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ORDOVICIAN *VS.* "CAMBRIAN" ICHNOFOSSILS IN THE ARMORICAN QUARTZITE OF CENTRAL PORTUGAL

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INTRODUCTION

The Armorican Quartzite is one of the most characteristic units of the Paleozoic of SW Europe, being represented in the Lower Ordovician succession of Brittany and Normandy (western France), and also over most of the Hesperian and Iberian massifs of the Iberian Peninsula (in the clarified sense of San José, 2006), with the exception of the Ossa-Morena and South-Portuguese zones (Gutiérrez-Marco et al., 2002; Vera, 2004; Ribeiro, 2006). In Portugal and from north to south, the Armorican Quartzite facies is equivalent to the Marão Formation of Trás-os-Montes (Sá et al., 2005), the Santa Justa Formation of the Tabagón-Valongo-Tamames domain (Romano and Diggens, 1974), the Armorican Quartzite Formation of the Buçaco and Amêndoa-Mação areas (Young, 1988; Romão, 2000a) and the Serra do Brejo Formation in the Dornes area (Cooper, 1980). In spite of the generalized absence of biostratigraphical ties for correlation other than ichnofossils and a few chitinozoan or graptolite data, the latter generally coming from the overlying shales, the Armorican Quartzite in Portugal have been considered as involving a diachronism in sedimentation from Arenig to Llandeilo, becoming younger from west to east (Ribeiro, 1974) according to regional data from the Valongo to Trás-os-Montes areas. These data have been compiled in some syntheses (Hammann et al., 1982; Romano, 1982; Oliveira et al., 1992). However, the single paleontological argument in support of such diachronism, a Llandeilian trilobite found in the middle part of the Marão Formation at Moncorvo (Teixeira and Rebelo, 1976) was later reviewed by Gutiérrez-Marco et al. (1995), and Sá et al. (2003, 2009), who demonstrated that the supposed trilobite was in reality the trace fossil *Rusophycus carleyi* (James), also recorded in other Gondwanan areas within the Arenigian succession (Seilacher, 1970; Gibb et al., 2010). No other authors were able to demonstrate the claimed diachronism in the sedimentation of the Armorican Quartzite, whose deposit took place entirely in the *Eremochitina brevis* chitinozoan biozone (Paris, 1981, 1990; Paris et al., 1982, 2007), regarded as

"early-mid Arenigian" or as late Floian according to the global scale (Paris et al., 2007; Videt et al., 2010).

Romão et al. (2010) recently questioned the current age of the Armorican Quartzite in the southern Central Iberian Zone, and supported a local late Cambrian age for this formation in the Amêndoa-Carvoeiro synform based in a couple of ichnological data, a single U-Pb dating, and some highly speculative tectonostratigraphic inferences which in our opinion are far from being demonstrated. Also with reference to this area, Romão et al. (2010) envisaged the Armorican Quartzite as a highly diachronic late Cambrian to Early Ordovician unit for the Iberian Peninsula. This statement is refuted here with the presentation of new ichnologic evidence that supports the previous Early Ordovician dating of the Armorican Quartzite in the Amêndoa-Carvoeiro synform.

ICHNOFOSSIL DATA

Romão et al. (2010) mentioned the occurrence of *Cruziana* cf. *ománica* (sic) and *Cruziana? barbatarugosa* (sic) in the base of the Armorican Quartzite of the Amêndoa-Carvoeiro synform, located in the southern Central Iberian Zone (Fig. 1). With reference to the data of Seilacher (2007), they believe that these ichnospecies will support a late Cambrian depositional age for the Armorican Quartzite in the studied area. As the unit is dated as Arenigian in other parts of central and northern Iberia, Romão et al. (2010) concluded that the Armorican Quartzite represents a diachronous facies "between Upper Cambrian and Arenig from SW to NE across the Iberian Terranes (...) consistent with a foreland to the NE, in the basement of the Cantabrian Zone".

According with the *Cruziana* stratigraphy for Paleozoic sandstones presented by Seilacher (1970, 1992, 1994, 2007), *Cruziana omanica* Seilacher 1970 is a late Cambrian form characterized by endopodal scratches reflecting a trifid leg with a stronger claw in the middle. *Cruziana barbata* Seilacher, 1970 and *C. rugosa* d'Orbigny, 1839 are two different ichnospecies, being the first exclusive of middle Cambrian beds (Seilacher, 1970, 2007) and the second ranging from Early to Upper Ordovician strata (Seilacher, 2007; Egenhoff et al., 2007). So far, no transitional specimens between *C. barbata* (middle Cambrian) and *C. rugosa* (Ordovician) have been described in the ichnological literature.

The ichnotaxa identified by Romão et al. (2010), although presented in open nomenclature, are clearly insufficient to confirm a particular age of the Portuguese occurrence. The recorded samples may correspond respectively to a *Cruziana* isp. (poorly preserved?) that may resemble *C. omanica*, and a "transitional" *Cruziana*? isp. (perhaps a single lobe of the trace?) between *C. barbata* and *C. rugosa*. The first identification, even if cautionary, is very strange, because the peculiar tricuspidate claw formula of *C. omanica* serves to recognize it even with a few isolated scratches. On the other hand, the single ichnotaxobase shared in common by *C. barbata* and *C. rugosa* is the existence of transverse markings to the bilobed trace, formed by the front legs of the tracemaker when digging in a procline position (Seilacher, 1970, 2007), which may be confused in eroded specimens.

In order to obtain an independent confirmation of the ichnological age given by Romão et al. (2010), our fieldwork in the area lead to the discovery of a very prolific ichnofossil site located in the Armorican Quartzite of the northern flank of the Amêndoa-Carvoeiro synform (Fig. 1). The fossiliferous outcrop is situated in the northern side of route EN 224 southeast of Amêndoa (GPS WGS84 coordinates N 39° 39' 15.52", W 8° 03' 48.78"), and was mapped as belonging to the upper part of the Armorican Quartzite by Romão (2000a, 2000b, 2006). In the laterally continuous quartzite beds, dipping south, we have collected abundant ichnofossils arranged in parallel to the bedding plane (ichnogenera *Cruziana, Monomorphicnus,*

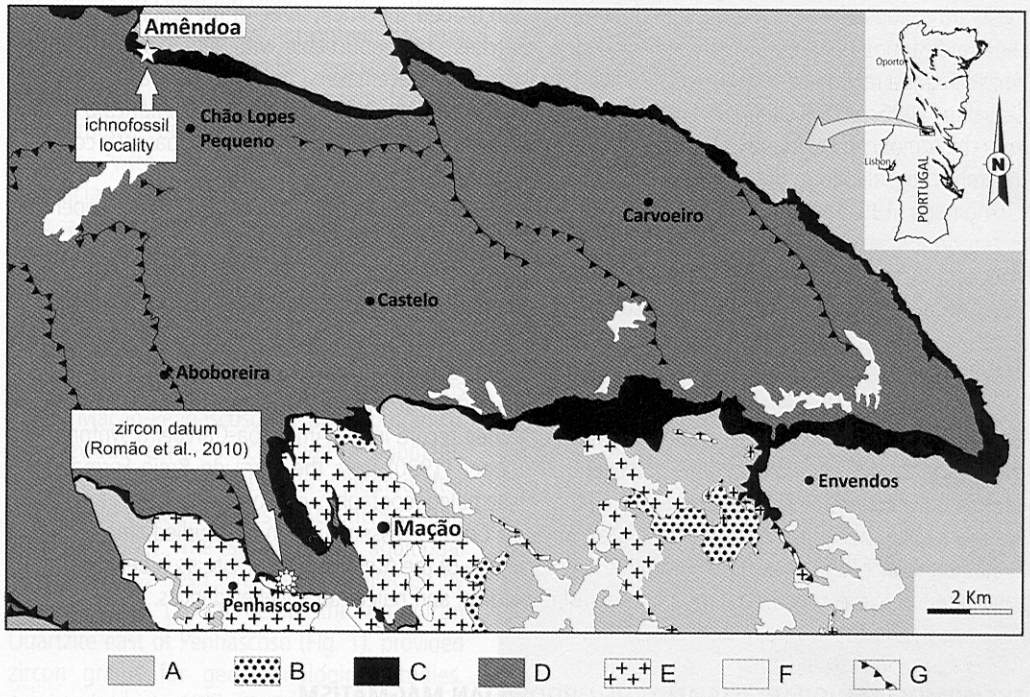

Figure 1. Geological sketch map of the Amêndoa-Carvoeiro syncline (adapted from Romão, 2000b) showing the position of the studied ichnofossil locality bearing *Cruziana imbricata* Seilacher (upper left) and the zircon sample on the Mação-Penhascoso laccolith yielding an Ordovician age (lower left). Inset map shows the location of the area in central Portugal. A, pre-Ordovician basement (Beiras Group); B, Vale do Grou Group (Tremadocian); C, Armorican Quartzite (Floian); D, Other Paleozoic (Darriwilian to Lochkovian) sediments; E, Paleozoic granites (Mação-Penhascoso laccolith); F, Post-Paleozoic cover; G, Traces of the main Variscan thrusts.

Rusophycus, Arthophycus, Crossopodia, Protovirgularia, Palaeophycus, Planolites, Phycodes and *Teichichnus*) as well as others oriented at high to perpendicular angles to it (*Lockeia, Lingulichnites, Arenicolites, Monocraterion, Skolithos, Daedalus*). A large part of this assemblage is represented in the Armorican Quartzite of central and northern Portugal (Cooper, 1980; Romano, 1991; Neto de Carvalho et al., 2003; Sá, 2005; Sá et al., 2003, 2006, 2007; Neto de Carvalho, 2006), which has been known since Delgado (1886, 1887, 1904).

Among the frequent traces of the *Cruziana rugosa* group, we have collected a well-preserved specimen of *Cruziana imbricata* Seilacher, 1970, a typical Arenigian form previously recorded in Portugal from the Armorican quartzite of the southeastern end of the Vilha Velha do Ródão syncline (locality Serra de São Miguel in Delgado, 1886, pl. 34, fig. 1-3: specimens of "*Rysophycus* cfr. *Rouaulti*, Lebesc." partly redrawn by Seilacher, 1970, fig. 7-14). Our material (Fig. 2) is a well preserved arched "bathtub" variant lacking the characteristic prominent endopodal scratches typical of the ichnogenus, which in this ichnospecies are replaced by scale-like "segments" shingling towards the front end, the anteriormost having a lobate aspect. These front-leg markings are difficult to interpret in terms of the digging action by the tracemaker. Seilacher (2007, p. 194) cannot refer them to flaplike appendages resembling the abdominal legs of chelicerates, because their shingling is not orientated towards the narrower rear part, as usually occurs in

these arthropods. However, on the right lobe of our non eroded specimen, three of the combed dig-marks show indications of up to six very faint rounded scratches –only noticeable with very low angle light–, which suggest a producer more related with the *Cruziana* tracemakers. In the same sense, Neto de Carvalho (2006, p. 257) cited a possible gradational specimen between *C. rugosa* and *C. imbricata* coming from the Armorican Quartzite at Penha Garcia (Penha Garcia-Monfragüe syncline), but apparently confused the imbricate seleniform dig-marks of *C. imbricata* with the true scratches.

Romano (1991) situated the Central Iberian occurrences of *Cruziana? imbricata* (sic) in the upper part of the Armorican Quartzite both in Portugal and Spain. Sá et al. (2006) added the occurrence of *C.* cf. *imbricata* in the Santa Justa Formation at Arouca. The single record of *C.*? cf. *imbricata* reported from Salamanca by Pickerill et al. (1984, fig. 2d) probably doesn't belong to the ichnospecies but resembles an ill-defined specimen of *Monomorphichnus* or *Rusophycus*. Outside the Central Iberian Zone, *C. imbricata* has also been reported from the Armorican Quartzite of the Iberian Cordillera (Kolb and Wolf, 1979).

According to Seilacher (1990, 1992, 1994, 2007), *Cruziana imbricata* is a typical Lower Ordovician ichnospecies on Ibero-Armorica and north Africa, and their record in the Amêndoa-Carvoeiro synform also matches with the ichnological data presented by Cooper (1980) from the Serra do Brejo Formation, a lateral equivalent of the Armorican Quartzite in the close paleogeographic vicinity of the Dornes area. Both occurrences contradict the existence of a late Cambrian *Cruziana* assemblage in the studied area, as stated by Romão et al. (2010), and agrees with the Arenigian age of the Armorican Quartzite as is being currently considered in SW Europe based on a number of geological and paleontological evidences.

THE ARMORICAN QUARTZITE AND THE ORDOVICIAN MAGMATISM

The available biostratigraphic information has demonstrated that the deposition of the Armorican Quartzite took place entirely within the Early Ordovician (essentially during the Floian) over a large area of NW Europe. In the northern Central Iberian Zone, the unit immediately postdates an important Cambrian–Early Ordovician magmatic activity ("Ollo de Sapo" belt and related rocks: Díez-Montes et al. 2010; Navidad and Castiñeiras, 2011 and references therein). This makes the Ordovician magmatism older than in other Iberian places outside the depositional area of the Armorican Quartzite facies (Casas et al., 2011).

Modern geochronometric dating of the upper part of the Armorican Quartzite in northern Iberia revealed the presence of age clusters in detrital zircons ranging between 550–800 and 2500–2800 Ma (Fernández-Suárez et al., 2002), as well as a 477.47 ± 0.93 Ma age from magmatic zircons in a single K-bentonite bed (Gutiérrez-Alonso et al., 2007), the latter establishing an absolute minimum age for the rifting that led to the opening of the Rheic Ocean in this peri-Gondwanan section. An age of 470.1–474.6 Ma was recently obtained for magmatic zircons in the volcaniclastic Ordovician unit underlying the Armorican Quartzite in northern Portugal (Gomes et al., 2009), roughly coincident with some imprecise U-Pb zircon and Rb/Sr whole rock dating from similar units in the western Armorican Massif (Bonjour et al., 1988; Bonjour and Odin, 1989).

In the southwestern border of the Central Iberian Zone, Romão et al. (2010) report the existence of the Maçao-Penhascoso microgranite, which intrudes in the lower portion of the Armorican Quartzite of the southern part of the Amêndoa-Carvoeiro synform (Fig. 1). It is a pre-orogenic tabular body (a laccolith), more than 80 m thick (far from the kilometric thickness illustrated by Romão et al., 2010, fig. 1B), that also shows intrusive contacts with the pre-Ordovician basement (Beira Group) and with the basal units of

the Armorican Quartzite (Vale do Grou Group), including the two "Sardic" unconformities that separate them. The laccolith grades into a northern rim of subvolcanic rhyolite textures with eruptive breccias, and it was affected, together with the sedimentary Cambrian-Ordovician host rocks, by three phases of Variscan deformation, being the D1 and D2 accompanied by cleavage and the D3 leading to the formation of the Amêndoa-Carvoeiro synform.

According to Romão et al. (2010), the pre-tectonic morphology and contact relationships of the Mação-Penhascoso laccolith contradicts its previous early-Variscan age assignment, dated in 402 ±15 Ma by the Rb/Sr method after six whole-rock samples (Abranches and Canilho, 1982). The study of an additional sample from a fresh microgranite collected by Romão et al. (2010) below the Armorican Quartzite east of Penhascoso (Fig. 1), provided zircon grains for geochronological studies. Among them, the U-Pb (ID-TIMS) analysis of an individual prismatic zircon resulted in an Ordovician age of "ca 483 Ma" (sic) for this sample, which is considered by these authors as coincident with the age of the laccolith intrusion.

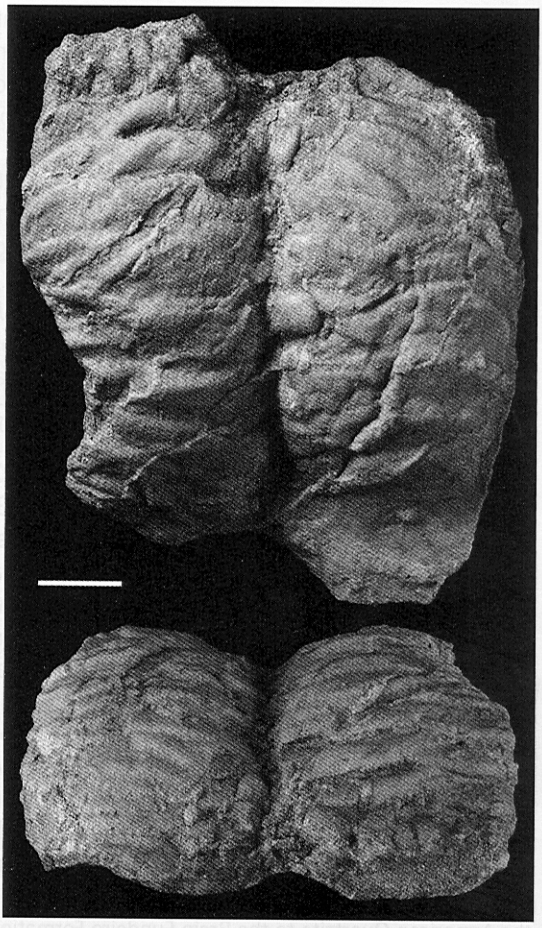

Figure 2. *Cruziana imbricata* Seilacher, 1970. A well preserved specimen from the upper part of the Armorican Quartzite at Amêndoa, in lower (above) and oblique-anterior views. Scale bar=1 cm.

On the basis of the single evidence provided by this zircon datum (the uncertainty range and the number of analyzed zircons were never specified), Romão et al. (2010) hypothesized a sequence of facts leading to the present cartographic expression of the Mação-Penhascoso laccolith. These authors argue that the laccolith is posterior to the sedimentation, the slight "Sardic" tectonism and also the partial erosion that affected the "Upper Cambrian" Vale do Grou Group. And that it intrudes as a "relatively shallow" magmatic body the quartzite and conglomerate beds of the Armorican Quartzite before this unit ends its sedimentation in a coastal environment. As the intrusion of the laccolith was supposedly coeval to the sandy deposition leading to the Armorican Quartzite, which already needed to be of "some thickness and be compacted", the age of this unit should be estimated as "prior to ca 483 Ma (base of Tremadoc and Upper Cambrian)".

Following the sequential model of Romão et al. (2010), the Armorican Quartzite was "bent by the intrusion" of the mushroom-shaped granitic laccolith before completing its sedimentation. This fact supposedly generates a rising area above the intrusion, composed of poorly consolidated strata, which

were "rapidly eroded by marine erosion" or "may eventually emerge". This complex process may explain, in their opinion, the variations in thickness of the Armorican Quartzite (from 0-15 m above the laccolith to about 40-50 m around it), and furthermore, that the microgranite shows in some places an erosive contact with the Middle Ordovician shales of the Brejo Fundeiro Formation, in absence of any thermometamorphic effect in the latter unit.

The highly speculative hypothesis of Romão et al. (2010) for the Mação-Penhascoso granite implies the assumption, not only of a surprising dating for the Armorican Quartzite in a really complicated intrusive setting, but also an age-readjustment for the remaining units and the angular unconformities involved in the area. Thus, the improperly-considered "major Sardic s.l." phase on the Central Iberian Zone is dated by Romão et al. (2010) as "intra-Cambrian (base of the Upper Cambrian to Middle Cambrian?)", when the same Toledanian Unconformity in Central Iberia is simply described as pre-Ordovician (Gutiérrez-Marco et al., 2002). However, the true Sardic Unconformity in Sardinia and the Pyrenees is formed by the angular contact between middle Berounian rocks over a Cambrian to middle Arenigian basement (Leone et al., 2002, and references therein). A second consideration about the diachronism of the Armorican Quartzite from SW to NE across Iberia, is that Romão et al. (2010) situated its equivalent in the Ossa-Morena Zone between middle Cambrian sediments and below the Barrancos Formation, but this particular facies has never been described from this zone. Third, a shallow emplacement of the laccolith during the sedimentation of the Armorican Quartzite in a marine environment necessarily would involve a phreatomagmatic volcanism, similar to the one observed in the Armorican Quartzite of the Cantabrian Zone, because the homogeneous and well calibrated sands that typify the Armorican facies could have remained porose and uncemented during millions of years. Fourth, the pair formed by the Lower Ordovician Armorican Quartzite (dated by *Cruziana imbricata* and the remaining traces) plus the Middle Ordovician fossiliferous shales are the same in the Amêndoa-Carvoeiro synform as in other Central Iberian Portuguese areas located further north (Buçaco, Valongo, Moncorvo). The interpretation of a local uplift followed by the partial erosion of this unit and the lacolith, if occurred before the deposition of the Brejo Fundeiro Formation, should involve an hiatus only explained by the authors at a local scale, i.e. between an Armorican Quartzite (of upper Cambrian-basal Tremadocian age for these authors) and the lower Oretanian shales. In the northern part of the Amêndoa-Carvoeiro synform, for instance, the sequence from the Armorican Quartzite to the Brejo Fundeiro Formation seems to be continuous, without any evidence of such long hiatus in sedimentation as if the lower unit were really older than in other Portuguese sections. In fifth and last place, the existence of an erosive contact between the base of the Brejo Fundeiro Formation and the Ordovician granites, as well as an eroded top for the Armorican Quartzite, needs to be adequately demonstrated through detailed sedimentological studies, lacking at present. In our opinion the tectonic nature of these contacts cannot be disregarded.

FINAL REMARKS

The discovery of *Cruziana imbricata* in the Armorican Quartzite of the northern part of the Amêndoa-Carvoeiro synform supports an Early Ordovician age for the unit, instead of the late Cambrian age suggested by Romão et al. (2010) through some misidentified trace fossils and from an absolute Tremadocian age derived from a tabular microgranite intruding the basal part of the quartzite. Both data have introduced a highly speculative model about the supposedly notorious diachronism of the Armorican Quartzite at an Iberian scale, independently regarded as of uniform age, indicated by the widespread Mid

Ordovician shales that overlie the quartzites. The uplifting of the area during the sedimentation of the Armorican Quartzite and the erosive processes that affected this unit and to the granitic laccolith before the Middle Ordovician are very unlikely and need a detailed demonstration.

The geochronometric Ordovician age of "ca 483 Ma" (sic) derived from a single zircon sample on the granite laccolith may relate its intrusion with the generalized Early Ordovician magmatism recorded in the northern Central Iberian Zone prior or partly simultaneous with the deposition of the Armorican Quartzite in some areas. Interestingly, the laccolith intrusion followed the tectonism that affected the Early Ordovician successions below the Armorican Quartzite in many places of the southern Central Iberian Zone, and whose volcanic influence is substantiated in Spain as well as Portugal: Vale de Bojas and Eucísia formations in Trás-os-Montes (Sá et al., 2005), "Montalto unit" of Valongo anticline (considered as "Proterozoic/Cambrian?" by Couto, 1993) or Serra Gorda Formation of Penha García Syncline (Sequeira, 1993). In any case, the present data are inconclusive until more analyses of magmatic zircons and the isotopic signatures of the Mação-Penhascoso microgranite body are completed. For the moment, the more conservative working hypothesis seems to relate this magmatism and their subvolcanic textures with the same volcanic arc affinity of the Early Ordovician Ollo de Sapo magmatic rocks in the northern part of the Central Iberian Zone.

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