Asthenospheric upwelling and lithosphere rejuvenation beneath the Hoggar swell, Algeria: evidence from mantle xenoliths

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The Cenozoic volcanism of the Hoggar region (Algeria) represents one of the most important magmatic areas in the north African belt [Ed: See also the webpage The Hoggar swell and volcanism, Tuareg shield, Central Sahara]. It covers more than 10,000 km^2 and is associated with a regional crustal swell of Pan-African terranes, approximately 1000 km in diameter (Figure 1). The oldest Cenozoic volcanic rocks comprise a thick pile of tholeiitic plateau basalts (35-30 Ma) characterized by an isotopic signature typical of EM1-type enriched mantle (*Aït-Hamou et al.*, 2000). Younger (Neogene-Quaternary) volcanic rocks have an alkaline affinity and include both basic lavas and trachyte-phonolite differentiates, with a prevalent HIMU (high μ) Pb-Nd-Sr isotopic signature (*Allègre et al.*, 1981; *Azzouni-Sekkal et al.*, 2007). In the Manzaz (Central Hoggar) district, the youngest volcanic episodes are markedly alkaline (basanites and nephelinites) and sometimes entrain the mantle xenoliths which are the subject of this study.

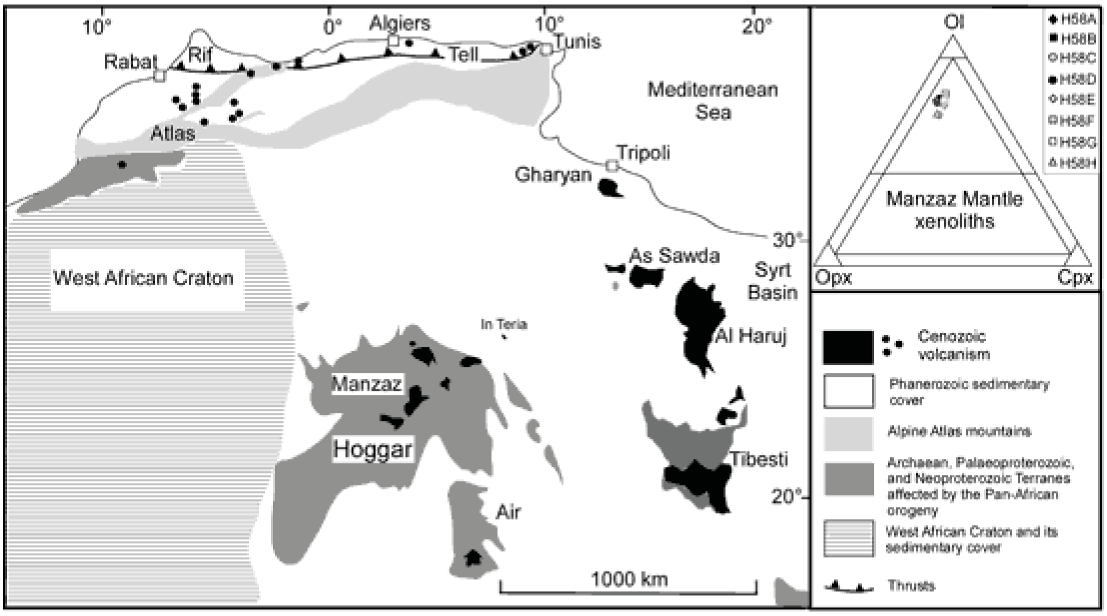

Figure 1. Sketch map showing locations of the main Cenozoic volcanic fields of north Africa, after Liégeois et al. (2005). Modal compositions of the Manzaz mantle xenoliths in terms of olivine (ol), orthopyroxene (opx) and clinopyroxene (cpx) are shown. Click here or on figure for enlargement.

The mantle xenoliths are proto-granular anhydrous spinel lherzolites. Major- and trace-element analyses on bulk rocks and constituent mineral phases show that the primary compositions are widely overprinted by metasomatic processes. Trace-element modelling of the metasomatised clinopyroxenes allows the inference that the metasomatic agents that enriched the lithospheric mantle were highly alkaline carbonate-rich melts such as nephelinites/melilitites (or extreme silico-carbonatites). These agents were characterized by a clear HIMU Sr-Nd-Pb isotopic signature. There is no evidence of EM1 components which are recorded by the Hoggar Oligocene tholeiitic basalts.

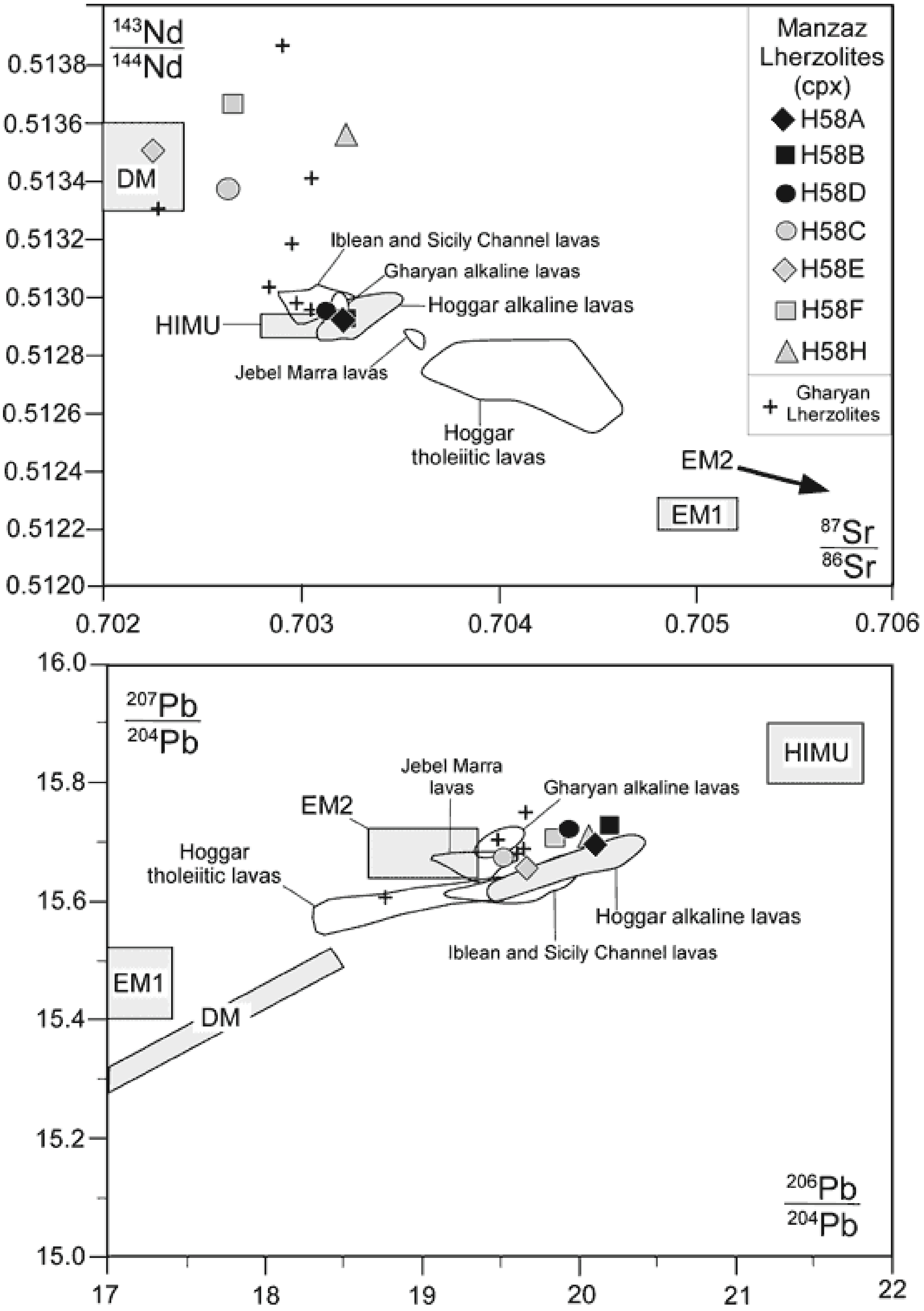

Figure 2. Sr-Nd-Pb isotopic variations of clinopyroxenes from Manzaz mantle xenoliths. Composition of mantle xenoliths from the Gharyan district of Libya (Beccaluva et al., in press), and Cenozoic alkaline lavas from various African volcanic areas, are given for comparison: Hoggar (Allègre et al., 1981), Jebel Marra (Davidson & Wilson, 1989; Franz et al., 1999), Iblean - Sicily Channel Districts (Beccaluva et al., 1998; Bianchini et al., 1998; Civetta et al., 1998). Isotopic mantle end members (DM, HIMU, EMI and EMII) are from Zindler & Hart (1986).

This can be interpreted as resulting from replacement of the older lithospheric mantle, from which the tholeiites were generated, by upwelling asthenosphere with a HIMU signature. Accordingly, this rejuvenated lithosphere (accreted asthenosphere without an EM signature) may represent a possible mantle source from which deep alkaline basic melts could have been generated and shallower mantle xenoliths derived. The systematic occurrence of Neogene alkaline lavas and associated mantle xenoliths with a clear HIMU affinity across the African plate indicates that it is a ubiquitous sub-lithospheric component across Central-Northern Africa. In fact this component is considered related to the ultimate fate of subducted oceanic lithotypes which create high U/Pb and Th/Pb mantle domains that, after long-term storage, result in highly radiogenic Pb compositions (*Weaver*, 1991; *Carlson*, 1995; *Hofmann*, 1997). Accordingly, *Wilson & Patterson* (2001) physically locate this component above the 670-km discontinuity in the upper mantle, where geophysical evidence shows subducted slab relics flatten over wide upper-mantle regions (*e.g.,* in the Central Mediterranean; *Faccenna et al.*, 2001; *Beccaluva et al.*, 2005).

The available data on the lherzolite xenoliths and alkaline lavas (including He isotopes with R/Ra < 9) indicate that there is no requirement for a deep plume anchored in the lower mantle. Sources in the upper mantle can satisfactorily account for all the geochemical, petrological and geophysical evidence characterizing the Hoggar swell. The relatively low $^3He/^4He$ ratios observed for the Saharan districts are a further indication that this metasomatic component is confined in the upper mantle, unlike the Ethiopian-Yemen plateau basalts ($^3He/^4He$ up to 20 Ra) which have been related to a deep mantle plume possibly generated from the core-mantle boundary (*Pik et al.*, 2006) [Ed: But see also Helium Fundamentals page]. By contrast, relatively low $^3He/^4He$ can be satisfactorily explained by degassing of shallow mantle domains and/or the addition of recycled components to the upper mantle (*Moreira & Kurz*, 2001).

Moreover, the lithosphere uplift that resulted in the Hoggar swell conforms with geophysical evidence such as the gravity field data (Bouguer anomaly of -90 mGal; *Lesquer et al.*, 1988) and the thermal anomaly centred on the Atakor volcanism (heat flow 63 mW/m^2; *Lesquer et al.*, 1989). Seismic tomography of the mantle beneath north Africa shows that the lithosphere thickness in the Sahara area is variable due to local asthenospheric upwellings (*Ayadi et al.*, 2000) which generally do not extend deeper than ca. 400 km, thus precluding the existence of deep mantle plumes anchored in the lower mantle (*Davaille et al.*, 2000; *Sebai et al.*, 2006).

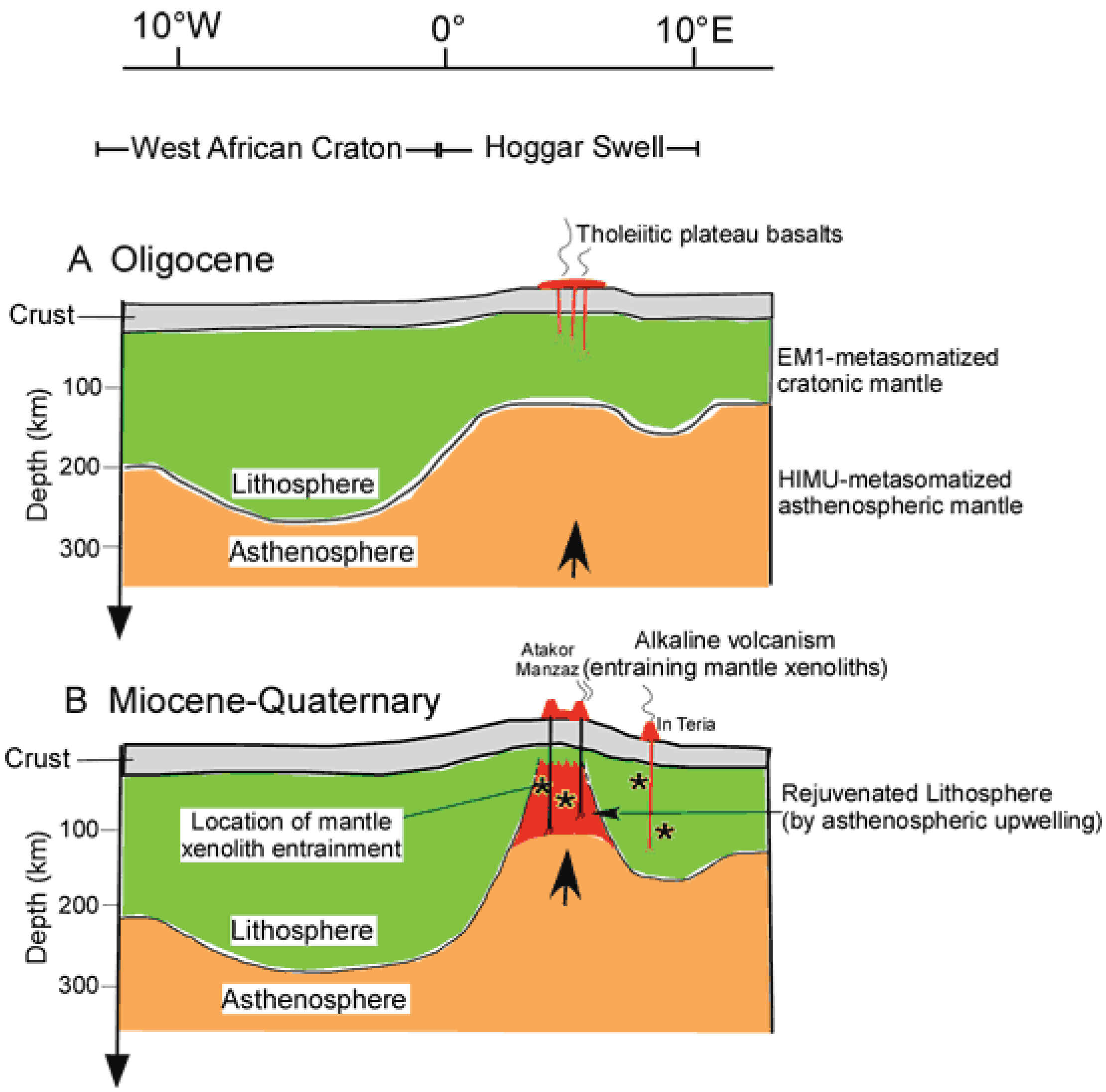

Figure 3. Simplified cartoon showing the hypothesised lithosphere/asthenophere interactions beneath the Hoggar swell. (a) Tholeiitic plateau basalts (35-30 Ma) formed by high degrees of melting of EM1-metasomatised mantle of the Pan-African cratonic lithosphere. (b) Younger alkaline volcanism of the Atakor-Manzaz area generated from low degrees of melting of HIMU-metasomatised mantle sources. The latter probably represents a rejuvenated lithosphere formed by intra-cratonic upwelling and accretion of asthenopheric material. The Manzaz spinel lherzolite xenoliths may therefore represent fragments of this rejuvenated lithosphere, whereas the garnet/spinel peridotite xenoliths from In Teria (Dautria et al., 1992) may represent the older cratonic mantle of the Pan-African lithosphere.

In conclusion, convection in the upper mantle and lithosphere/asthenosphere interactions mainly along lithospheric discontinuities such as craton/mobile belt borders, as proposed by the edge-driven convection model (*King & Anderson*, 1995; 1998) is the most appropriate geodynamic scenario for the mantle evolution of the Hoggar swell.

Hoggar volcanism, as well as other volcanism in the Saharan belt, is thus probably related to passive asthenospheric mantle upwelling and decompression melting linked to extensional stresses in the lithosphere during Cenozoic reactivation and rifting of the

Pan-African basement. This can be considered a far-field foreland reaction to the Africa-Europe collisional system subsequent to the Eocene.

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