A comparison of the Neoproterozoic / Lower Palaeozoic lithostratigraphy of Morocco and southwestern Iberia. Geodynamic interpretations

Comparación del Neoproterozoico/Paleozoico inferior de Marruecos y del SO de Iberia. Interpretaciones geodinámicas.

A. Tahiri [1], J.F. Simancas [2], H. El Hadi [3], F. González Lodeiro [2], A. Azor [2] y D. Martínez Poyatos [2]

[1] Institut scientifique, Département de Géologie BP 703 Agdal-Rabat. Morocco. abdelfatahtahiri@yahoo.fr
[2] Universidad de Granada, Departamento de Geodinámica, Campus de Fuentenueva s/n, 18002 Granada, Spain.
[3] Faculté des Sciences Casa Ben Msik, Département de Géologie, Casablanca. Morocco

RESUMEN

El Neoproterozoico del sudoeste de Iberia (Serie Negra y Formación Malcocinado) es contemporáneo de un magmatismo calcoalcalino (Precámbrico PIII del Anti-Atlas de Marruecos) que sella la Orogenia Cadomiense. El Cámbrico inferior y medio está representado, tanto en Iberia como en Marruecos, por secuencias detríticas y vulcanosedimentarias formadas en un contexto de rifting. Sin embargo, la evolución de estas dos regiones se diferenció a partir del Cámbrico superior: en el sudoeste de Iberia, la actividad extensional continuó durante el Ordovícico, desarrollándose dominios oceánicos; en Marruecos, dominó durante el resto del Paleozoico inferior un régimen de plataforma débilmente extensional.

Key words: Iberia, Morocco, Neoproterozoic, Early Palaeozoic, lithostratigraphy, magmatism, geodynamic setting.

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Introduction

This paper aims to compare the Neoproterozoic/Lower Palaeozoic series and magmatism of Morocco and Iberia, in order to discuss some aspects of the pre-Variscan geodynamic evolution in these two regions of the Variscan orogen (Fig. 1A). The Variscan outcrops of Iberia are grouped into the Cantabrian, Western Asturian/Leonese, Galicia-Trás-os-Montes, Central Iberian (CIZ), Ossa Morena (OMZ) and South Portuguese (SPZ) zones (Fig. 1B). The Cantabrian Zone and the SPZ are considered external orogenic zones due mainly to the abundance of synorogenic sediments; the other zones are characterized by deformation and metamorphism of variable intensity and abundant granitic plutonism (Pérez Estaún *et al.*, 2004).

The Moroccan Variscides are organized in the following domains (Fig. 1C): i) the Eastern Meseta (including the Atlasic inliers), with late Devonian deformation and metamorphism, as well as Visean calc-alkaline magmatism; ii) a transitional zone or Nappe zone, with Visean deformation; and iii) the Western Meseta characterized by a Westphalian-Stephanian deformation, with metamorphism and granitic bodies (Piqué, 1994). The Variscan structures verge towards the weakly deformed blocks, i.e., the Coastal block to the west and the Anti-Atlas to the south. To the north, the Sehoul exotic block, composed of Cambrian-Ordovician rocks which were deformed in Ordovician times, thrusts onto the Western Meseta (El Hassani, 1990).

The Neoproterozoic

Southern Iberia includes the southernmost part of the ZCI, the OMZ and the SPZ (Fig. 1B). However, the SPZ will not be considered henceforth since it lacks pre-Devonian rocks. In the OMZ and the southernmost CIZ, the Neoproterozoic is represented by the «Serie Negra», made up of dark detrital deposits (schists, greywackes, and black quartzites) and amphibolites (Eguiluz, 1987). The age of the Serie Negra can not be older than Vendian, as revealed by the ages (560-600 Ma) of its youngest detrital zircons (Schäfer *et al.*, 1993; Ordóñez, 1998; Fernández Suárez *et al.* 2002). The transition to the Cambrian corresponds to a volcanosedimentary formation with calc-alkaline signature (Malcocinado Formation; Sánchez Carretero *et al.*, 1989).

In the Moroccan Meseta (Fig. 1C), the Neoproterozoic also contains volcanogenic deposits in a few localities of the Coastal block (El Jadida; Cornée et al, 1986) and Central Morocco (Jebel Hadid; Verset, 1988; Ouali *et al.*, 2003), but the «Serie Negra» is not present. Much more extensive outcrops are found in the Anti-Atlas region (Fig. 1C), where the Neoproterozoic unconformably overlies a basement of around 2000 Ma (PI). The Neoproterozoic is divided into the Anti-Atlas Supergroup (PII) and the Ouarzazate Supergroup (PIII) (Thomas *et al.*, 2004). The Pan-African orogeny took place in the range 680-620 Ma, with the plutonic and volcanic rocks of the PIII (615-550 Ma) representing the late/post orogenic history (Piqué *et al.*, 1999; Soulaimani *et al.*, 2001; Thomas *et al.*,

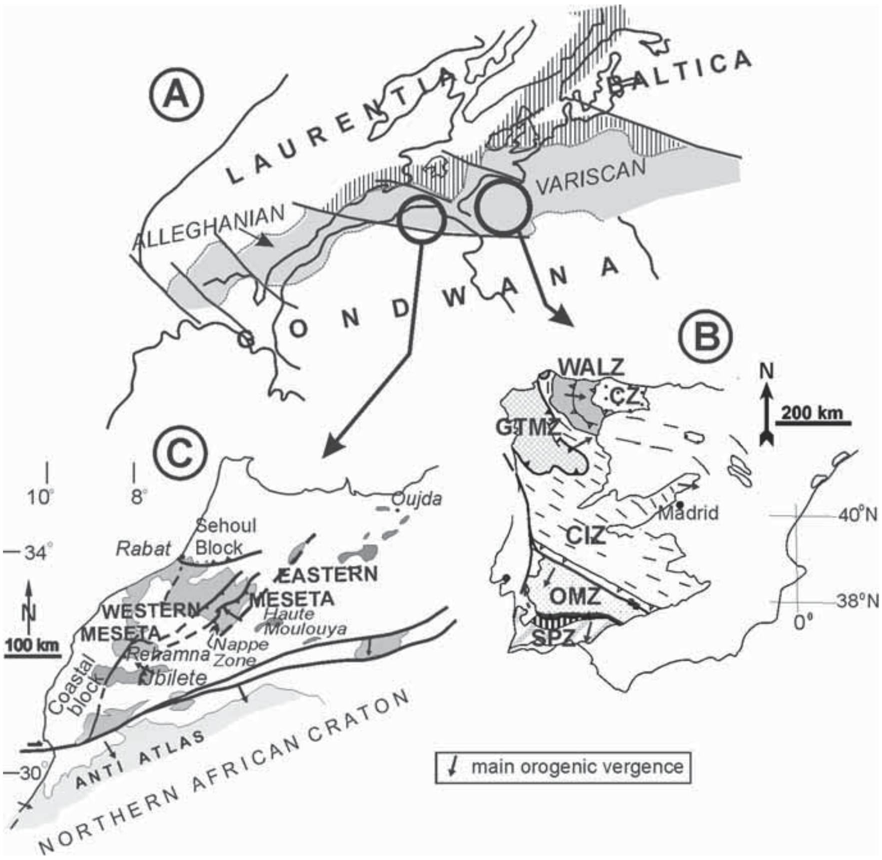

Fig.1.- A: The Variscan-Alleghanian orogenic belt (grey color). The ruled area corresponds to the Caledonian-Taconic orogenic belt. B: Zones of the Iberian Variscides: CZ, Cantabrian; WALZ, Western Asturian-Leonese; GTMZ, Galicia-Trás-os-Montes; CIZ, Central Iberian; OMZ, Ossa-Morena; SPZ, South Portuguese. C: Sketch of the Moroccan Variscides (Palaeozoic outcrops in grey color).

Fig. 1.- A: Cinturón orogénico Varisco-Alleghaniense (banda gris). La banda rayada corresponde al cinturón orogénico Caledoniano-Tacónico. B: Zonas de los Varíscides de Iberia: CZ, Cantábrica; WALZ, Asturorccidental-leonesa; GTMZ, Galicia-Trás-os-Montes; CIZ, Centroibérica; OMZ, Ossa-Morena; SPZ, Sudportuguesa. C: Esquema de los Varíscides de Marruecos (con tono gris, los afloramientos paleozoicos).

2004). Particularly, the upper part of the PIII (575-550 Ma), which is the time equivalent of the southern Iberia Neoproterozoic, is a blanket of lavas, volcanoclastic rocks and coarse-grained clastic and epiclastic deposits, extending unconformable along the entire Anti-Atlas (Fig. 2A).

The Lower Cambrian

The Lower Cambrian deposits in Iberia include clastic sedimentary episodes followed by carbonates and, at the top, new clastic episodes (Zamarreño, 1983); particular features of southwest Iberia are a volcanosedimentary formation at the Precambrian-Cambrian transition and an Early Cambrian volcanism (Liñán and Quesada, 1990). In the Moroccan Meseta, a similar succession is observed in Western Jebilet (the silty, the carbonate and the sandy formations; Huvelin, 1977; Tahiri, 1982; Mayol, 1985), in Réhamna (Michard, 1982) and in Central Morocco (Allary *et al.*, 1976; Ouali, 2001). In the Anti-Atlas (Fig. 1C), Adoudounian deposits of carbonates, sandstones and shales «lie de vin» overlap the PIII, followed in continuity by Lower Cambrian carbonates and shales (Fig. 2B). Thus, at this time, both palaeogeography and latitudinal positions were comparable for the Iberian and Moroccan Variscides.

The Middle-Upper Cambrian

In the OMZ (Fig. 1B), the Middle-Upper Cambrian is represented by pelites and greywackes associated to bimodal, tholeiitic and alkaline (sometimes calc-alkaline) volcanic and plutonic complexes, which attest a rifting stage (Liñán and Perejón, 1981; Sánchez García *et al.*, 2003). These volcanosedimentary deposits display many similarities with those of the Western Meseta Rift in the Coastal block (Western Moroccan Meseta; Fig. 1C), where the Middle Cambrian is represented by the *Paradoxides* schists of Bouznika and associated volcanics (Bernardin *et al.*, 1988; Destombes and Jeannette, 1966). However, when compared with the OMZ rifting, the Western Meseta Rift is both spatially and temporally restricted: the El Hank's quartzite (Middle/Late Cambrian) apparently marks the end of the intense but restricted extensional tectonics in western Morocco.

The Lower Ordovician

In the CIZ, the Ordovician starts with the Armorican quartzite (Arenig), which unconformably overlies Cambrian/Upper Neoproterozoic deposits. Similar quartzitic deposits lack in the OMZ, where silty slates, sandstones and some alkaline magmatic rocks make up the record of this time span (Gutiérrez-Marco and Robardet, 2004). In the Moroccan Meseta, after the basal Arenig conglomerates (Mansouriah section; Destombes and Jeannette, 1966), the sedimentation developed in a siliciclastic platform, very rarely associated to peraluminous magmatism (northwestern Meseta; El Hassani, 1990). Despite the lack of the Armorican quartzite lithofacies, the depositional conditions and the scarcity of magmatism in Morocco point to a palaeogeographic scenario similar to central Iberia rather than to the OMZ.

The magmatism

There is a broad similarity (calc-alkaline affinity) between the latest Neoproterozoic magmatism in Morocco (mainly represented in the Anti-Atlas region) and the one in the OMZ and CIZ (Boyer *et al.*, 1978; Sánchez Carretero *et al.*, 1989). However, fine comparative geochemical studies have not been made yet.

The Early Palaeozoic magmatism of Morocco is volcanic and volumetrically limited, located in the *Paradoxides* schists of Middle Cambrian age (Destombes and Jeannette, 1966). The rocks are rich in LILE and LREE, with an Nb negative anomaly in most of them (Ouali *et al.*, 2001 and 2002; El Hadi *et al.*, 2005). The tholeiitic nature of the

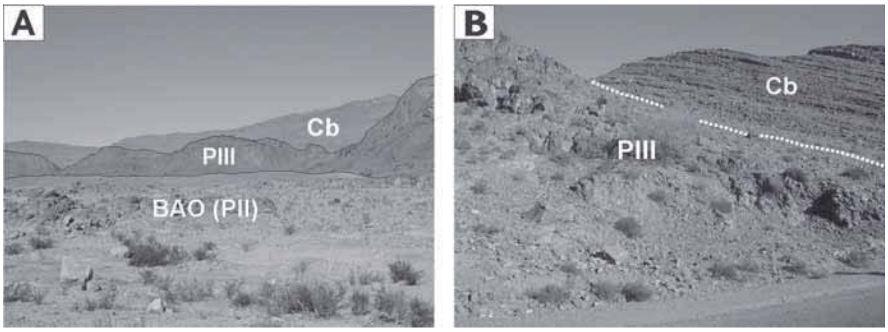

Fig. 2.- A) Panoramic view of the PIII Neoproterozoic, which unconformably overlies the Bou Azzer ophiolitic complex [BAO (PII)]. Over the PIII volcanic and volcanoclastic rocks, Adoudounian-Lower Cambrian carbonates, sandstones and shales lie (Cb). B) Top of the PIII volcanics and base of the Adoudounian and Lower Cambrian sedimentary deposits (Cb), at the NE border of the Zenaga «boutonnière».

Fig. 2.- A) Vista panorámica del Neoproterozoico PIII, que reposa discordante sobre el complejo ofiolítico de Bou Azzer [BAU(PII)]. Sobre las rocas volcánicas y volcanoclásticas de PIII se disponen carbonatos, areniscas y pizarras del Adoudouniense-Cámbrico inferior (Cb). B) Techo de las vulcanitas PIII y base de los depósitos del Adoudouniense-Cámbrico inferior, en el borde NE del ojal de Zenaga.

volcanism at Bou Acila (Morocco central), alkaline at Sidi Said Maachou (Coastal block) and Haute Moulouya, and calc-alkaline at Oued Rhebar (Coastal block), reflects a heterogeneity in the composition of the lithospheric source and probably also different rates of mantle partial melting (Ouali *et al.*, 2000, 2001, 2003; El Attari, 2001; El Hadi *et al.*, 2005).

In southwest Iberia, the magmatism consists in volcanic rocks, granites and gabbros of Cambrian and Ordovician age. Some of the granitoids are alkaline while others are peraluminous (Galindo and Casquet, 2004). The Cambrian volcanism, although bimodal, is dominated by basalts; its affinity is subalkaline to alkaline or tholeiitic (e.g., Mata and Munhá, 1990; Giese and Bühn, 1993; Sánchez García *et al.*, 2003). The enrichment in incompatible elements (REE, Zr, Nb) of some volcanic rocks is typical of intraplate continental alkaline basalts. The Ordovician magmatism of the ZOM is mainly plutonic and alkaline.

Geodynamic interpretations

The 615-550 Ma Neoproterozoic rocks in Morocco postdate the main Pan-African events of deformation (680-620 Ma; Thomas *et al.*, 2004; Fig. 2A). Since the Serie Negra and the Malcocinado Formation in southwest Iberia are younger than 600 Ma, it is very unlikely that they have recorded the main events of the Pan-African (Cadomian) orogeny. This conclusion accords well with previous suggestions that in southwest Iberia there have been some structural misinterpretations attributing to the Cadomian (e.g. Eguiluz, 1987; Abalos *et al.*, 1991) tectonic fabrics actually generated during the Variscan orogeny (Azor *et al.*, 1993; Martínez Poyatos *et al.*, 1995; Simancas *et al.*, 2004). Furthermore, the uppermost PIII (575-550 Ma) volcanic and volcanoclastic calc-alkaline rocks of the Anti-Atlas seem to have been formed in a geodynamic extensional scenario rather than being related to a final Cadomian subduction stage (Piqué *et al.*, 1999). The same interpretation could be applied to the Malcocinado Formation in southwest Iberia.

In Early Cambrian times, after the Pan-African (Cadomian) orogeny, both Morocco and Iberia were part of a broad tectonic scenario (the NW Gondwana margin) characterized by moderate extension. Sedimentation occurred in a platform, dominated either by siliciclastic or carbonate deposits; associated volcanicity was rare (tuffs in Western Jebilet; lava flows in the Anti-Atlas) or moderate (in the OMZ).

The most intense period of continental rifting was the Middle-Upper Cambrian. In the Western Meseta of Morocco, the rift strikes NE-SW (Bernardin *et al.*, 1988; Piqué *et al.*, 1995) and generated volcanic rocks of tholeiitic (Ouali *et al.*, 2000) or calc-alkaline (El Attari, 2001; El Hadi *et al.*, 2005) signature; the age of this rift is restricted to the Middle Cambrian. In the OMZ, rifting is responsible for tholeiitic, alkaline and calc-alkaline plutonic and volcanic rocks. The persistence of the rifting during the Ordovician, mainly in the form of alkaline intrusive rocks, is well documented in southwest Iberia, where oceanic domains would have formed at that time. The calc-alkaline signature of some rift-related igneous rocks in both Morocco and Iberia may be due to partial melting of a mantle previously metasomatized during the Pan-African subduction (El Hadi *et al.*, 2005).

The evolution of southwest Iberia and the Moroccan Variscides was different from the Late Cambrian. In southwest Iberia, the Cambrian rifting evolved until the creation of oceanic crust, as attested by the OMZ northern (Azor *et al.*, 1994; Simancas et al, 2001; Gómez-Pugnaire *et al.*, 2003) and southern (Crespo Blanc and Orozco, 1988; Fonseca and Ribeiro, 1993; Fonseca *et al.*, 1999) orogenic sutures. By contrast, the Western Meseta rift in Morocco aborted before the Late Cambrian, the evidences of extension becoming moderate since then. The Moroccan Mesetas were, during the Late Cambrian and the Ordovician, a relatively stable epicontinental platform affected by moderate intracontinental extension. This extension was responsible for the Late Ordovician palaeogeography (deep zones to the east and coastal zones to the west; Hammoumi, 1988), as well as for the development of a Silurian rift in the Coastal Meseta (Oulad Abbou; El Kamel *et al.*, 1998). The moderate extensional regime in the Moroccan Mesetas lasted until the Devonian-Dinantian, when new sedimentary basins (Sidi Bettache basin) opened in a different context of Variscan strike-slip or transtensif tectonics (Hoepffner, 1987; Tahiri, 1991; Piqué, 1994). To conclude, the Moroccan Variscides best correlate with central and northern Iberia, the OMZ and SPZ zones having no equivalent in Morocco (Simancas *et al.*, 2005; El Hadi *et al.*, 2005).

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