

Transient inversion during the opening stage of the Wilson cycle “Sardic phase” in the Iberian Variscides – stratigraphic and tectonic records

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ABSTRACT

Keywords: Variscides; Iberia; Sardinia; Cambrian; Ordovician; transient inversion; rifting.

The sedimentary sequences of the Cambrian to Ordovician age contains unconformities that were designated as "Sardic phase" by correlation with similar tectono-sedimentary events in Sardinia. Recent studies showed diachronism between these events in Sardinia and Iberia; however, the migration of a major geodynamic regime that changes in time might be a reflection of a spatial variation of major events at plate scale. We studied two critical areas in the Centro-Iberian Zone (CIZ): the Marão anticline in the northeast and the Amêndoa-Carvoeiro synform in the southwest. Two unconformities can be emphasized: a stronger lower unconformity of a Volcano-Sedimentary Complex (VSC) of Lower Arenig (and Tremadoc?) age on top of a Cambrian clastic sequence with flysch characteristics; and a milder upper unconformity of Armorican Quartzite of Arenig age on top of both the VSC and the Cambrian sequences. The Sardic event corresponds to folds with steep axial planes at high angles to Variscan structures and thrusts. Together, Sardic folds and thrusts suggest a brief period of transient inversion between a major extension regime during Cambrian to Devonian. The obliquity of Sardic structures to Variscan compression indicates a component of transpression during the Sardic event, corresponding to a tectonically enhanced unconformity near the Cambro-Ordovician boundary. The transient Sardic inversion is interpreted in terms of a break-up and unconformity related to a migration of an intracratonic-rift setting, situated to the southwest of the Ossa-Morena Zone (OMZ), since the Ordovician that become the southwest Iberian suture during the Variscan Wilson Cycle. This migration induced transient compression and dextral strike-slip in the major boundary between CIZ and OMZ due to the presence of incipient primary arc curvature in this segment of the Ibero-Armorican Arc.

The Variscan orogen results from a Wilson cycle of major Paleozoic oceans as well as subordinated minor oceans. The location of these oceans is inferred from the presence of sutures; some are easy to recognise according to paleogeodynamic criteria but some are disputed and are a source of disagreement between different authors. During most of the Palaeozoic, a major Rheic-Prototethys ocean separated the Avalon-Baltica-Siberia craton from the Gondwana craton (Stampfli, 2000). The closure of the Rheic-Prototethys is partially coincident with the opening of the Paleotethys, isolating the Hun Super Terrane or Armorica from the Gondwana continent since the Ordovician (Von Rammer *et al.*, 2002). This is followed by the collision of the Hun Super Terrane with Laurussia during the Devonian. Later on, the progressive closure of the Paleotethys from the Lower Devonian to Lower Carboniferous produces the final shape of the Variscides by oblique dextral collision between Laurussia and Gondwana (Ribeiro *et al.*, 1995; Shelley Bossière, 2000; Matte, 2001). Indentation by the Cantabrian block, a promontory of Gondwana (Dias & Ribeiro, 1995), causes the tightening of the Ibero-Armorican Arc (IAA) with an antithetic sinistral transpressive regime in the Iberian branch (Dias & Ribeiro, 1994) as opposed to the main dextral transpressive regime in the Armorican branch of the Arc.

If the geodynamic evolution and contemporary structures related to the closure of the Variscan oceans have been a major concern in most of the Variscides studies (Matte, 1991; Dias & Ribeiro, 1994), the earlier and related deformation of the opening stages of these oceans are poorly known. This is a major constraint in the understanding of this Fold Belt because the occurrence of widespread inversion episodes in these stages (Coward, 1994) could give rise to significant structural features. The importance of these early stages is emphasised by the generalised "Caledonian" isotopic ages obtained in the basement of the Variscan orogen in regions not affected by this lower Paleozoic major tectonic event. Indeed, these ages could be explained by the thermal resetting induced by the lithospheric stretching related to the opening of the Rheic and the Paleotethys oceans (Crowley *et al.*, 2000).

In Iberia, the presence of a pre-Ordovician deformation preserved in Cambrian metasediments has long been recognised. The sedimentary sequences of Cambrian to Ordovician age contain unconformities that were designated as "Sardic phase" by correlation with similar tectonosedimentary events in Sardinia. Recent studies showed diachronism between these events in Sardinia and Iberia but the migration of a major geodynamic regime that changes in time might be a reflection of a spatial variation of major events at plate scale. We studied two critical

areas in the CIZ: the Marão anticline in the northeast (Coke *et al.*, 1995; 2000) and the Amêndoa-Carvoeiro synform in the southwest (Romão & Ribeiro, 1999; Romão, 2000; 2001) that we surveyed in detail. Two unconformities can be emphasized, as elsewhere in CIZ: a stronger lower unconformity of a Volcano-Sedimentary Complex (VSC) of Lower Arenig (and Tremadoc ?) age (Coke & Gutiérrez Marco, 1995) that lies over a Cambrian clastic sequence with flysch characteristics; and a milder upper unconformity of the Armorican Quartzite Formation (AQF) of Arenig age that lies over both the VSC and Cambrian sequences.

The Sardinic event corresponds to folds with steep axial planes at high angles to Variscan structures that produce the penetrative cleavage that cuts across the unconformity surfaces. Sardinic thrusts are also present (Silva & Ribeiro, 1985; Romão & Ribeiro, 1993) and can be explained by thin-skinned Sardinic compressive tectonics. Together, Sardinic folds and thrusts suggest a brief period of transient inversion between a major extension regime during the Cambrian and Ordovician to Devonian. The obliquity of Sardinic structures to Variscan compression suggests a component of transpression during the Sardinic tectonic event, corresponding to a tectonically enhanced unconformity near the Cambro-Ordovician boundary.

Bimodal magmatism, near the Upper Cambrian/Lower Ordovician boundary, occurs at an Iberian Variscides scale. Granitic plutonism generally predates the early magmatism and it is caused by partial melting of the crust (calc-alkaline granites) or of a mantle component (alkali to peralkaline granites) (Ribeiro, 1987; Crowley *et al.*, 2000). Most authors have interpreted the geodynamic significance of these types of magmatism as related to a rift genesis environment. However, the calc-alkaline geochemical signatures are not compatible with this tectonic environment, but can be explained as products of anatexis of pre-existing crustal material (Ryan & Soper, 2001) with calc-alkaline affinities; in these conditions the granitoids resulted from an increased geothermal gradient arising from an incubating mantle plume (Crowley *et al.*, 2000).

This magmatic activity generated an intrusion situated, in general terms, at the low-angle high unconformity; locally it is possible to observe small intrusions in the AQF, as for example in the Amêndoa-Carvoeiro synform (Romão, 2000). At the NE limit, a volcano-sedimentary sequence occurs with intercalated felsic magmatic rocks, commonly known as *Ollo de Sapo*, (Iglésias & Ribeiro, 1981)—incidentally *Ollo de Sapo* means Eye of Toad. The coarser lithofacies of the *Ollo de Sapo* unit were dated at 488 Ma using the U-Pb zircon dating method (Gebauer *et al.*, 1993). Other orthogneiss bodies of the same unit were dated at 488-468 Ma by the same method (Vaquero & Dunning, 1998). At the CIZ/OMZ contact, at a similar lithostratigraphical position, we observe another magmatic group, whose isotopic dating has very little precision, but the field relationships point to similar stratigraphic ages.

In general, these magmatic rocks groups show identical petrographic and lithostratigraphic characteristics, as well as similar relative ages. These facts suggest that these magmatic rocks are related with the extensional episode that generated them and might be associated to an event of worldwide scale.

All the characters of the “Sardinic phase” in Iberia could be explained by a jump in the intracratonic rift zone from the axis of CIZ during Cambrian to the SW margin of the OMZ after the Lower Ordovician. This would induce various effects: thermal uplift followed by thermal subsidence in the CIZ during the jumping episode, and shortening in both the OMZ and CIZ due to the presence of thermal uplift to the SW of the OMZ, that would later produce the Paleotethys ocean. Thus, the “Sardinic phase” has the significance of a unconformity break-up in terms of sedimentary evolution controlled by rifting. This jump in rifting could be associated with an important dextral strike slip component at the arc, at least in part; primary the extension direction must be in some section of the OMZ/CIZ boundary. The initiation of break-up must take place near the Cambro-Ordovician boundary in accordance with the reconstruction of Paleozoic oceans based in paleomagnetism and paleogeographic relationships (Stamply, 2000); in fact the Paleotethys closed in the Early Ordovician but opened substantially already in the early Silurian. As these ocean widen to the east in present geographical co-ordinates, the diachronism between the Sardinic events in Sardinia and in Iberia can correspond to migration of the tip of the progressively opening ocean; this suggests that the inversion episode was of shorter duration in Iberia than in Sardinia.

The magmatism related to the Sardinic tectonic event can be explained by decompression melting of the mantle generating mafic dykes that induced anatexis in the intra-cratonic rift basin (Ryan & Soper, 2001). These anatexis were producing large amounts of granitic melts in the form of plutovolcanic complexes such as the *Ollo de Sapo*, coincident dykes and volcanism near the OMZ/CIZ boundary.

We conclude that the “Sardinic” transient inversion—explained by a refined plate tectonics model based on modern analogue models—confirms the view that the Variscan Fold Belt is the product of plate tectonic processes, although in quite distinct modalities from those that generated the more typical Alpino-type orogens, such as the Alps and the Caledonides.

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