SUBCOMMISSION on SILURIAN STRATIGRAPHY in SARDINIA

Fieldmeeting
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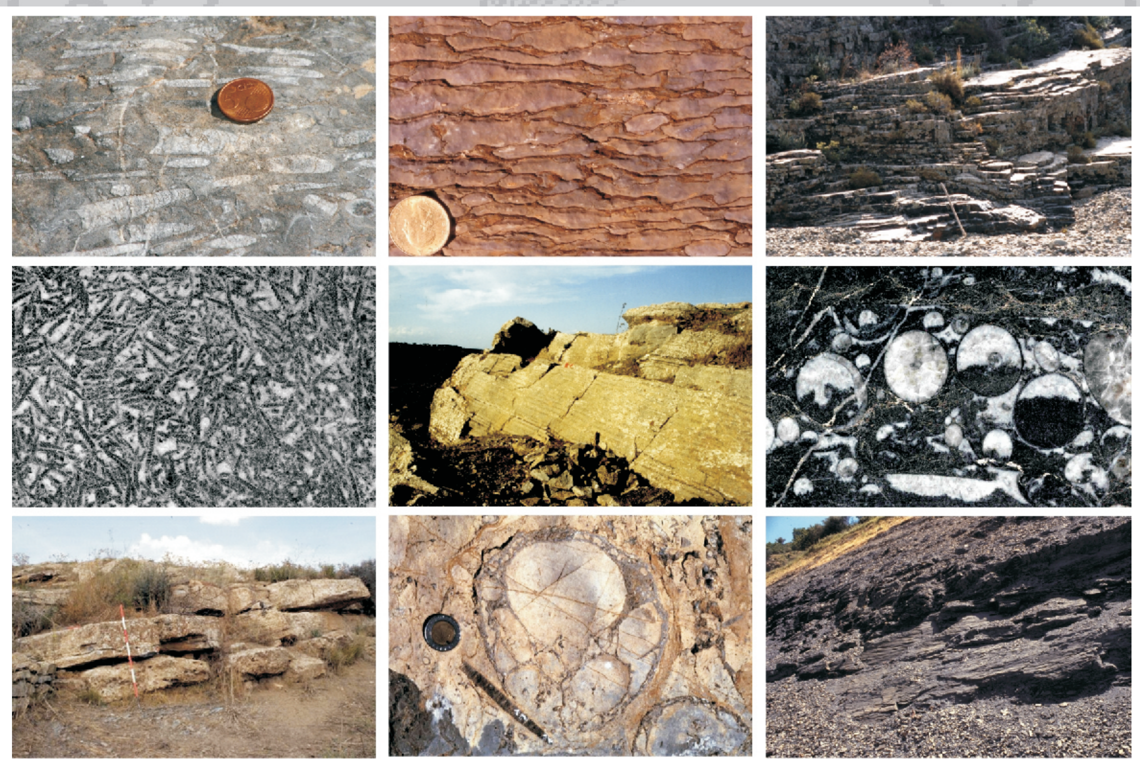
Time and life in the Silurian: a multidisciplinary approach

Rendiconti

della Società Paleontologica Italiana

THE SILURIAN OF SARDINIA



SUPPLEMENTO AL BOLLETTINO DELLA SOCIETÀ PALEONTOLOGICA ITALIANA, VOL.48, N.1

SOCIETÀ PALEONTOLOGICA ITALIANA
MODENA - 2009

Rendiconti della Società Paleontologica Italiana

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The Silurian of Sardinia

volume in honour of
Enrico Serpagli

Edited by
Carlo Corradini
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Società Paleontologica Italiana
2009

Rendiconti della Società Paleontologica Italiana, 3 (1), 2009: 67-76

Silurian Palaeogeography of northern Gondwana: where was Sardinia at that time?

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Abstract - An unambiguous collocation of the actual European sectors in Silurian times is still far from accepted. The most recently published data appear to contradict and disprove current models. The position of Sardinia within this ill-defined scenario is still unclear.

Key words - Silurian, Northern Gondwana, Southern Europe, Palaeogeography.

Introduction

The present-day geographic configuration of Europe was never in existence at any point during the Palaeozoic. The actual setting arose from a collage of diverse terranes, progressively assembled within the continent of Europe through a long process which culminated in the Alpine Orogeny (Cocks & Torsvik, 2006). In order to reconstruct the principal ancient configurations, different scientific approaches have been traditionally proposed. The analysis of faunal affinity between geographic sectors, as well as studies on palaeomagnetism, sedimentary successions, volcanic suites and structural evidence have been used to produce a kinematically valid series of successive palaeomaps (see for example Fig. 1 after http://www.geodynamics.no/PLATEMOTIONS/500-400).

A multidisciplinary approach, embracing and comparing results across vast time intervals, has recently provided new data for discussion of this intriguing topic and justifies this brief overview. In this still tentative global geographic scenario, the role of Sardinia, as well as that of many adjacent sectors, has not yet been established with certainty.

The geographic configuration of Europe

The Silurian is the shortest period of the Palaeozoic Era, lasting only 27 Ma, about half the duration of the Cambrian or the Devonian. At that time, the equatorial belt was occupied by a series of large continents, that had maintained a generally consistent position confirmed by palaeomagnetic data. Laurentia was located across the equator, while Baltica was placed in the southern subtropical belt, having the famous limestones and bioherms of Gotland positioned at about 20°S in the Wenlock (Claesson, 1979; Trench & Torsvik, 1991). The opening of the Rheic Ocean caused the detachment of Avalonia (embracing part of eastern North America and part of North Europe) from Gondwana in the Ordovician, as revealed by changing faunal affinities of trilobites and brachiopods (Cocks & Fortey, 1982, 1990) and by palaeomagnetic data. Avalonia occupied tropical palaeolatitudes in the Silurian (Cocks & Torsvik, 2006). The Iapetus Ocean separated Laurentia from Baltica and Avalonia. By the late Silurian (Cocks & Torsvik, 2006), Baltica, Avalonia and Laurentia joined together to give birth to the supercontinent of Laurussia.

One of the most controversial topics in recent palaeogeographic reconstructions of the Silurian regards the very large palaeocontinent of Gondwana and especially its northern margin with a number of derived peri-Gondwanan terranes of little known history and barely identifiable palaeogeographic configuration. Palaeomagnetic data were not able to provide an unequivocal solution as two diverse polar wander paths were proposed (Robardet, 2003). For that time, most of southern Europe has been commonly located at moderately high latitudes, in an ambiguous "northern Gondwana" setting, according to palaeontological affinities and to sedimentological evidence that had documented a glaciation and proximity to the South Pole in the Late Ordovician. A series of peri-Gondwanan terranes, originally integral parts of Gondwana, have been progressively recognized and located North of northern Gondwana along the southern margin of the Rheic Ocean. At various times in the Palaeozoic, these terranes possibly separated and rifted from it. Their existence is today under discussion, as strong criticism has been put forward by so-called "palaeogeographical splitters" (Servais, 2007).

Stampfli & Borel (2002) proposed an integrated approach to Palaeozoic and Mesozoic palaeogeographies, combining the analysis of dynamic plate boundaries, plate buoyancy and ocean spreading rates with major tectonic and magmatic events. They introduced the concept of the Hun Superterrane as a ribbon-like terrane extending for more than 10,000 km, embracing the Variscan terranes spread along the Gondwana margin, and following the opening of a former peri-Gondwanan ocean – the Prototethys. Stampfli et al. (2006) and von Raumer & Stampfli (2008) subsequently post-dated to the Devonian the detachment of these terranes, renaming those composing future European sectors as a Galatian terrane (Fig. 2). These terranes started their drift to Laurussia in the earliest Devonian, following the opening of the Palaeotethys Ocean after a long rifting phase began in the Late Ordovician.

Among those terranes located along the northern margin of Gondwana, Armorica, Perunica and the eastern Alps represent crucial units. Parts of Spain and France, together with minor other geographic sectors, had been included in Armorica or the Armorican Terrane Assembly (ATA), situated North of the northern margin of Gondwana according to palaeomagnetic (Van der Voo, 1979, 1982; Tait et al., 1997) and faunistic data (Fortey & Cocks, 2003). Tait et al. (2000) suggested that Armorica began a 4000 km North drift separating from Gondwana in the Late Ordovician. Robardet (2003), in a critical review of palaeomagnetic data that had supported Armorica's existence and palaeoclimatic and palaeobiogeographic records found no evidence for an ocean between Armorica and Gondwana, suggesting that "the concept of an Armorica microplate can thus be considered a fiction" and that southern European regions remained along the northern margin of the Gondwana mainland till the Devonian. Linnemann et al. (2004) recently confirmed this view by the study of Nd-isotope data of Late Neoproterozoic to Early Carboniferous sedimentary rocks of Saxo-Thuringia, detecting no significant change in sediment provenance from the Neoproterozoic to the Early Carboniferous. According to the authors, several sectors of the pre-Variscan basement in western and Central Europe, usually

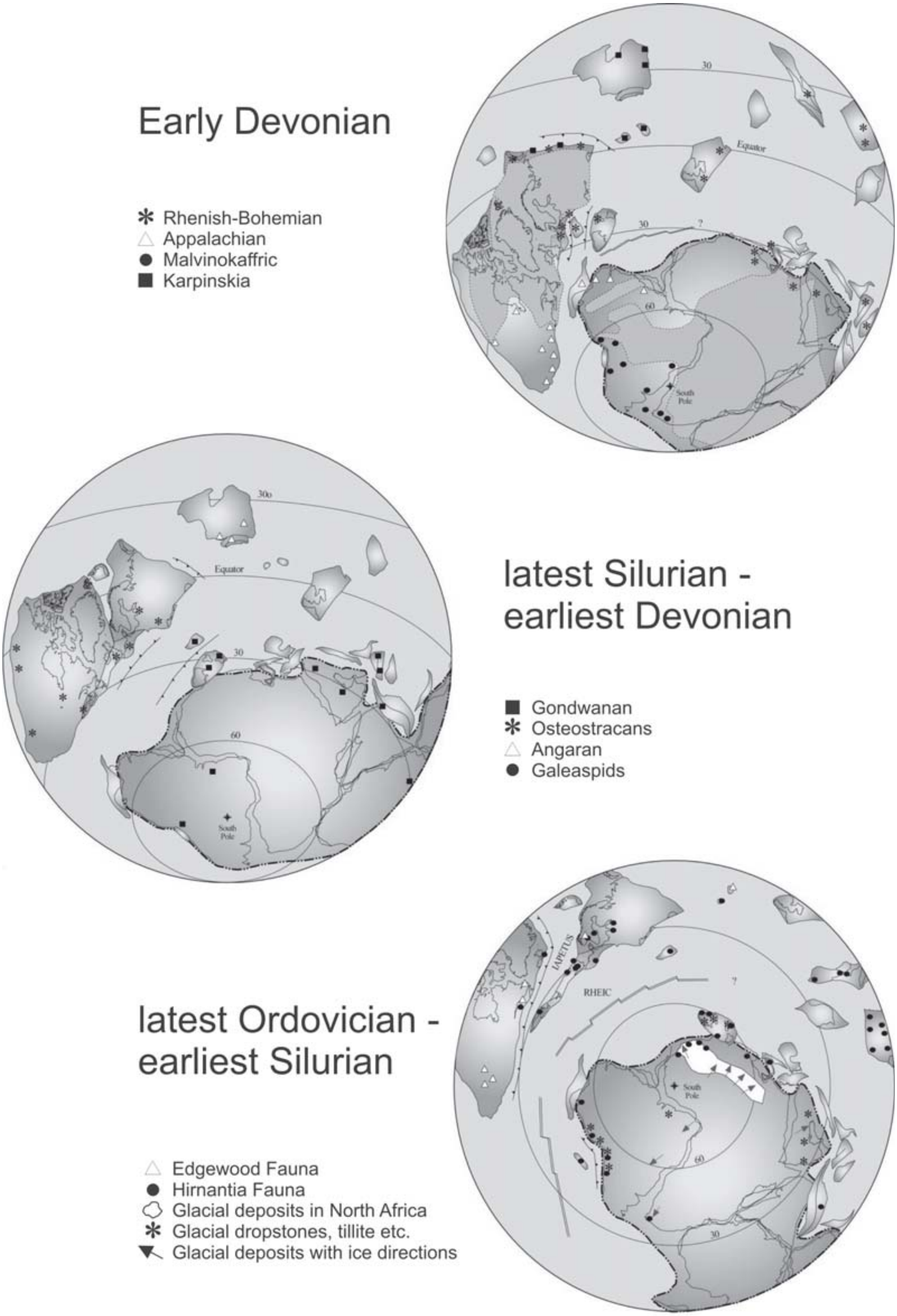

Fig. 1 - Main palaeogeographic reconstructions of the latest Ordovician-Early Devonian (after Torsvik, http://www.geodynamics.no/PLATEMOTIONS/500-400).

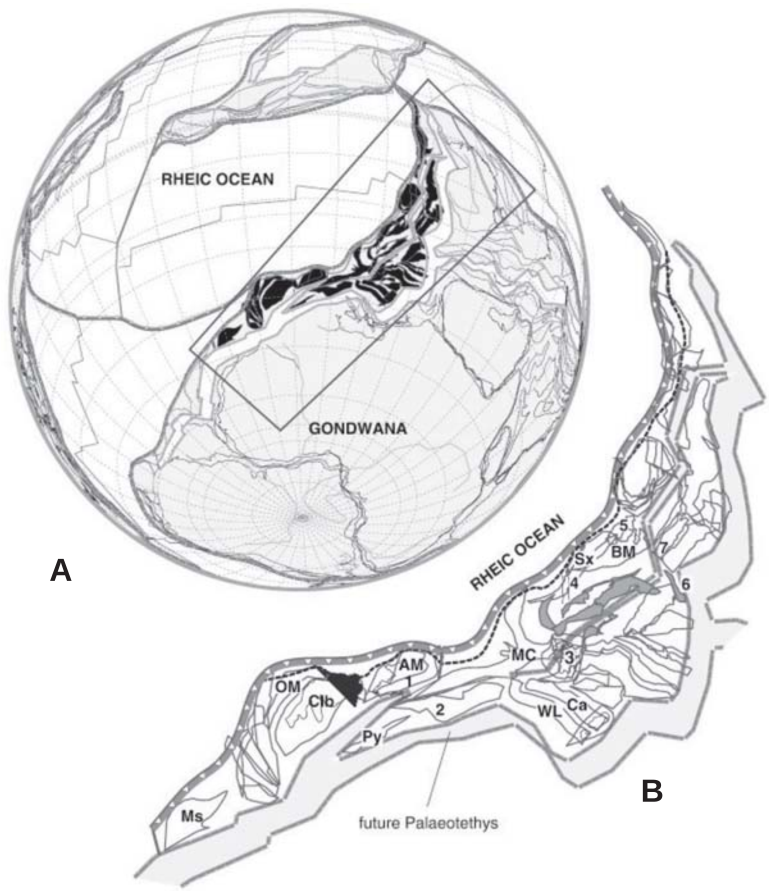

Fig. 2 - A. Global tectonic situation at the beginning of the Devonian. B. Detail of A illustrating the Galatian terrane assemblage. 1: Southern Brittany; 2: North Spain; 3: Sardinia; 4: S. Black Forest; 5: Barrandian; 6: Carnic Alps; 7: Graz Palaeozoic. AM: Armorican Massif; BM: Moldanubian part of the Bohemian Massif; Ca: Cantabrian Zone; CIb: Central Iberia; MC: French Massif Central; Ms: Meseta; OM: Ossa Morena Zone; Py: Pyrenees; Sx: Saxothuringian; WL: Westasturian Leonese Zone (after von Raumer & Stampfli, 2008).

assigned to Armorica, were still attached to Gondwana, "which makes Armorica a remnant of a "Greater Africa" in Gondwanan Europe" (Linneman et al., 2004).

The Perunica microplate, containing the classic Prague Synform in the southeastern Barrandian Region, was originally recognized by Havlicek et al. (1994) on the basis of its peculiar brachiopod and trilobite fauna and by palaeomagnetic data (Krs et al., 1986, 1987; Tait et al., 1994). Comparable to other areas of peri-Gondwana or northern Gondwana, even for Perunica a long drift from high southern to low northern latitudes was supposed after its detachment from the main continent in the Early Ordovician. The existence of Perunica as an independent palaeoplate was recently challenged by Servais & Lehnert (2006) who stated that Perunica was only a part of northern Gondwana.

Sediments of Silurian age are present in the eastern Alps (Austria and northern Italy), with three locations north of an important Alpine structural divide – the Periadriatic Line, and in the Carnic Alps south of the latter, in the present-day northern part of the Italia

Terrane, also called the Apulia Terrane s.l. (Stampfli et al., 1998; Cocks & Torsvik, 2002). Palaeomagnetic data indicates a palaeolatitude of 30–40°S for the Silurian (Schönlaub, 1997). The Proto-Alps in the Late Ordovician were not part of northern Gondwana but a separate (peri-Gondwanan) terrane (Schätz et al., 2002). Histon et al. (2007) recently analyzed 97 K-bentonite levels from the Austrian Carnic Alps, ranging in age from the Late Ordovician to the Early Devonian. They attributed most of the K-bentonites to widespread rifting related volcanism, which possibly persisted till the end of the Middle Devonian, having its source in the peri-Gondwanan area.

The Sardinia Corsica Microplate within the South Variscan Realm

As for the Sardinia-Corsica Microplate (SCM), studies so far conducted have not provided an unequivocal position. The SCM was placed either in Armorica (e.g., Cocks & Torsvik, 2002) or in Gondwana according to geological constraints (Matte, 2001).

The present-day arrangement of the South Variscan Realm (SVR) first of all results from a several hundred- kilometre shift of the Variscides away from Bohemia due to the large clockwise rotation-translation of Gondwana towards North America (Bard, 1997). During this shift, which occurred in Westphalian-Stephanian times, several blocks spread out along a strike-slip dextral mega shear zone that displaced the Sardinia-Bohemia Virgation (Fig. 3) (Bellot, 2005). Moreover, during the Alpine cycle, further dispersion resulted from Tethyan oceanization, Alpine collision and opening of the Mediterranean back-arc basins.

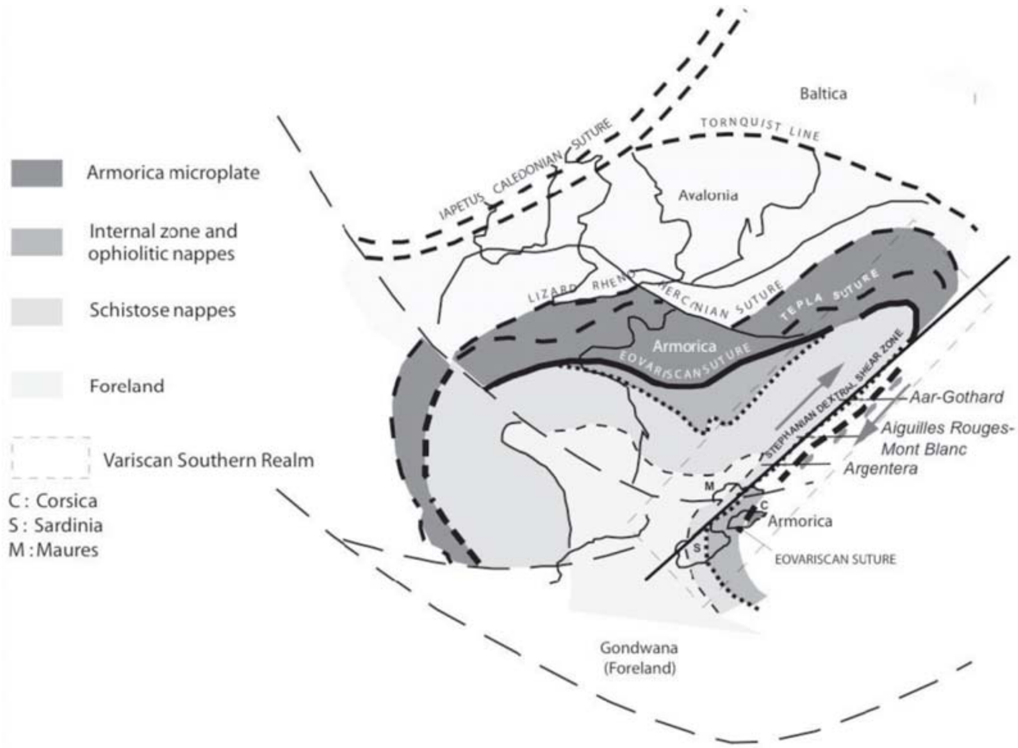

Fig. 3 - Late Carboniferous (Stephanian) arrangement of the Variscan belt (after Rossi et al., in press, mod).

Blocks within the SVR share, however, common characteristics such as the association of low-grade Pan-African-Cadomian basements, Eo-Variscan HP metamorphic events and presence of Mg-K granites. Among these fragments, the Sardinia-Corsica Microplate (SCM) exhibits one of the best-preserved segments of the Variscides. A transect across it gives a remarkable and constructive picture for the reconstruction of the "Southern Variscan Realm" (SVR) from Bohemia through the Alps, the Maures Massif, the SCM and southward to Calabria and Kabylie.

When the SCM is restored to its original position, before the Burdigalian rotation, several fits are found between the Maures Massif and northwestern Sardinia. These concern collision-related, prograde zoneography and a similar post-collision evolution of the Variscan basement (Buzzi et al., 2007). As for the pre-Variscan evolution, several sedimentary and magmatic features are shared by the different units of the Maures and Sardinia including Cambro-Ordovician metasandstones, Lower Ordovician felsic igneous rocks, Upper Ordovician alkaline metabasite, Silurian, graptolite bearing, black shales (Bellot, 2005 and bibliography therein). All these common features allow the Maures, SCM and – after the restoration of the Stephanian dextral shear – also part of Bohemia to be considered as belonging to the same geographic domain.

Von Raumer & Stampfli (2008), besides the report of the well-known calcalkaline Ordovician magmatism, do not consider other evidence from SCM in the reconstruction of the North Gondwana margin evolution. According to their complex pattern, local back-arcs basins, or intra-continental rifts, developed in the Early Cambrian and were followed by Late Cambrian-Early Ordovician closure, and, in turn, by Mid-Ordovician extension, with a large-scale volcanic activity and opening of Palaeotethys. During this time period, the future Hun Superterrane began the drift away from the eastern Gondwana margin. The passive margin of the remaining Gondwana was composed of the Galatian superterranes, constituents of the future Variscan basement areas. This reconstruction hardly fits the field evidence and the geochronological and petrological data of the Sardinia Variscides. Within the Sardinia-Corsica segment of the Variscan chain, Cappelli et al. (1992), Carmignani et al. (1994) and Carmignani (2001), considered the belt marked by the occurrence of MORB-derived eclogites (Posada-Asinara Line) as a tract of the South-Variscan suture, tectonically transported on the Gondwana crust. This belt is sandwiched between the hinterland ("Armorica" crust), cropping in Corsica at Argentella, and the Nappe Zone of the Sardic segment of the Variscan Chain (North Gondwana Margin) and is rooted in the discontinuity, stitched by the Mg-K plutonic association, that actually can separate two different terranes. The age of the Mg-K granites (in the range of 340 My) predates the dextral strike-slip shear zone that displaced Sardinia from Bohemia; as a fact similar Mg-K intrusions crop out from South Bohemia throughout Western Alps down to Corsica, marking the south Variscan suture (Rossi et al., in press).

Before the Variscan collision - bracketed between the Tournasian and Westphalian - according to the sequences exposed in Sardinia, the North Gondwana margin exhibits sedimentary aspects typical of passive margin since the Ediacarian. Then the SCM, comprised in this margin, experienced the onset of an Andean type magmatic arc (Di Pisa et al., 1992; Carmignani et al., 1994; Carmignani, 2001) during the Middle Ordovician. The related calcalkaline products are sub-aerial; they postdate the Sardic phase (post Arenig) and pre-date the Caradoc-Ashgillian transgressive sequence topped with Hirnantian glaciomarine deposits (Leone et al., 1991; Oggiano & Mameli, 2006). Hence no evidence of Cambrian ocean closure and/or evidence for Middle Ordovician rifting originate from the Palaeozoic of Sardinia. Conversely the onset of a rift, after the collapse of the magmatic arc, could have invested the North Gondwana margin starting from Late Ordovician times as testified by alkaline (Ricci & Sabatini, 1978; Di Pisa et al., 1992) metabasalts and epiclastites interbedded within Upper Ordovician and Lower Silurian deposits (Gattiglio & Oggiano, 1990; Oggiano & Mameli, 2006).

If the detachment of “Armorica” or ATA from North Gondwana ever occurred in the Early Palaeozoic, it must be placed in the early Silurian. In any case whether the intervening oceanic space and the related latitudinal gap between Gondwana and “Armorica” shelves was wide enough to support faunal differentiations is to be established. For sure, assuming current spread rates in back arc basin and oceanic rifts, until the early Silurian North Gondwana and its nearby areas - at least those involved in SVR - must be set at high latitude. In fact Late Ordovician glacial deposits occur also in Brittany (Picarra et al., 2002), Corsica (Barca et al., 1996) and Thuringia (Erdtmann, 1991) within crust sectors, which all have to be placed in the ensemble of terranes that detached from Gondwana and accreted to Laurussia.

The rich faunal content of the Silurian sequences, exposed especially in southwestern Sardinia, has enabled palaeobiogeographic considerations. The rich cephalopod fauna collected from southwestern Sardinia reveals clear affinity with Bohemia (Serpagli & Gnoli, 1977; Gnoli, 1987, 1990, 1994, 2003), with 36 species (of 55 total) in common (Gnoli, 1990). Q-mode cluster analysis was applied to estimate faunal similarities between Silurian-Early Devonian nautiloid assemblages from northern Gondwana (Gnoli, 2003). According to these data, major faunal similarity exists between southwestern Sardinia and the Prague Basin (0.89), followed by similarity between southwestern Sardinia, the Prague Basin and the Carnic Alps (0.70).

Similar conclusions had been already suggested by the analysis of bivalves. Gortani (1923) stressed that the bivalve fauna collected in southwestern Sardinia was of the same type as that occurring in the Carnic Alps and Bohemia. Kriz & Serpagli (1993) further detailed the close affinity of the Silurian and earliest Devonian bivalves of southwestern Sardinia and Bohemia, suggesting the existence of direct connections between the two areas, with only minor differences for the late Ludlow-earliest Pridoli attributed to a diverse subsidence of the basin floor in Sardinia.

A gradual faunistic homogenization in the Silurian was documented by a statistical and graphical study on Orthida brachiopods (Tychsen & Harper, 2004) from the major terranes of the Greater Iapetus Ocean Region (including the European Massifs, Core Gondwana, Avalonia, Baltica and Laurentia). This phase was later followed by a successive differentiation in two distinct faunal associations of low-mid and high latitudes. While the peri-Gondwanan European areas appear to have maintained a faunal integrity, remarkable is the loss of affinity of Bohemia with these sectors, possibly indicating a movement of a distinctive terrane.

Graptolites from southeastern Sardinia have been compared with coeval graptolite assemblages recorded in the Saxo-Thuringian Zone of the Bohemian Massif and those from other pelagic deep-water European areas (Barrandian, Alps, Carpato-Balkanids, Ossa Morena Zone, Scania, Bornholm and Great Britain; Barca & Jaeger, 1990). Close links with Barrandian and, in particular, Saxo-Thuringian graptolite faunas are obvious. In turn, some graptolite taxa of Llandovery age, common for North African Silurian shelf, Central Iberian and Ossa Morena zones of Hesperian Massif, and Brittany, are missing in Sardinia, Bohemia and Thuringia (Storch & Massa, 2007). Rickards et al. (1990) recognized a specific graptolite Mediterranean Subprovince neighbouring with Rheic Subprovince in the north and embracing North Africa and the whole Variscan Europe except for Bohemia. Storch (1998) assigned Bohemia and other terranes of the Variscan Europe to “Graptolite province of peri-Gondwanan Europe” with graptolite fauna transitional between low-diversity cold-water, shelfal fauna of North Africa and highdiversity, presumably sub-tropical, fauna of Avalonia and Baltica. Minor faunal differences among the respective terranes may be assigned to depth and nutrient-related constraints on graptolite distribution (Storch, 1998).

If Silurian data appear to indicate a rather cosmopolitan situation, much more defined was the situation in the Late Ordovician. Analysis of the brachiopod fauna (Havlicek et al., 1987) of Katian (early Ashgillian) age revealed substantial differences between the closely-related brachiopod associations of Sardinia and the Carnic Alps from that of the Barrandian area, as the "typical" Mediterranean (Bohemian-Moroccan) elements were subordinate in the first two regions, where invasion of North European warm-water elements was also documented by genera which are completely absent from the North African regions. Similar conclusions were also derived from Late Ordovician conodonts (Ferretti & Serpagli, 1998), stressing strong affinity of Sardinia and the Carnic Alps for the extreme paucity of markers of the Mediterranean Province and the presence of low-latitude genera, already reported in sectors of the conodont British Province (*sensu* Sweet & Bergström, 1984). Vennin et al. (1998) and Villas et al. (1999) had located Sardinia in the Late Ordovician at about 50 degrees South, in strict connection with the eastern Pyrennes, Montagne Noire and Catalonia, on the basis respectively of the main sedimentary facies, and of the *Hirnantia* brachiopod Fauna distribution. The late Katian *Foliomena* brachiopod fauna, that occurs in the Barrandian area and includes many brachiopod and trilobite taxa common in Avalonia and Baltica (Havlicek & Mergl, 1982; Storch & Mergl, 1989), is absent, in turn, in other parts of peri-Gondwanan Europe.

Acknowledgments

We acknowledge with pleasure Kathleen Histon for critical reading and useful comments and Paolo Serventi for graphic support. This paper represents a contribution to the IGCP Projects n. 499 "Devonian sea-land interactions: evolution of ecosystem and climate" and n. 503, "Ordovician palaeogeography and palaeoclimate".

Funding for this work was provided by MIUR-PRIN2007 (*Analysis of stratigraphic, palaeontological and structural features of the Hercynian basement and the Tertiary cover in Sardinia and Calabria, as a contribution to the geodynamic reconstruction of the central-western Mediterranean basin*).

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