



Early Exhumation of the Beni Bousera Peridotite-Granulite Unit (Internal Rif, Morocco) Inferred from Its Metasedimentary Cap; A New View on Some Marbles and Regional Implications

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Abstract

The exhumation of the Beni Bousera peridotites of the Internal Rif is currently ascribed to the Neogene tectonics of the Alboran Domain. Here we report on marbles included in a fault zone surrounding the Beni Bousera peridotite-granulite unit and overlain by the Filali gneiss and schists. They should derive from a sedimentary cap overlying unconformably the Beni Bousera unit. Their metamorphic evolution would have occurred beneath the Filali thrust burial. We examined the possible correlations with the Beni Malek serpentinites (External Rif) and the Ronda peridotites massifs (Betic Cordilleras), and infer a post-Permian, pre-Neogene exhumation of the Beni Bousera unit.

Keywords

Infracontinental Peridotites • Mantle exhumation • Hyper-extended margin • Gibraltar Arc • Rif Belt

1 Introduction

The largest complex of orogenic peridotites on Earth crops out in southern Spain (Ronda, Alpujarrides nappes) and northern Morocco (Beni Bousera, Sebtides nappes) within the Alboran Domain at the core of the Gibraltar Arc (Fig. 1).

Their exhumation up to the surface is currently ascribed to the Neogene tectonics of the Alboran Domain (Gueydan et al., in press and references therein). An early exhumation of the mantle rocks and juxtaposed granulites (kinzigites) up

to the middle crust depth is supposed to have occurred during the Jurassic rifting of the Alpine Tethys, based on scarce geochronological data (Michard et al. 2002; Hinsbergen et al. 2014). However, recent field studies of the southern Ronda massif have suggested that it was exhumed up to the surface as early as the Permian (Sanz de Galdeano and Ruiz Cruz 2016).

2 Geological Setting

The Beni Bousera massif stands to the SE of the Rif Internal Zones (Figs. 1 and 2); it is cored by the peridotites and their kinzigites envelope, which form together the Beni Bousera unit characterized by high-pressure, high-temperature mineral associations (Chalouan et al. 2008; Kornprobst 1971). The Beni Bousera unit is overlain by the Filali unit where mineral associations belong to the high-temperature, low-pressure metamorphic facies. Both units are shaped by a late, NW–SE trending antiform truncated obliquely by normal faults along its northeastern flank (Ras Araben fault system). These high-grade units (Lower Sebtides) are overlain by two sets of lower grade thrust units, from bottom to top, (i) the Federico units (Upper Sebtides) that include Permian–Triassic terrains likely detached from the Filali unit, and (ii) the Ghomarides-Malaguides nappes mainly constituted by Paleozoic terrains and their Mesozoic-Cenozoic non-metamorphic cover. The “Dorsale calcaire” detached units are pinched at the front of the Ghomarides-Sebtides nappe stack. They altogether form the southern part of the Alboran Domain thrust onto the Maghrebien Flyschs nappes (Fig. 1b). The latter nappes are made up of Cretaceous-Cenozoic deep marine turbiditic and clayey beds regarded as the infilling of the Alpine Tethys, which connected with the Central Atlantic from the Middle Jurassic to the Eocene (Frizon de Lamotte et al. 2011). The southern Alboran terrains are interrupted southeastward by the Jebha sinistral fault; they crop out again further to the east in the Bokkoya massif (Fig. 1b).

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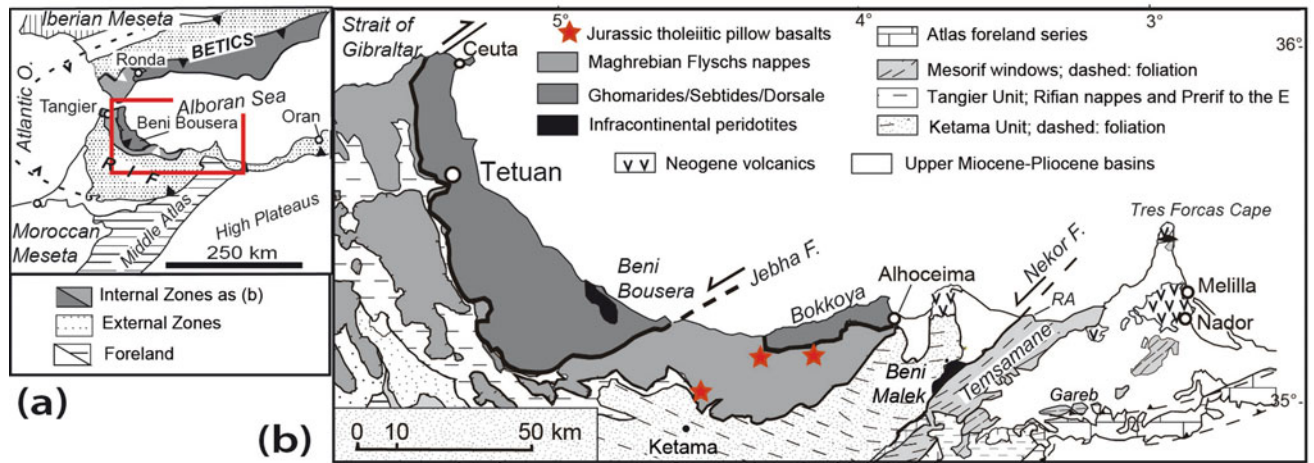


Fig. 1 **a** Sketch map of the Betic and westernmost Maghrebides (Rif-Tell) Alpine belts, after (Durand-Delga et al. 2000). **b** Structural map of the northern Rif after (Chalouan et al. 2008)

The Flysch nappes are in turn thrust upon the External Zones that derive from the inversion of the North African hyper-extended margin (Michard et al. 2007). The Beni Malek serpentinites and associated metabasalts are pinched between the Lower Cretaceous sandstones of the Ketama unit (Intrarif) and the Tamsamane Jurassic-Miocene stacked units (Mesorif); they record an oceanic area of exhumed serpentinitized mantle during the Upper Jurassic (Michard et al. 2007). The Oligocene–Miocene suturing of this area was associated with a medium-pressure, low-temperature metamorphism. The same “Mesorif suture zone” can be recognized further to the east in the Oran Mountains (Michard et al. 2007).

3 Methods

A detailed mapping of the marble outcrops was carried out on both sides of the Oued Amter valley, which cuts across the southeastern pericline of the Beni Bousera antiform

(Figs. 2 and 3). In the marble outcrops, the structural analysis classical methods were implemented. Samples were collected for petrography. At the present stage of our work, thin sections have been studied only under the optical microscope (Christian Chopin courtesy, ENS Paris). Other samples are being processed for geochronological purposes.

4 Results

4.1 Mapping

Marbles have been mapped in detail over >1 km along the northeastern flank of the Beni Bousera antiform on both sides of the Oued Amter valley, and observed on the southwestern flank of the pericline in the Oued Jouj (Fig. 3).

On the northeastern flank of the antiform (Fig. 4), the marbles occur in the form of dismembered, 10–30 m thick minor units in a fault zone whose thickness varies from ~300 m near Taza-village to only ~30 m or less at Inoualine.

Fig. 2 **a** Structural map of the Beni Bousera massif and juxtaposed units of the southern Alboran Domain, after (Chalouan et al. 2008). **b** P–T paths of the southern Sebides units after (Chalouan et al. 2008)

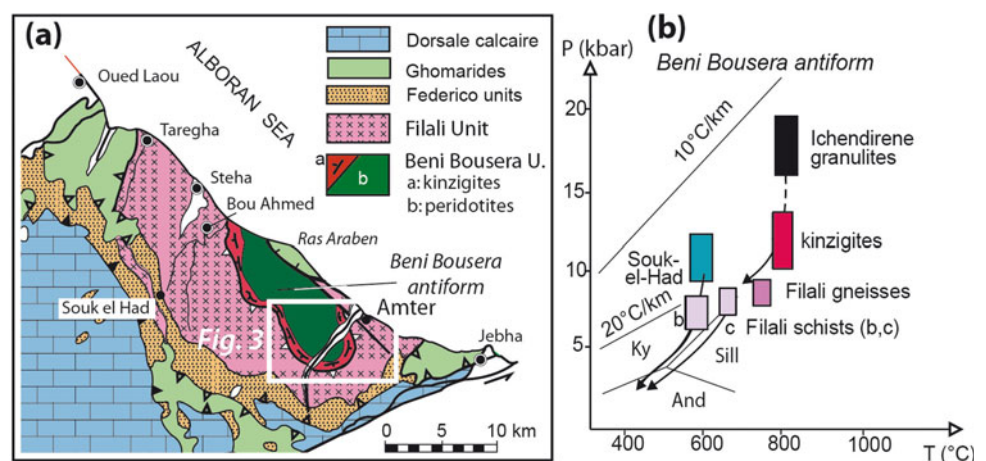


Fig. 3 SE pericline of the Beni Bousera antiform after (Kornprobst 1971) in the Geological map of Morocco, scale 1:50,000, Bab Berred sheet, modified. Framed: location of Fig. 4

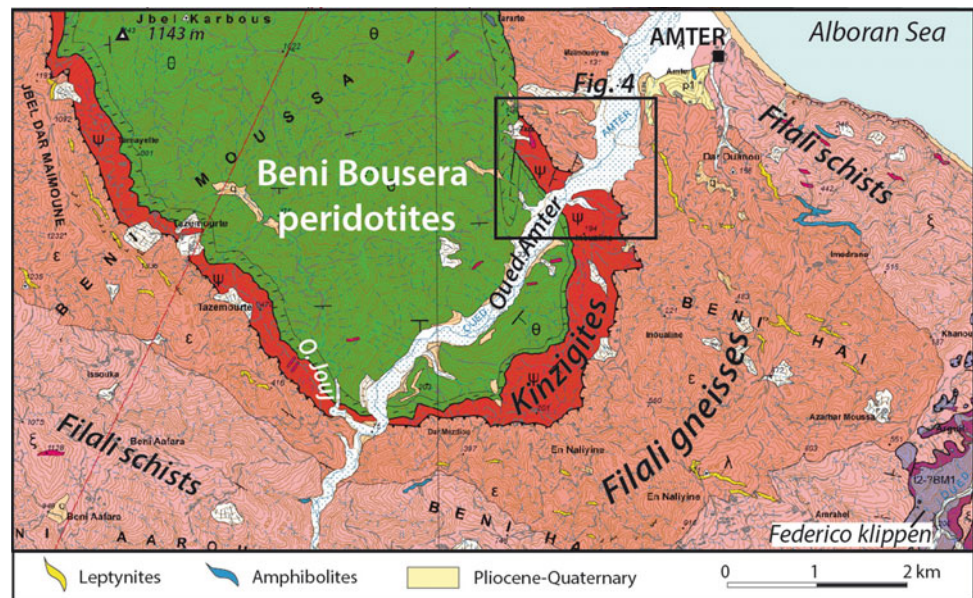
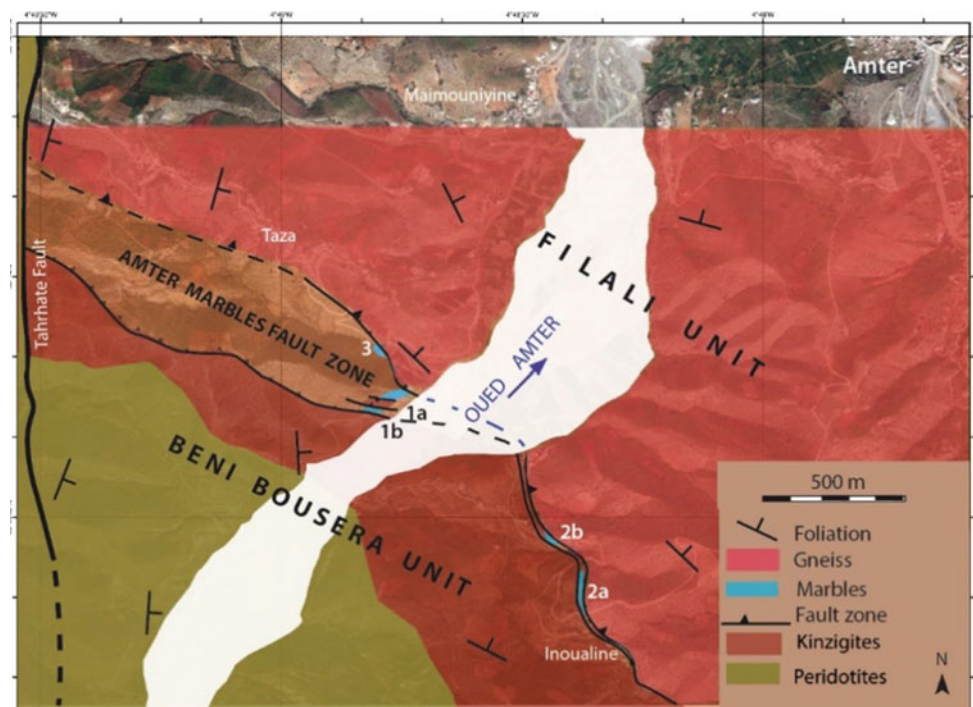


Fig. 4 Geological map of the Amter Marbles Fault Zone (a mix of marbles, kinzigite and gneiss spalls) along the NE flank of the Beni Bousera Unit. Location: Fig. 3



4.2 Lithology, Structure, Mineralogy

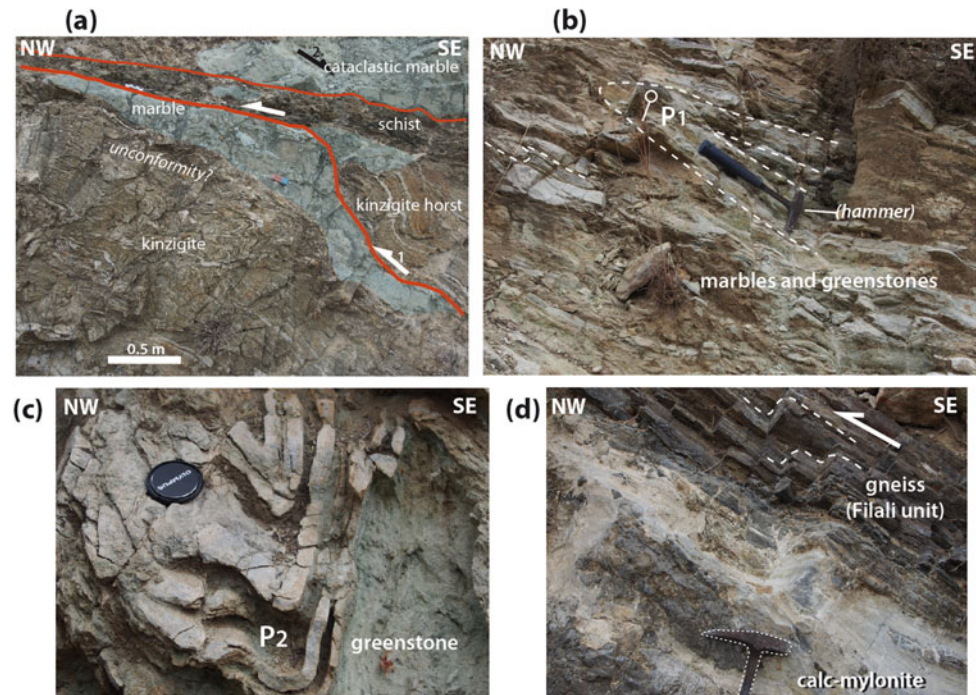
The marbles frequently display alternating beds of pure and silicate-rich facies or of thinly bedded marble and green phyllitic facies (Saddiqi 1988), which demonstrates unequivocally their sedimentary origin (Fig. 5a–c). Locally (outcrop 2a, Fig. 4), thinly layered meta-clastites are interleaved within the marbles. Two outcrops (1b and 2b, Fig. 4) suggest a primary unconformity onto the kinzigites (Fig. 5a). In contrast, the upper limit of the marbles at the bottom of the Filali unit is a NW-verging thrust fault involving a

meter-thick calc-mylonite with fractured fragments of the overlying gneiss (Fig. 5d).

Within each marble elementary unit of the “Amter Marbles Fault Zone”, NNE-trending folds are conspicuous. Locally two generations of folds can be observed (Fig. 5b, c). The second-order faults within the fault zone exhibit either the characters of northwestward ductile thrusts (Fig. 5a) or that of northward dipping, brittle normal faults.

The marbles exhibit varied metamorphic minerals either scattered or arranged in foliation planes within the recrystallized calcite ground mass. Pending the results of

Fig. 5 **a** Basal contact of Inoualine marbles (location 2b, Fig. 4). **b, c** Thinly bedded marbles with alternating phyllitic beds showing superimposed folds P1, P2 (location 3, Fig. 4). **d** Calc-mylonite with gneiss spalls on top of the marbles beneath the Filali unit (location as b, c)



micro-chemical analyses, we confirm the occurrence of diopside, scapolite, K-feldspar, and titanite, already noticed by Kornprobst (1971). We also observed abundant phlogopite lamellae and late talc, likely recording an evolution of the conditions of metamorphism of magnesian limestones or dolostones. Detrital minerals include quartz, K-feldspar and zircon grains. Rounded phyllitic aggregates could derive from peridot (Kornprobst 1971) or pyroxene of detrital origin.

5 Discussion

5.1 Amter Marbles Significance

Kornprobst (1971) considered the marbles as intercalations within the kinzigites series. Our results show that the Amter marbles are not intercalated within the kinzigites, but concentrated in a relatively thin fault zone between the kinzigite envelope of the Beni Bousera unit and the overlying Filali unit. Moreover, it seems that the marbles only suffered high-temperature, low-pressure metamorphism (Kornprobst 1971), similar to that of the Filali unit and contrasting with that of the granulite-facies kinzigites. Therefore, we assume that the Amter marbles derive from marine, basically carbonate deposits with scarce clay fraction and detrital input that initially capped the kinzigites. This implies that the Beni Bousera unit was exhumed up to the seafloor at the time when these calcareous facies were deposited. The metamorphism of the marbles was presumably acquired together

with that of the Filali unit and beneath the same burial, judged on a broad estimate of their conditions of recrystallization.

5.2 Early Exhumation of the Gibraltar Arc Peridotites

Pending the results of datings, we propose to correlate the Amter marbles either to the Triassic (?) marbles described over the SE part of the Ronda peridotites (Sanz de Galdeano and Ruiz Cruz 2016) or to the Jurassic (?) marbles that overlie the Beni Malek serpentinites in the Mesorif Suture Zone (Michard et al. 2007, 1992, 2018) (Fig. 1). In both cases, the exhumation of the Beni Bousera-Ronda peridotites up to the land surface or to a few hundred meters (the average thickness of the granulite envelope) beneath the seafloor appears as a post Variscan event, linked to the Permian–Triassic rifting of Pangea and subsequent opening of the Central Atlantic—Alpine Tethys realm. This is consistent with the Early Jurassic–Early Cretaceous U–Pb SHRIMP zircon ages previously measured from a Ronda pyroxenite (Sánchez-Rodríguez and Gebauer 2000).

The Beni Malek serpentinites were exhumed at the toe of the hyper-extended African margin (Michard et al. 2007; Gimeno-Vives et al., in press). The Beni Bousera and Ronda peridotites-granulites belong to the Alboran Domain, which was located at the southeastern margin of Iberia until the Late Eocene onset of the Tethyan crust subduction (Fig. 6a; Jabaloy Sánchez et al. 2019) and references therein). The

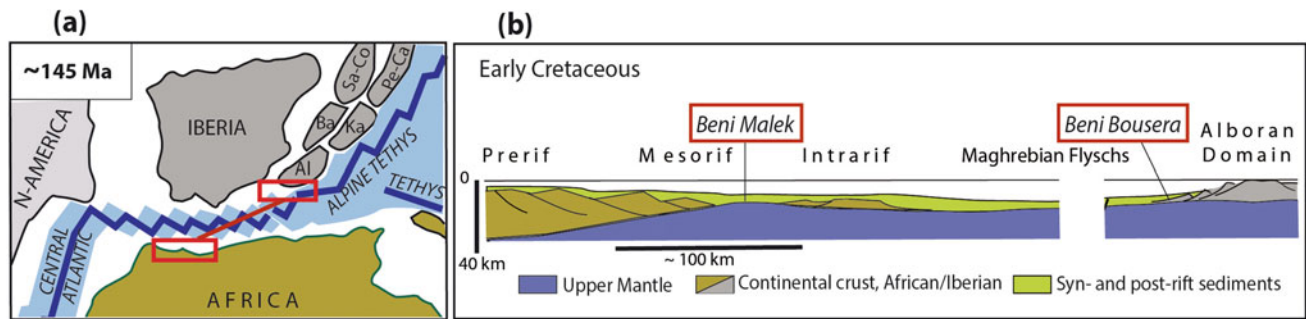


Fig. 6 a Plates setting by the end of Jurassic times, after (Sallarès et al. 2011). Crustal blocks partly detached from of Iberia: Al, Alboran; Ba, Balearic Isl., Ca, Calabria; Co, Corsica; Ka, Kabylia; Pe, Peloritani; Sa, Sardinia. Framed: conjugate margins shown in profile (b).

b Conceptual profile of the conjugate African and Alboran margins and intervening Tethyan corridor (Maghrebian Tethys) between the Central Atlantic and the Alpine Tethys. After Michard et al. (2007), modified

African and Iberian conjugate margins were affected coevally by the prolonged extensional tectonics of the Alpine Tethys (Michard et al. 2002; Frizon de Lamotte et al. 2011), which triggered upper mantle exhumation up to or very close to the Earth surface (Fig. 6b). Accordingly, the Neogene exhumation that occurred by the end of the subduction and orogenic thickening of the Alboran Domain (Gueydan et al., in press; Gervilla et al. 2019) should be now regarded as a secondary process with respect to the Triassic-Jurassic exhumation of the Gibraltar Arc mantle rocks.

5.3 Beni Bousera—Filali Units Relationships

A metamorphic gap occurs between the granulites and kinzigites of the Beni Bousera unit and the gneisses and schists of the Filali unit (Chalouan et al. 2008; Kornprobst 1971 and references therein). A similar gap is noticed in the Betic branch of the Gibraltar Arc between the granulitic gneisses above the Ronda peridotites and the Jubrique migmatitic gneisses and schists. This has been explained by ductile thinning of the intermediate crustal rocks in the context of crustal extension (see Chalouan et al. 2008; Jabaloy Sánchez et al. 2019) and references therein).

The occurrence of the Amter marbles in between the Beni Bousera and Filali units makes us reconsider this interpretation. As a working hypothesis, we might assume that thinning actually operated via a ductile low-angle normal fault during the early exhumation of the mantle and lower crust rocks, but that this structure inherited from the Triassic-Jurassic evolution has been inverted as a ductile thrust fault during the Cenozoic contractional events. As reported above, the thrust fault structures (locally observable today: Fig. 5d) are superimposed by late normal faults, which operated in brittle conditions, likely during the Miocene rifting of the Alboran Basin.

6 Conclusion

Our map of the Amter marbles on top of the Beni Bousera peridotite-unit brings a strong geological argument in support of an early exhumation of the mantle rocks and juxtaposed lower crust granulite virtually up to the seafloor.

This early exhumation would have occurred during the Triassic-Jurassic rifting and drifting evolution that gave birth to the Alpine/Maghrebian Tethys. As such, the exhumation of the Beni Bousera and Ronda mantle rocks of the Alboran Domain could be older than or coeval with that of the Beni Malek serpentinites at the toe of the African margin.

The Beni Bousera granulites-kinzigites preserved on top of the peridotites are separated from the overlying mid-upper crustal Filali gneisses by a mylonitic thrust contact, which could originate from the Neogene inversion of a former extensional low-angle ductile fault associated with the early exhumation of the mantle rocks.

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