



Letter to the Editor

Reply to the Comment on “*The Moroccan Hercynides*” by Roddaz M., Soula J.C., Benabbou M., Brusset S., Debat P., Ntarmouchant A., Driouch Y., & Béziat D.

The paper “The Moroccan Hercynides” is primarily a synthesis of the Paleozoic development of Morocco, developed from existing data. It is not its aim to present a new geodynamic model, nor to discuss in detail the characteristics of each of the available tectonic models. Accordingly the hypotheses presented by Roddaz et al. (2002) have not been overlooked, and they have been quoted in several places in the text (e.g. Benabbou, 2001; Benabbou et al., 2001; Roddaz et al., 2002; N’tarmouchant, 2003) and their model presented in a figure. Therefore we reject the assertion that we neglected their important contributions.

In fact, in their comment Roddaz et al. emphasize the works of Benabbou et al. (2001) and Roddaz et al. (2002) that dealt with the structural setting of the Carboniferous basins, the characteristics of the associated magmatism and the tectonic framework of the Hercynian (=Variscan) belt in Morocco. However, many statements present in these papers still remain at least partly hypothetical and we take the opportunity here to give more precision on some important points that must be kept in mind.

1. The Moroccan Late carboniferous foreland basins

Since publications by Bouabdelli (1989) and Bouabdelli and Piqué (1996), the Azrou-Khenifra zone is defined as a Carboniferous foreland basin characterized by the westward migration through time of both sedimentation and deformation. Benabbou (2001) and Benabbou et al. (2001) confirm Bouabdelli’s previous work and they illustrate the development of the foreland basin in the northeastern part of the zone by the study of the Addarouch balanced section. Roddaz et al. (2002, and the comment) extend the Addarouch model to the entire central Meseta in an interesting approach, perhaps valuable in some areas, but essentially unproven for the whole domain. For instance, the sections presented for the Khouribga-Oulmès anticline and the rela-

tionship with the Sidi-Bettache basin, presented by Benabbou (2001) as balanced sections, are just working hypotheses. Detailed mapping and structural analysis are obviously required before extending this model to other parts of the Meseta. In another instance, mapping at the scale of 1/50 000 recently realized in the Khouribga-Oulmès anticline, points to the existence of early slicing, but does not explain the relation of these slices with the Devonian-Carboniferous sedimentation in the Sidi-Bettache basin (Izart et al., 2001; Razin et al., 2001; Chévremont et al., 2001). Moreover, the gravity nappes emplaced in the Azrou-Kenifra zone (Allary et al., 1976; Bouabdelli, 1989), the Jbilete (Huvelin, 1977) and the Aït Tamlil Atlasic inlier (Jenny and Le Marrec, 1980; Jenny et al., 1989) are not taken into account in the model of Roddaz et al. (their discussion). In the Mrirt area, existence of these nappes is even refuted (N’tarmouchant, 2003). The authors of the comment should give an explanation for these nappes and their emplacement in the Carboniferous basins.

2. The Late Carboniferous magmatism and the geodynamic setting

In the western Meseta many authors, including Kharbouch (1994, for the various massifs), Aarab (1995, for the Jebilete), Remmal (2000, for the Fourhal area), and El Kamel (2004, for the Rehamna), show that the mafic flows and intrusions that were emplaced from Tournaisian to Namurian times clearly present a transitional-alkaline to tholeiitic affinity, the only calc-alkaline trend being noticed in the Jebilete felsic intrusive rocks. On the other hand, in the eastern Meseta the calc-alkaline nature of the Late Viséan-Namurian magmatism has been known for a long time (Hoepffner, 1981; Kharbouch et al., 1985; Chalot-Prat, 1990; Kharbouch, 1994; Ajaji et al., 1998).

Obviously, two magmatic provinces were represented in Morocco during Carboniferous times. However, in their comment, Roddaz et al. argue that “from a comprehensive

study of the previous data calc-alkaline magmatism was the rule in the Central Meseta”. Now, the quoted reference (Bennouna et al., 2004) for which one of us (C.H.) acted as a co-author, concerns the Tazekka massif in eastern Meseta and therefore it is not possible to present it as an argument for the calc-alkaline character of the central Meseta magmatism. In the same way, we believe that the three (3) analyses extracted from Kharbouch (1994) and presented in the paper of Roddaz et al. (2002) are not sufficient to exclude the tholeiitic character of the flows.

In fact, we are still convinced that the calc-alkaline trend deciphered by Benabbou (2001) and Roddaz et al. (2002) in the Namurian mafic rocks present in a restricted part of the central Meseta (the northeastern part of the Fourhal) is not sufficient by itself to determine the magmatic character of the whole domain. Surely, a detailed, objective and really comprehensive discussion is a prerequisite to any explanation of the co-existence of the above-evoked two magmatic provinces in the Meseta. Such a discussion would also take into account the structural setting of their emplacement, that is widely dated from the beginning of the Hercynian shortening. The mafic magmas, presenting an alkaline-transitional to tholeiitic affinity, have been considered as the signature of an intra-plate extension. They have been described as pre-orogenic (Aarab, 1995), or syn-orogenic in a transpressive regime (Essaifi, 1995; Essaifi et al., 2003).

3. Toward a geodynamic model for the late Carboniferous Moroccan Hercynian belt

Since the Carboniferous, the Moroccan Meseta was an orogenic prism where sedimentation, magmatism and the tectono-metamorphic evolution developed within a tectonic framework which is still actively debated. Two alternative models have been proposed during the last 20 years:

- (i) an oceanic subduction followed by a continental collision; the oceanic lithosphere was dipping to the west, below the present Meseta (Kharbouch et al., 1985; Boulin et al., 1988; Roddaz et al., 2002);
- (ii) a limited continental subduction along crustal faults dipping to the east (Lagarde, 1989; Piqué and Michard, 1989; Kharbouch, 1994; Piqué, 2001) or the west (Chalot-Prat, 1990).

All the authors agree that the Hercynian *s. str.* tectonic evolution was intracontinental, the possible oceanic subduction being achieved at the beginning of the Carboniferous. The problem is the existence, at any time during the Devonian, of an oceanic lithosphere. To solve this question three arguments have been considered:

- *The calc-alkaline magmatism*: This question has been examined above. Moreover, the arguments in favour of the subduction of a Paleozoic oceanic crust or an

intra-continental evolution are largely debated by Chalot-Prat (1990), Kharbouch (1994), Ajaji et al. (1998) and Roddaz et al. (2002);

- *The suture*: Generally, a suture zone is revealed by the presence of ophiolitic complexes, HP metamorphism and syn-collisional granitoids. Such markers, observed in many places within the sutures (even cryptic) in the Hercynian belt of Europe, are not known in the Hercynian belt of North Africa, in Morocco and elsewhere. Roddaz et al. (their comment) admit the absence of these markers and they explain it by comparing the Hercynian belt of Morocco with the present Andean-type orogen and the Pacific subduction, although, following their model, the deformation began with the latest Devonian–Carboniferous continental collision and not during the Devonian subduction. Moreover, Roddaz et al. locate a suture 500 km probably east of Morocco (under present Algeria?). Unfortunately such a hidden suture cannot be traced, either by geological or geophysical arguments, throwing some doubt on its reality;
- *Paleogeographic reconstructions*: It is admitted nowadays that the Hercynian belt of North Africa is part of the peri-Atlantic chains and more precisely that it was connected, before the Alpine orogeny, to the Hercynian belt of western Europe. On the other hand, some reconstructions suppose the existence of oceans between Meseta and Anti Atlas, in the northern part of the West African craton, during the Early Paleozoic (Feinberg et al., 1990) or the Devonian (Stampfli and Borel, 2002). However, some of the paleomagnetic arguments are controversial (Khattach et al., 1995) and anyway there is no geological argument calling for an oceanic separation between Meseta and Anti Atlas. On the contrary, the only oceanic domains identified by Matte (2001), El Hassani et al. (2003) and Simancas et al. (2005) in the Variscan Belt are located north and west of the Meseta. In other words, the model presented by Roddaz et al. (this comment) is not supported by any paleomagnetic or paleogeographic reconstruction.

Finally, the model defended by Roddaz et al. gives the opportunity to delve further into the discussion of the Hercynian orogeny in Morocco. However, based upon a restricted area of the central Meseta, it remains largely hypothetical and it is far too early for it to be extended to the rest of the Hercynian domain of Morocco in the absence of geophysical studies, especially those devoted to the deep crust of the Meseta.

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