

Early exhumation of the Beni Bousera granulites and peridotites at the northern margin of the westernmost Tethys (Rif belt, Morocco); new constraints from overlying marbles

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The Beni Bousera (BB) and Ronda subcontinental peridotites of the Alboran Domain

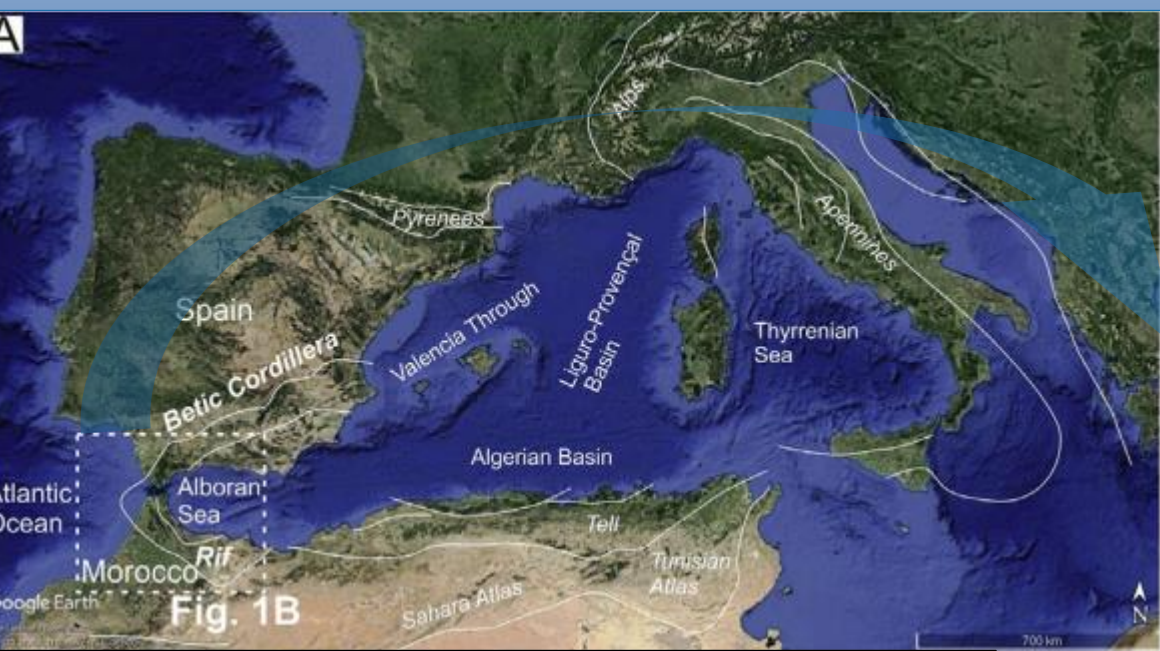


Fig. 1. (A) The Mediterranean region with location of the Betic-Rif orogen

- Part of an orocline Betic-Rif-Tell (B-R-T)
- Western most part of the Mediterranean alpine belts
- Betic and Rif forms Gibraltar arc

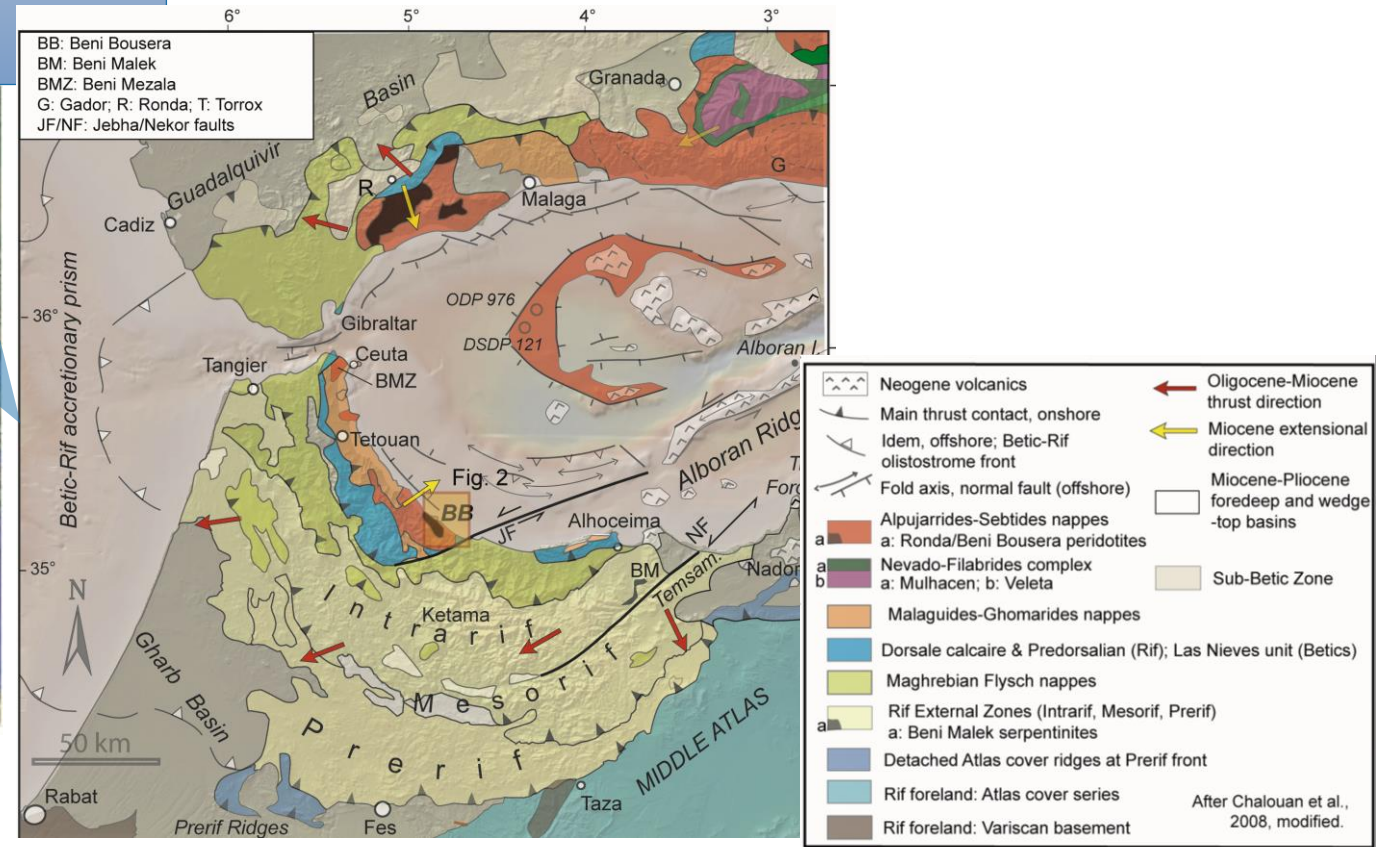


Fig. 1 (B) Structural map of the Gibraltar Arc, modified after Chalouan et al. (2008)

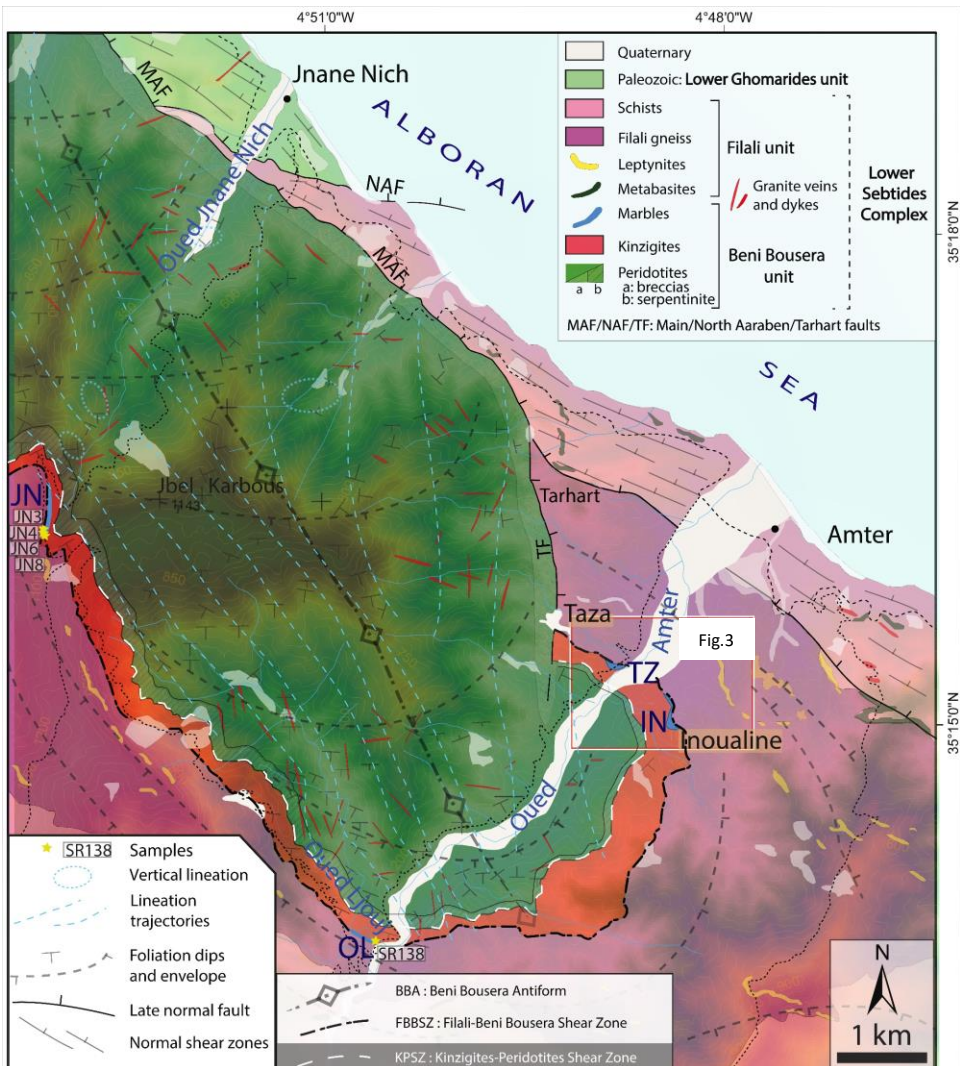


Fig. 2: Geologic map of the southeastern part of the Beni Bousera massif, after the Geological Map of Morocco, scale 1:50,000, sheets Bou Ahmed and Bab Berred (mapping by J. Kornprobst), (Farah et al 2021, and references therein). The TZ (Taza), IN (Inoualine), OL (Oued Ljouj) and JN (Jnane Niche) marble outcrops underline the Filali-Beni Bousera Shear Zone (FBBSZ)

- Since Kornprobst (1974), these marbles have been considered as simple intercalations within the kinzigites (migmatitic granulites) envelope of the BB peridotite.
- This interpretation was subsequently accepted by all the geologists who worked in the area, including the present authors (Reuber et al., 1982; Saddiqi, 1988; Chalouan and Michard, 1990).
- Saddiqi et al. (2019) and Michard et al. (2020a) have ultimately reopened the case.
- The **Beni Bousera Marbles** (BBMs) crop out around the **Beni Bousera antiform** of the Alpujarrides-Sebtides units of northern Rif (Morocco), exclusively located **in between** the **kinzigite envelope** of the Beni Bousera peridotites and the **overlying Filali gneisses (FBBSZ)**
- We present a new interpretation of these **BBMs** and infer geodynamic implications at the local and regional scale, based on the integration of **field mapping, structural and petrology investigations** and **SHRIMP U-Th-Pb geochronology**.



Field mapping

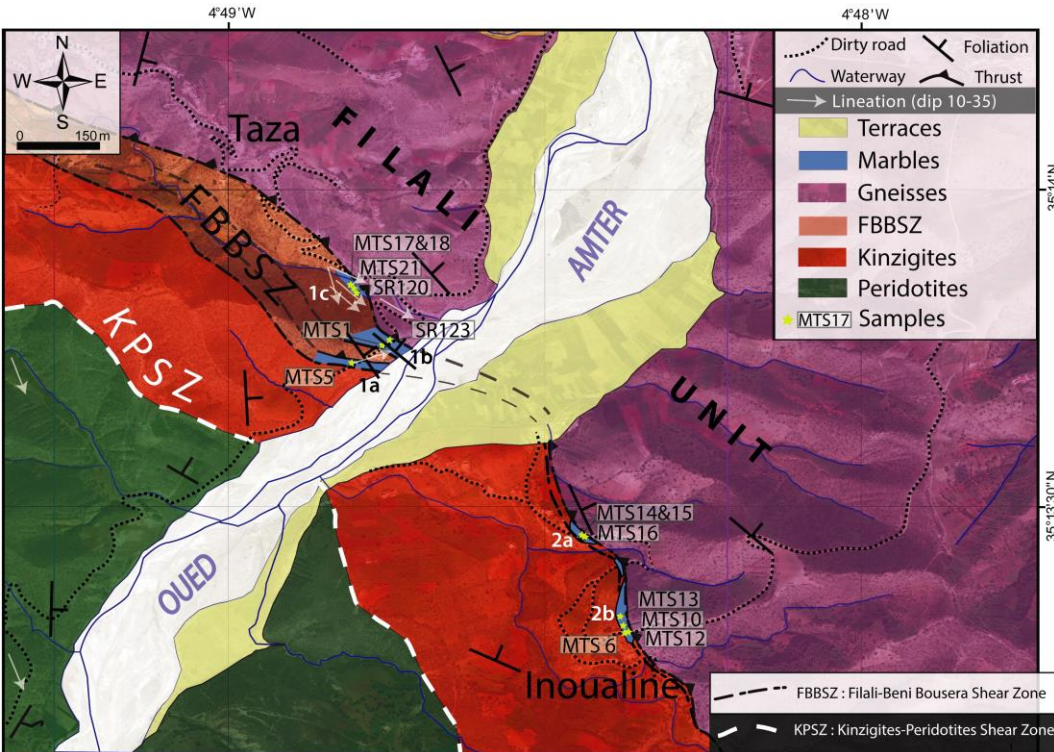
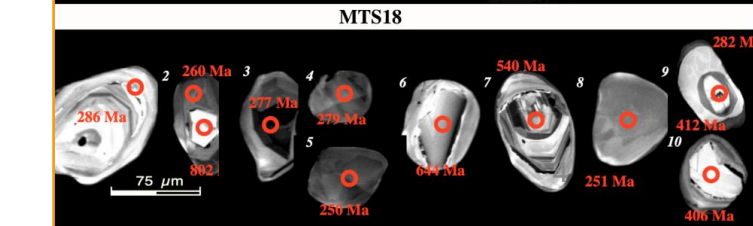
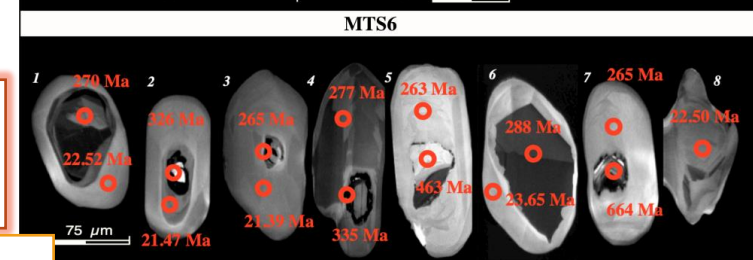
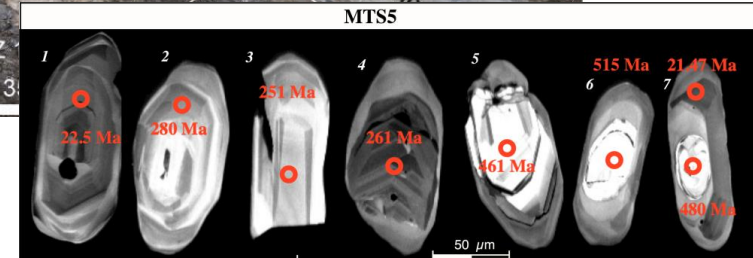
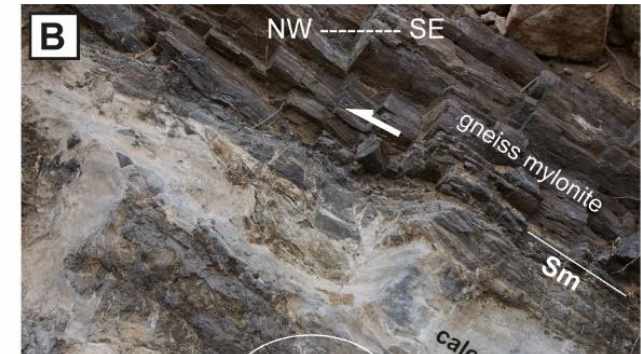
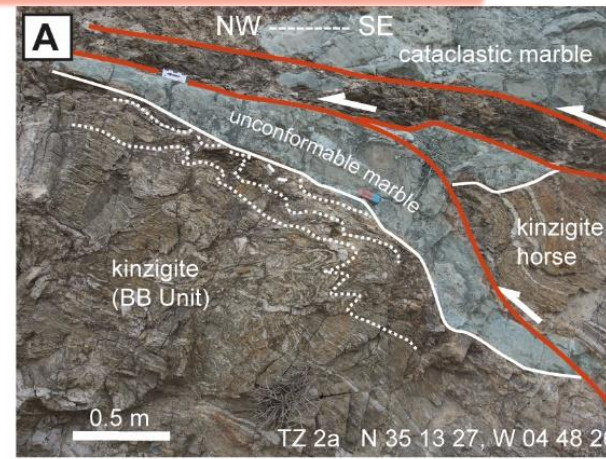


Fig. 3: Map of northwestern marble outcrops, ~7 km SW of Amter-village

Petrology investigations

For the petrological/textural analyses, thirty-three samples were collected within and around the marble outcrops in different stations around BBA TZ, IN, OL and JN.

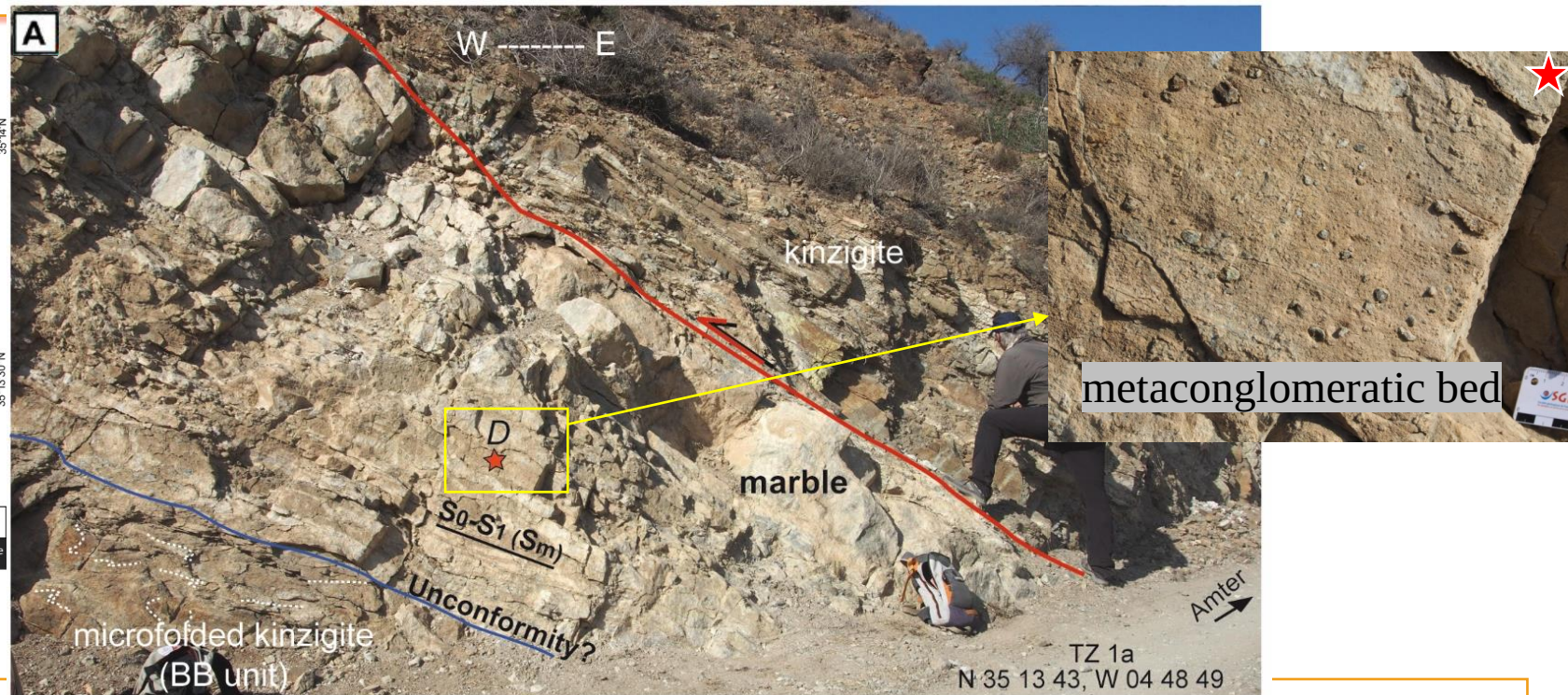
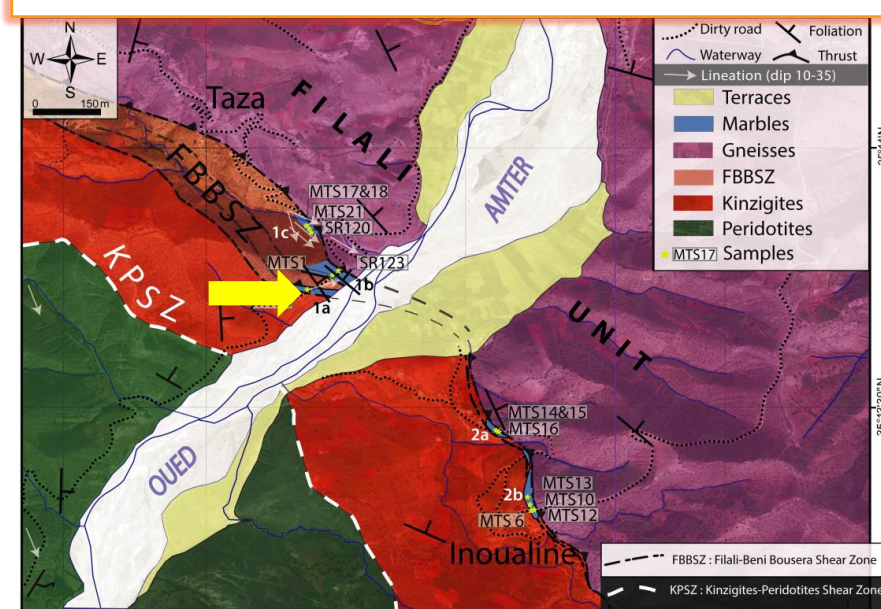
Structural analysis



SHRIMP U-Th-Pb geochronology.

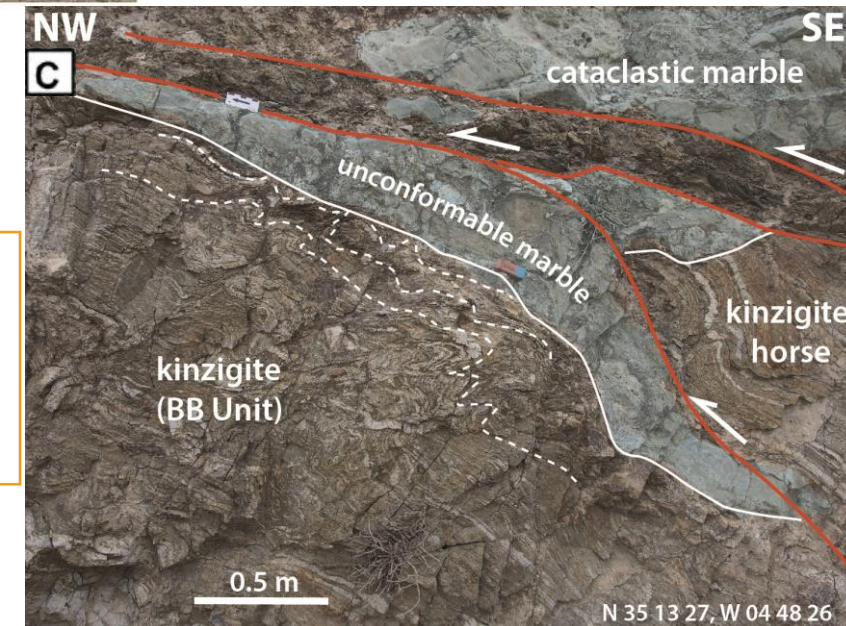
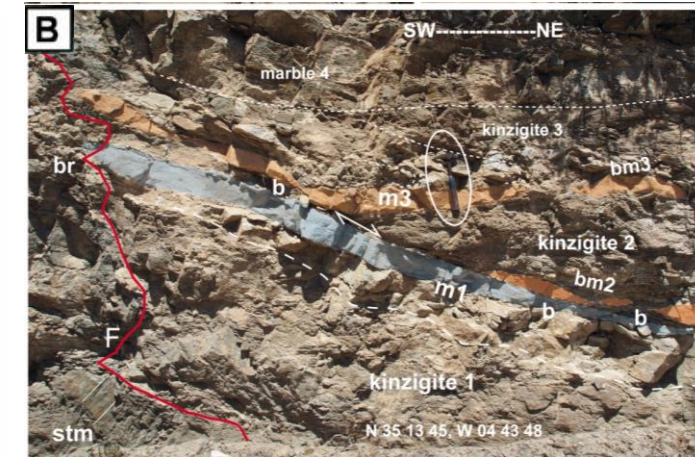
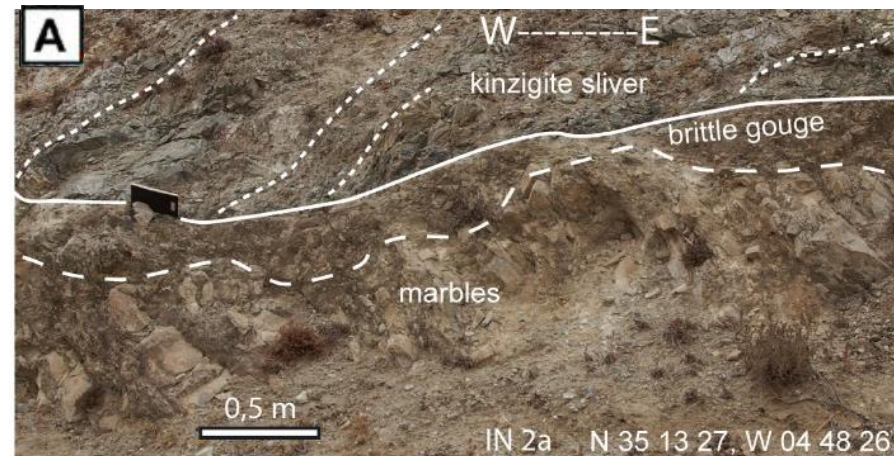
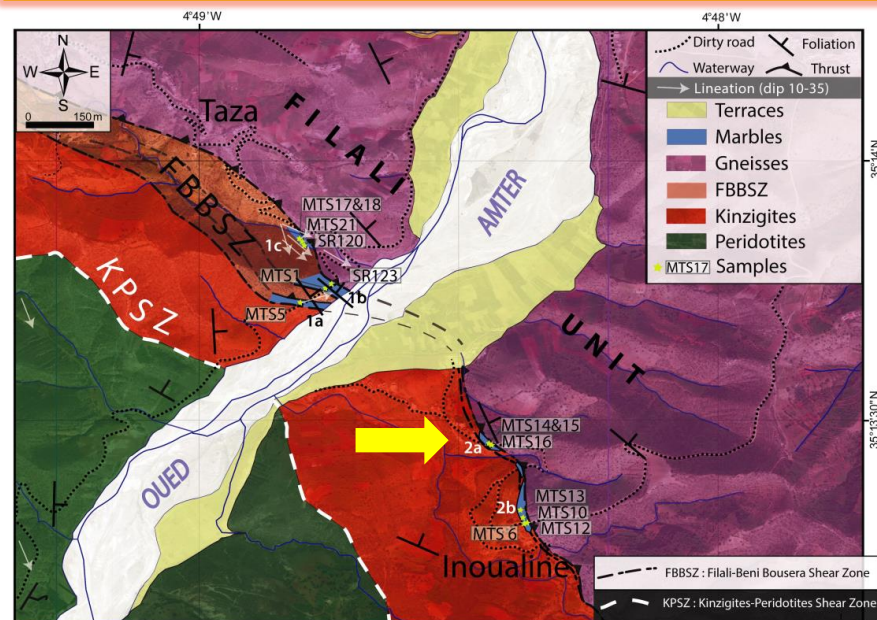
Five samples were collected from marble outcrops on both sides of Oued Amter

Syn- to post-metamorphic structures : lower contact of BBMs



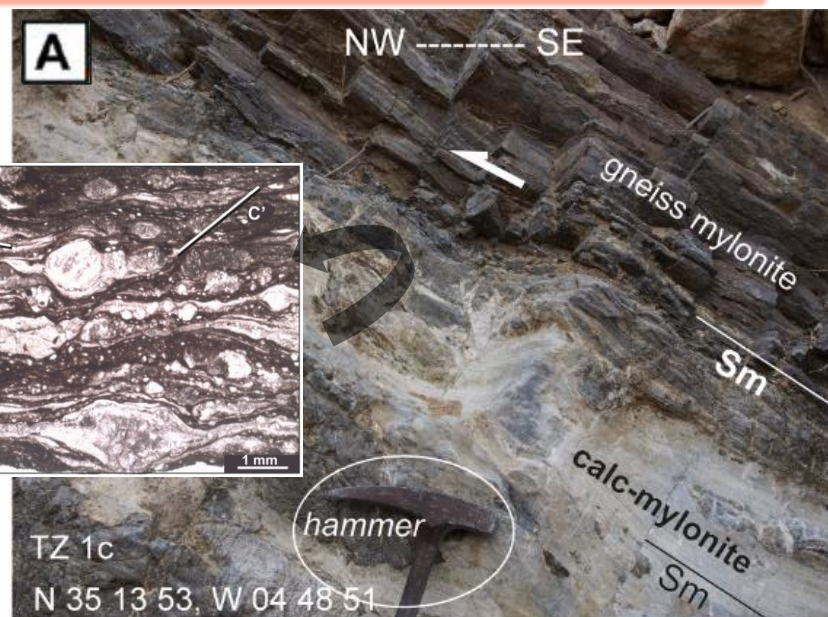
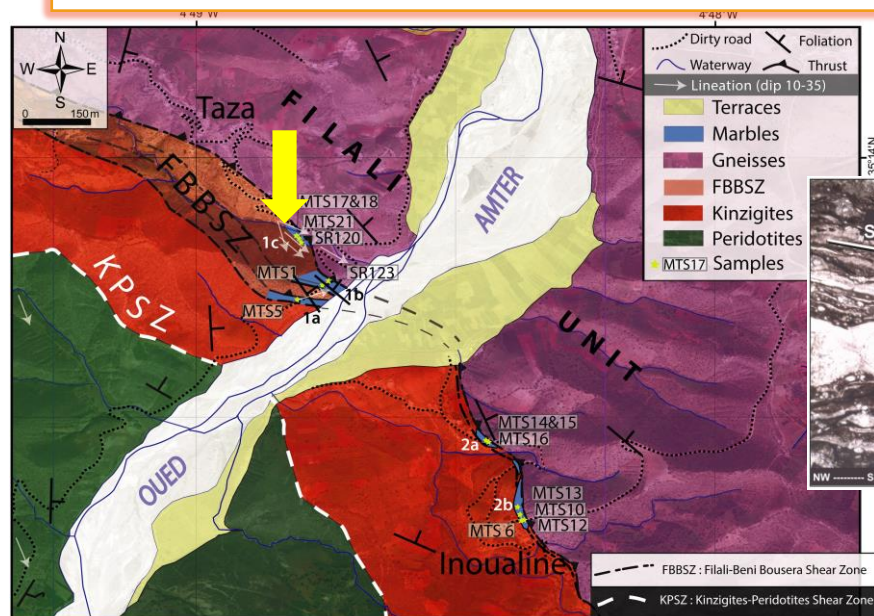
- In this area, the Outcrop displays conspicuous bedding marked by alternating pure and siliceous/silicate-rich carbonate layers.
- The occurrence of a metaconglomeratic bed supports the idea of metadetrital carbonate beds in this sequence.
- The outcrop bedding appears to parallel the basal contact of the marbles over the tightly folded kinzigites of the Beni Bousera Unit.
- Unconformable contact looks like a stratigraphic unconformity, but could be actually a low-angle fault
- The contact above the detrital marbles can be seen as a reverse fault beneath a kinzigite horse.

Syn- to post-metamorphic structures : lower contact of BBMs

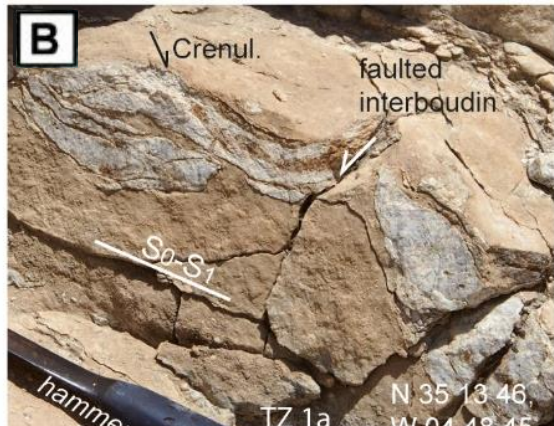


- Both the ductile and brittle-ductile structures are overprinted by place by late, east-trending brittle faults with gouge or breccia and striated mirror.
- Marble bed **unconformably overlying** the **kinzigites** of the Beni Bousera Unit & Two juxtaposed, northwest-ward verging **kinzigite-marble duplexes**.

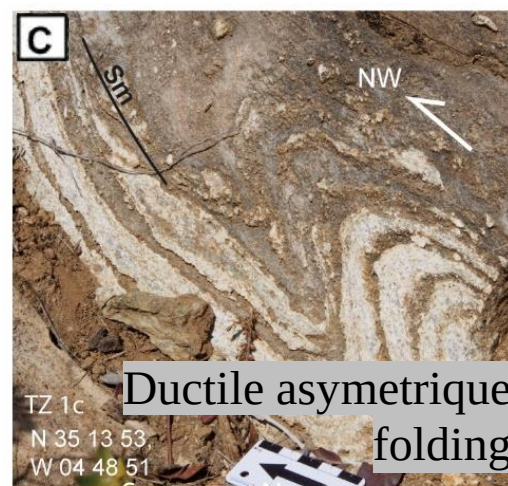
Syn- to post-metamorphic structures : Upper contact BBMs



Reverse ductile shearing is also observed in the uppermost parts of the marbles outcrops (upper boundary of the FBBSZ). The **boudinage** of gneissic mylonites in the juxtaposed calc-mylonite



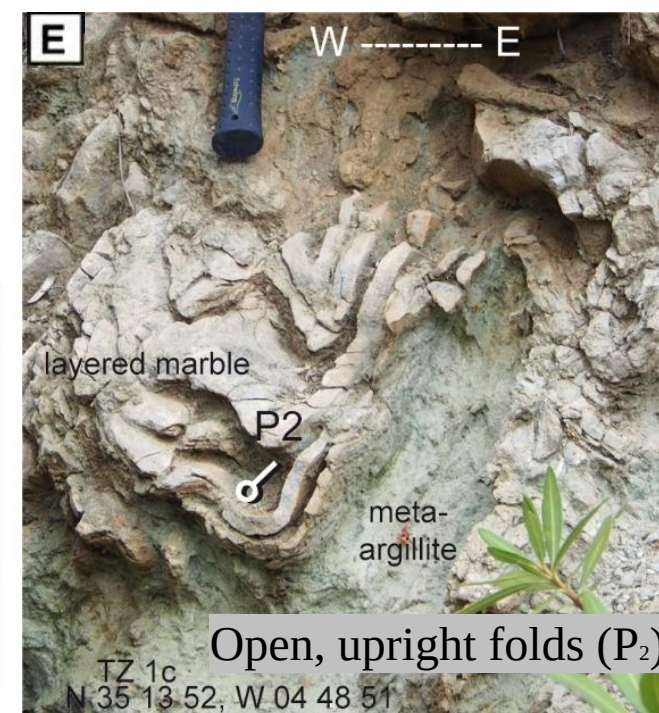
syn-D2 crenulation cleavage and brittle-ductile microfaults



Ductile asymetrique folding

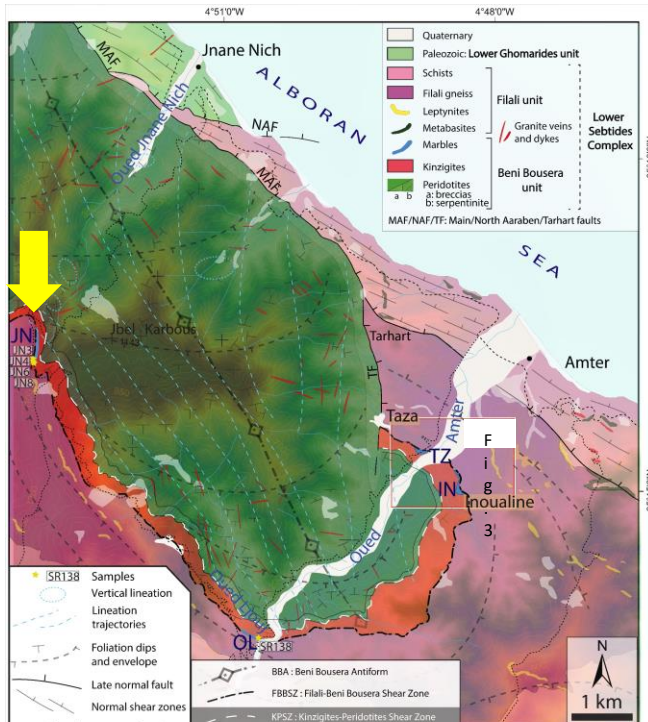


Isoclinal recumbent folds (P₁)



Open, upright folds (P₂)

Introduction & motivations



Methods

Results & Discussion

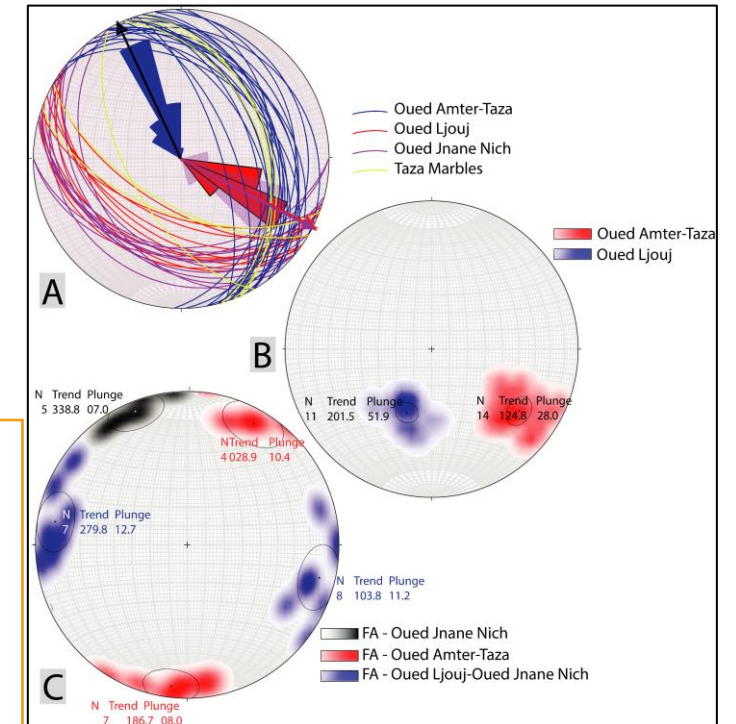
Conclusions



Structures of the marbles at Jnane Nich outcrop:

Complex structure involving both kinzigitic and calc-mylonitic sheets, and show an isoclinal fold observed there is filled by a calc-mylonite meta-breccia that contains small shreds and fragments of kinzigite-like material.

The FBBSZ widens, where kinzigite-marbles duplexes occur within the major shear zone, the structural data plot collected from different stations (marbles and surrendering unites), kinematic indicators suggest a dominant top to the NNW displacement; three sets of folds are observed reflecting late polyphase FBBSZ activity.



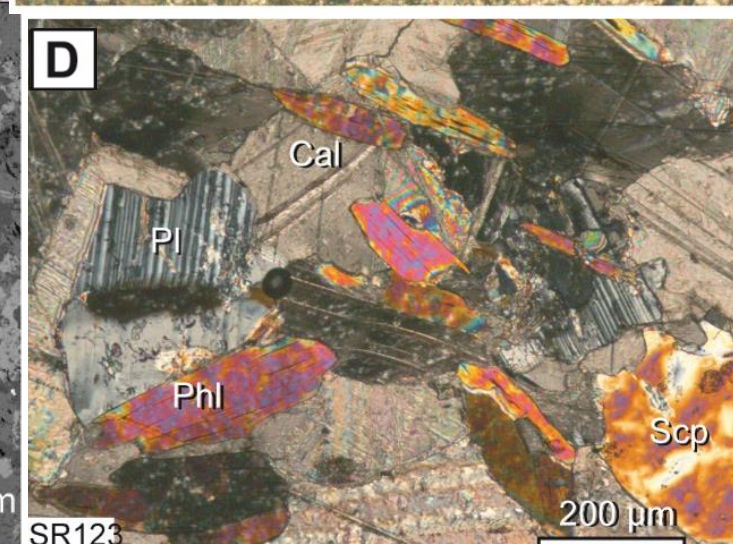
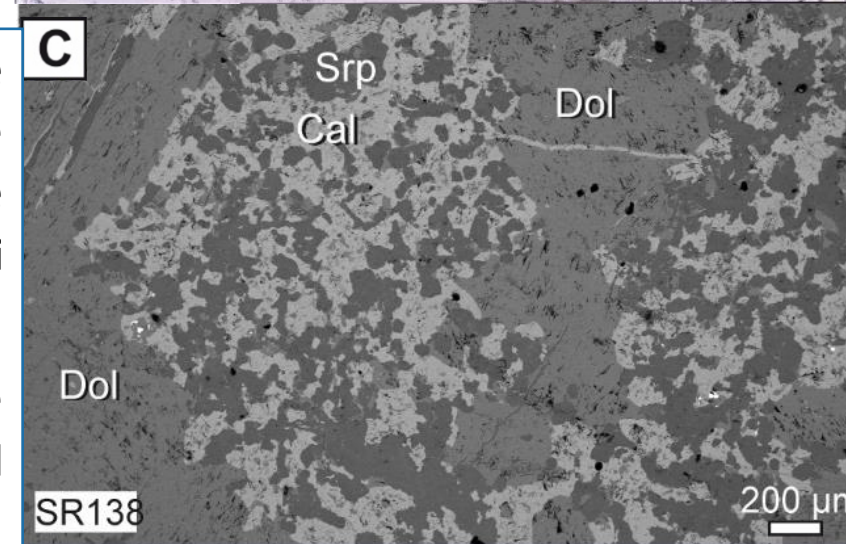
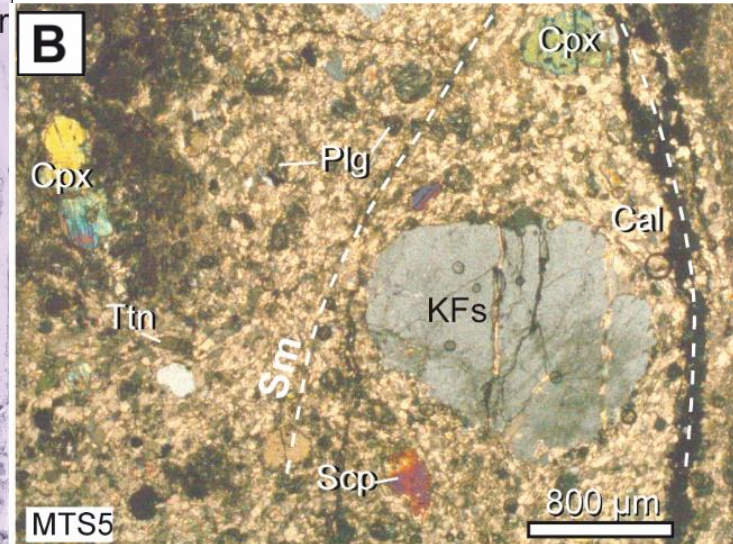
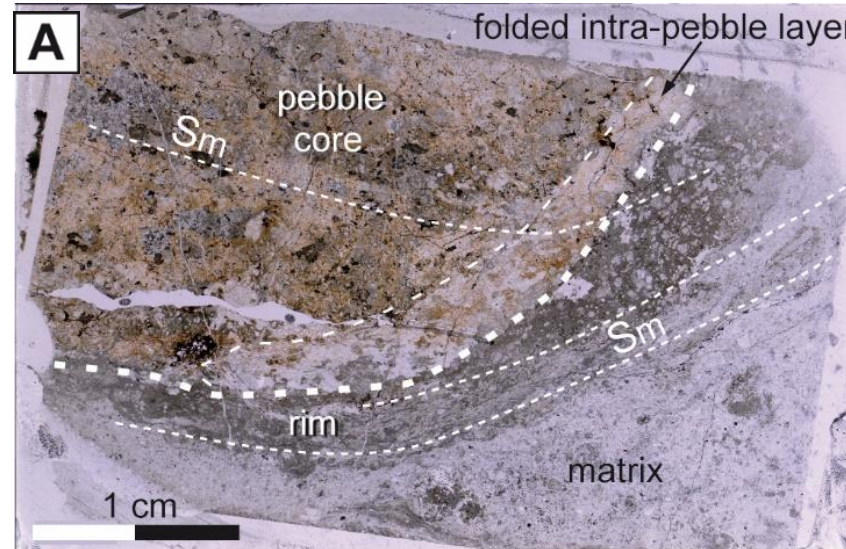
Petrography

Identification of four main rock types : **Conglomeratic marble**, standard **calcite marble**, **dolomite marble** and **siliceous marble**

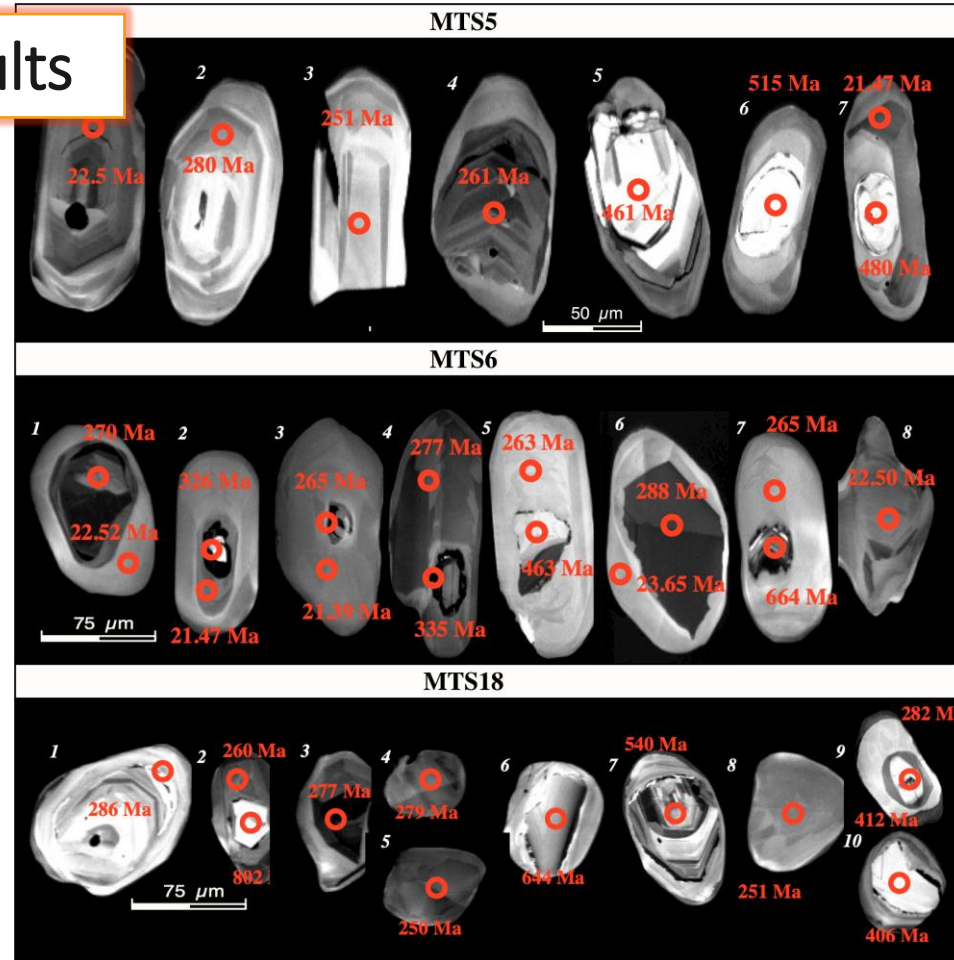
- Metadetrital by place conglomeratic beds with gneiss pebbles, which attest the detrital origin of most of silica of these marbles.
- two types of marbles: **dolomite marbles** with forsterite, Mg-Al-spinel, geikielite (MgTiO_3), phlogopite, and **calcite marbles** with phlogopite, scapolite, diopside, and titanite.

The peak metamorphic conditions (P-T) close to **750°C** and **≤ 4.5 kbar**. These conditions are distinct from the peak conditions of the **kinzigites** but compare with that of **Filali gneiss**.

The best regional comparison is with the **Triassic carbonates** deposited over the **crustal units** of the **Alpujarrides-Sebtides**.

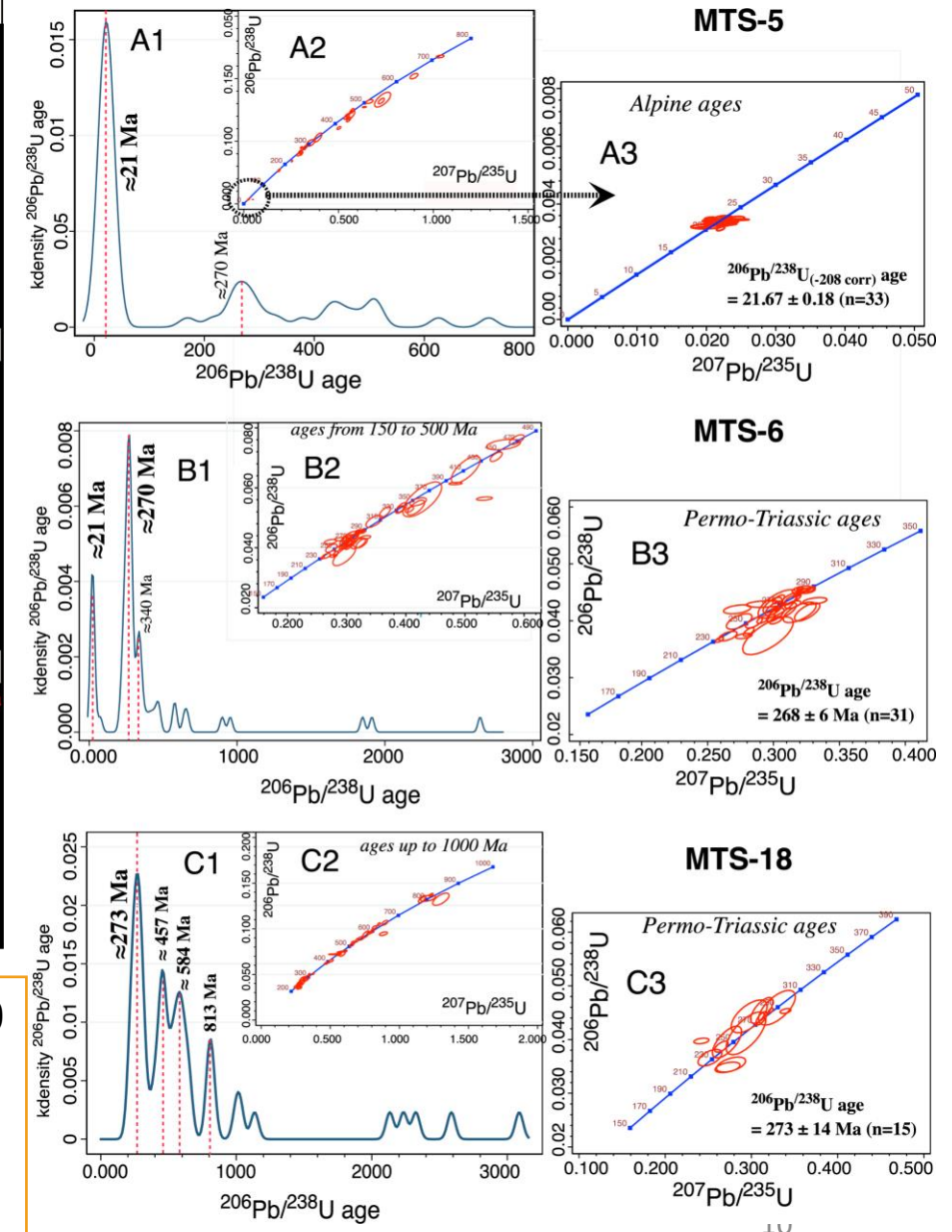


SHRIMP U-Th-Pb results



Detrital cores of zircon from the BBMs yield two U-Th-Pb age clusters of ~ 270 Ma and ~ 340 Ma, whereas their rims yield ~ 21 Ma ages.

The **youngest age cluster** from the cores peaks at ~ 270 Ma, which suggests the **erosion of Middle Permian magmatic sources**, and supports a **Triassic age** for the marbleprotoliths.



Interpretation & Implications

The contact between the Beni Bousera kinzigites and the Filali gneisses is clearly a **syn-metamorphic low-angle thrust fault locally assisted by the high ductile properties of the calc-mylonites**.

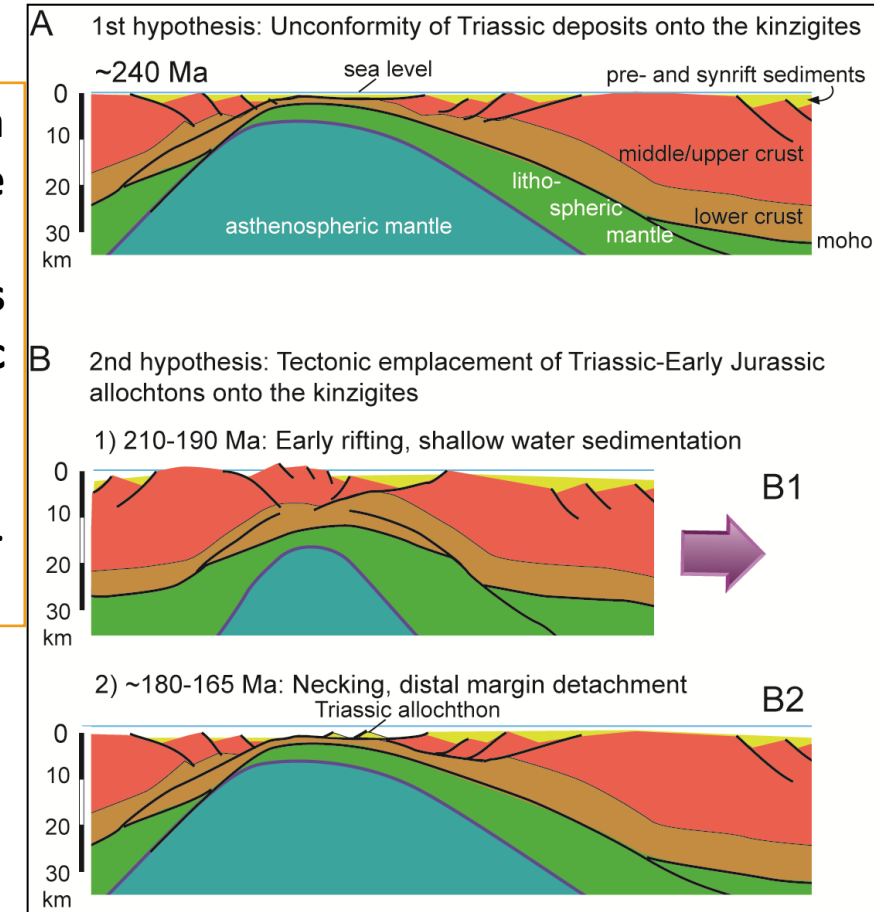
In contrast, the nature of the sharp **contact locally observed between the marbles and the underlying kinzigites** is more ambiguous, due to the **strong metamorphic and tectonic overprint**.

- it may receive two alternative interpretations, either **stratigraphic** or **tectonic**. Accordingly, we propose hereafter two alternative hypothesis.

Alternative models (A/B) accounting for the occurrence of the BBMs between the Filali and Beni Bousera units.

A: Triassic unconformable sedimentation onto the exhumed kinzigites (lower crust).

B: Triassic-Early Jurassic extensional allochthons (rafts) emplaced onto the exhumed kinzigites.

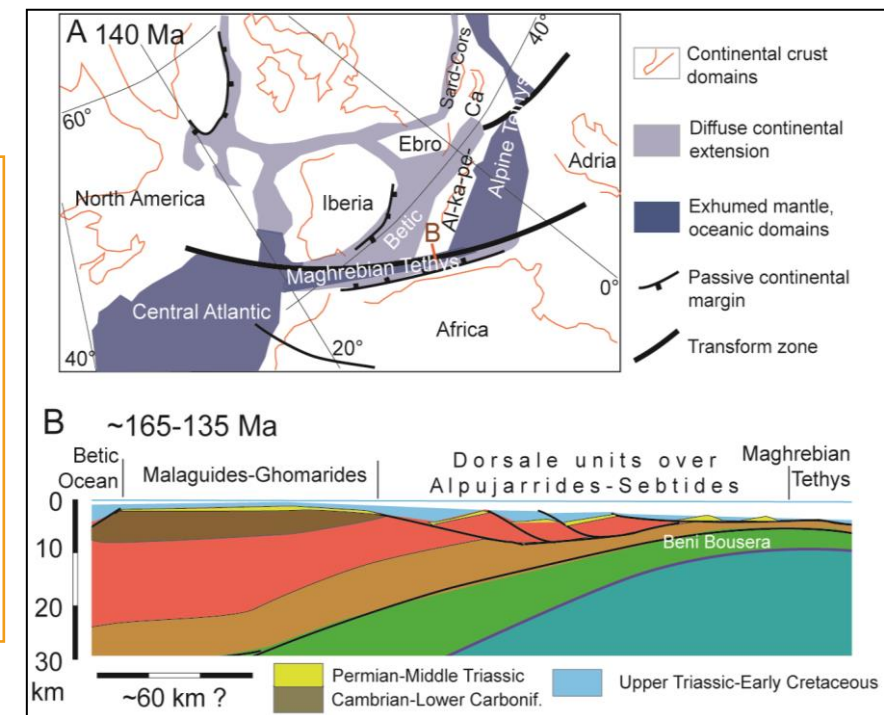


Interpretation & Implications

- Both cases are based on the assumption that the **lower crust and mantle rocks have been exhumed to the Earth's surface or close to during the rifting and subsequent extension.**

The **hyperextended margin of the Alboran Domain** during the **Late Jurassic-Early Cretaceous**, modified after Michard et al. (2021).

- **A: Location of the Alboran Domain** (southern part of Alkapeca) to the north of the Maghrebian Tethys; background map after Angrand et al. (2020), slightly modified.
- **B: Tentative restoration of the Alboran Domain margin** whose distal part corresponds to the **Alpujarrides-Sebtides crustal units overlain by the Dorsalian pre- and syn-rift sediments.**



- The **BBMs are not intercalated in the kinzigites**, but rather pinched within a **mylonitic thrust contact between the kinzigites and the overlying Filali mid-crustal unit**. The Filali–Beni Bousera Shear Zone (FBBSZ) can no longer be considered as **extensional** and equivalent to the deeper **Kinzigites-Peridotites Shear Zone (KPSZ)**.
- The **protoliths** of the most typical BBMs formed a **series of sandy** and sometimes **pebbly carbonates, dolostones, and magnesian limestones** locally interlayered with **argillites**. They are comparable with the **Triassic series** of the less recrystallized **Alpujarrides-Sebtides units**.
- **Zircon from the BBMs** exhibit cores of detrital origin with rim overgrowths dated at ~21 Ma. The **youngest age cluster** from the **cores peaks at ~270 Ma**, which suggests the erosion of **Middle Permian magmatic sources**, and supports a **Triassic age** for the marble protoliths.
- Two alternative explanations for the presence of these **marbles in the FBBSZ**: either the likely **Triassic beds** were deposited **unconformably onto the kinzigites**, or they were emplaced **as extensional allochthons above the detachment** allowing the **granulitic crust to be exhumed** during latest **Triassic–Early Jurassic time**.
- The **BBMs and their host rock units**, i.e., the peridotites and associated thinned crustal units, are relics of the **hyperextended southern margin** of the Alboran Domain severely affected by **re-burial, thrusting, and metamorphism during the Alpine orogeny** before their **final exhumation**.



Thank you

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