP-MS
	Metabasites	477.8+/-3.2 Ma	
Eastern Carpathians³			
Bretila terrane			
Bretila metamorphic unit	Haghimas granitoid	465 Ma	TIMS
	Mandra granitoid	468 Ma	
Rebra terrane			
Rebra metamorphic unit	Nichitas orthogneiss	460 Ma	TIMS
Negrisoara metamorphic unit	Pietrosu orthogneiss	485Ma	
Tulghes terrane			
Tulghes metamorphic unit	Brezuta orthogneiss	485Ma	TIMS

¹Balintoni et al. (2010a), ²Balintoni et al. (2010b), ³Pană et al. (2002)

Considering the timing, the above orogenic event corresponds to the Caledonian Orogeny. Considering the place, it is peri-Gondwanan, North African. We think that it deserves its own name in order to describe and discriminate it when compared with other orogenic events. Consequently, we propose the "Caledonian North African orogenic event" or "Caledonian North African orogen" as names describing these particular thermotectonic events happened in a specific paleo-geographic area. Therefore, we suggest that the Caledonian Orogeny, not to be limited only to the peri-Laurentian and peri-Baltican Ordovician to Silurian thermotectonic events, but expanded to the peri-Gondwanan events also, except the "Terra Australis Orogen" of the Cawood (2005).

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