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Reply

Reply to Comment on "The Jurassic–Cretaceous basaltic magmatism of the Oued El-Abid syncline (High Atlas, Morocco): Physical volcanology, geochemistry and geodynamic implications" by André Michard et al. (2013) [J. Afr. Earth Sci. 88 (December) (2013) 101–105]

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ABSTRACT

We welcome the comment by Michard et al. (2013) as it gives us the opportunity to better discuss the Jurassic–Cretaceous magmatism of the High Atlas (Morocco). In their comment, Michard et al. (2013) focus on three main points which are: (i) the age of the basalts from Naour, (ii) the structural history of the Central High Atlas and (iii) the geodynamic significance of the related Jurassic–Cretaceous magmatism. We will address these questions in the following sections.

1. Age of Naour basalts: B1 or B2 volcanic pulse?

In our previous study (Bensalah et al., 2013), the age of the Naour basalts was considered as formed during the B1 volcanic event based upon K–Ar dating on plagioclase (Westphal et al., 1979). Indeed, the base and the top of the Naour section gave an age of 173 ± 4 Ma and 166 ± 3 Ma, respectively (Westphal et al., 1979). Moreover, in the 1/100.000 geological map of Imilchil (Fadile, 2003), the Naour basalts are indicated as interstratified within sedimentary rocks of the Guettioua Formation and are considered as Bathonian (~164–167 Ma). However, we pointed out in our original study that the K–Ar age of the Naour basalts is subject to revision due to outdated analytical procedures, as well as alteration state of the plagioclases. Conversely, micropaleontological data (charophytes and ostracods) suggested that the Naour

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basalts are interstratified within the Jbel Sidal Formation (Barremian) and thus are Cretaceous in age (Haddoumi et al., 2010; Charrière et al., 2011). A Cretaceous age is also supported by pioneer paleomagnetic data of the Naour basalts (Westphal et al., 1979), for which the position of the virtual paleomagnetic poles of the base, middle and top of the sections are closer to the Cretaceous (poles at 140–100 Ma) rather than the Jurassic (180–150 Ma) segment when compared to a global apparent polar wander path (GAPWP) (Torsvik et al., 2012) (Fig. 1A).

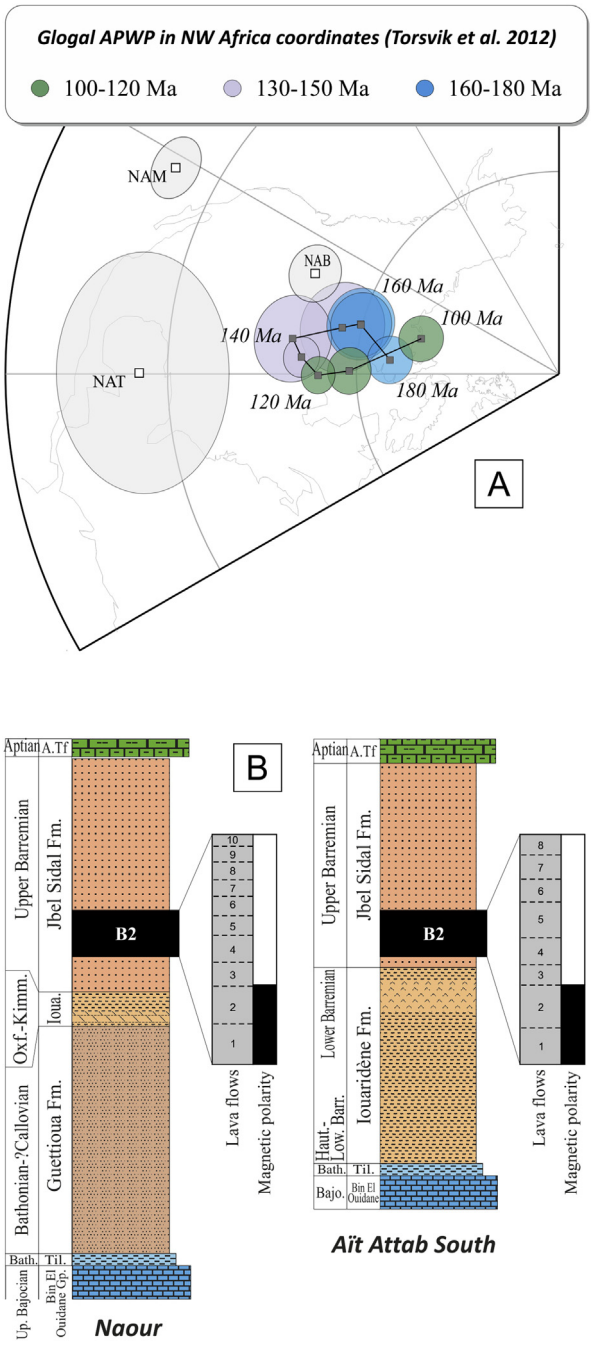

Fig. 1. (A) Virtual Geomagnetic poles of the Naour section (Westphal et al., 1979) compared to the global apparent wander path (GAPWP) of Torsvik et al. (2012) in Northwestern African coordinates (NAB = Naour base; NAM = Naour middle; NAT = Naour top). (B) Stratigraphic log of the Naour and Aït Attab South sections (modified from Haddoumi et al., 2010) showing that both sections share a geomagnetic reversal at the boundary between the second and third flows.

We also performed new paleomagnetic investigations in the Naour and Aït Attab South sections, but results were not available before the submission of the revised version of our original manuscript (Bensalah et al., 2013; Font, E., unpublished data). In both sections, we sampled all the lava flows and treated the samples by alternating field demagnetization in order to calculate the directions and polarity of the magnetic remanence recorded in these flows. Our new paleomagnetic data confirm the transition from normal (positive) to reverse (negative) magnetic directions at the base of the Naour section (between the second and third lava flow), as previously observed by Westphal et al. (1979). In addition, we identified the same magnetic polarity transition in the second and third flow of the Aït Attab South section (Fig. 1B). These new magnetostratigraphic data thus suggest that the Naour and Aït Attab South lava flows have the same age. Micropaleontological analysis of the red bed located below and above the Aït Attab basalts revealed a transition of the charophyte biozones, from *Globator mutabilis* of a lower Barremian age to the biozone with *Globator trochilidiscoïdes* of an upper Barremian age (Haddoumi et al., 2002; Mojon et al., 2009; Haddoumi et al., 2010).

Resuming, we agree with Michard et al. (2013) that the eruptions of the Naour basalts should be assigned to the B2 event, and we bring new magnetostratigraphic evidences to confirm a Cretaceous age for both the Naour and Aït Attab South sections. Independently of the age of the Naour basalts, the main implications of the Bensalah et al. (2013) work still remains valid.

2. The geodynamic significance of the Central High Atlas Jurassic–Cretaceous magmatism

In our paper, we mainly focus on the petrological aspects of the Central High Atlas magmatism and on its geodynamic significance on the basis of new geochemical and mineralogical data. In addition, during the preparation of the paper, it clearly appeared that, despite the number of studies carried out on the Atlas chain, the structure and the Mesozoic evolution of the High Atlas remains unclear and a consistent geodynamical model is still lacking. We thus limited the paper to the petrological aspects and postponed the interpretation of geodynamic aspects to a future paper which will be based on multiple data sources, including the publications referred to by Michard et al. (2013).

2.1. Age of emplacement of the magmatic rocks

We agree with Michard et al. (2013) that the role of halokinesis could have been important for the development of the High Atlas folds, as first suggested by Ettaki et al. (2007), and that dating the formations at the anticline tops (Charrière et al., 2009) removed the inconsistency of the exhumation of the magmatic bodies in such a short interval. This is supported by recent thermochronologic data suggesting that plutonic rocks were still located at depth in the 90–80 Ma time lapse (Barbero et al., 2007), as reported in our paper (Bensalah et al., 2013).

2.2. The West Moroccan Arch

The West Moroccan Arch (WMA) structure was first identified as a topographic structure, based on stratigraphic successions and palaeogeographic maps (Roch, 1950; Choubert and Faure-Muret, 1962; Favre and Stampli, 1992, Stets, 1992; Medina, 1995). The structure was named "Terre des Almohades" by Choubert and Faure-Muret (1962) and later renamed WMA, based on the fission track results by Ghorbal et al. (2008) and Saddiqi et al. (2009). Regrettably, the works of Choubert and Faure-Muret are rarely cited in modern literature.