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GRANULITE-FACIES METAMORPHISM IN THE HOGGAR (SOUTH ALGERIA): A REVIEW OF UHT AND HT METAMORPHISM DURING THE PALEOPROTEROZOIC AND THE NEO-PROTEROZOIC.

Sid Ali DOUKKARI[1], Khadidja OUZEGANE[2], Chakib HAROUZ[2], and Amar ARAB[3]

ABSTRACT

The Hoggar Shield in southern Algeria preserves a complex record of high- to ultrahigh-temperature (HT to UHT) metamorphism that provides valuable insights into lower crustal processes during the Paleoproterozoic and Neoproterozoic orogenic events. In the In Ouzzal terrane, early interpretations emphasized the preservation of Archean metamorphism, inferred from ca. 2.5 Ga granitic magmatism. However, recent studies combining petrology, thermodynamic modeling, and geochronology (e.g., Ouzegane *et al.*, 2003; Aït Djafer *et al.*, 2009; Doukkari *et al.*, 2018) have demonstrated that a pervasive Paleoproterozoic overprint associated with the Eburnean orogeny (ca. 2.0–1.9 Ga) erased most Archean signatures. This event involved extreme crustal heating, with UHT conditions locally exceeding 1000 °C, recorded by assemblages such as sapphirine–quartz and orthopyroxene–sillimanite–spinel. Similarly, in the Central Hoggar, early models described the region as a relatively stable metacraton only weakly affected by the Pan-African orogeny. However, more recent structural, petrological, and geochronological data (Ouzegane *et al.*, 2023, 2025; Bettioui *et al.*, 2022) have shown that the Pan-African event caused deep reworking of the LATEA domain, including widespread HT metamorphism, crustal melting, and the emplacement of granitoids between 635 and 580 Ma. These findings reflect a major reinterpretation of the metamorphic evolution of the Hoggar, shifting the paradigm from one of tectonic stability to dynamic, multi-orogenic reactivation of the lower crust. Current research efforts now focus on constraining the duration and thermal evolution of these HT and UHT events to better understand the geodynamic processes that sustained such extreme conditions in the Precambrian crust.

Keywords - Granulite-facies - Hoggar - Paleoproterozoic - Neoproterozoic.

[1]Laboratoire de Géodynamique, Géologie de l'Ingénieur et de Planétologie, FSTGAT-U.S.T.H.B., B.P. 32 El Alia, Dar el Beida, 16111-Algiers, Algeria. E mail : sidali.doukkari@gmail.com .

[2]Faculté des Sciences de la Nature et de la Vie et des Sciences de la Terre, Université de Bouira (UAMOB), Bouira, Algeria. a.arab@univ-bouira.dz

Auteur correspondant : Sid Ali Doukkari. E-mail: sidali.doukkari@gmail.com.

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LE MÉTAMORPHISME DU FACIÈS GRANULITE DANS LE HOGGAR (SUD DE L'ALGÉRIE) : SYNTHÈSE DES EPISODES DE MÉTAMORPHISME À ULTRA-HAUTE TEMPÉRATURE ET À HAUTE TEMPÉRATURE DURANT LE PALÉOPROTÉROZOÏQUE ET LE NÉOPROTÉROZOÏQUE

ABSTRACT

Le bouclier du Hoggar, situé dans le Sud de l'Algérie, conserve un enregistrement complexe d'événements métamorphiques de haute à ultra-haute température (HT à UHT), offrant des informations essentielles sur les processus affectant la croûte inférieure au cours des orogenèses paléoprotérozoïques et néoprotérozoïques. Dans le terrane d'In Ouzzal, les premières interprétations mettaient en avant la préservation d'un métamorphisme archéen, déduit de la présence d'un magmatisme granitique daté d'environ 2,5 Ga. Toutefois, des études récentes combinant pétrologie, modélisation thermodynamique et géochronologie (par ex. Ouzegane *et al*., 2003 ; Aït Djafer *et al*., 2009 ; Doukkari *et al*., 2018) ont démontré qu'une importante réactivation paléoprotérozoïque liée à l'orogenèse éburnéenne (≈ 2,0–1,9 Ga) a largement effacé les signatures archéennes. Cet événement s'est traduit par un réchauffement extrême de la croûte, avec des conditions UHT dépassant localement 1000 °C, attestées par des assemblages minéralogiques tels que sapphirine–quartz et orthopyroxène–sillimanite–spinelle. De manière similaire, dans le Hoggar central, les premiers modèles considéraient cette région comme un métacraton relativement stable, faiblement affecté par l'orogenèse panafricaine. Cependant, des données plus récentes issues d'études structurales, pétrologiques et géochronologiques (Ouzegane *et al*., 2023, 2025 ; Bettioui *et al*., 2022) ont montré que l'événement panafricain a entraîné une profonde réactivation du domaine LATEA, marquée par un métamorphisme de haute température généralisé, une fusion crustale importante et la mise en place de granitoïdes entre 635 et 580 Ma. Ces résultats conduisent à une réinterprétation majeure de l'évolution métamorphique du Hoggar, faisant évoluer le modèle d'un domaine tectoniquement stable vers celui d'une croûte inférieure soumise à des réactivations poly-orogéniques. Les travaux actuels visent désormais à mieux contraindre la durée et l'évolution thermique de ces épisodes HT et UHT afin d'améliorer la compréhension des processus géodynamiques ayant permis le maintien de conditions thermiques aussi extrêmes au sein de la croûte précambrienne.

Mots-clés - Faciès granulitique - Hoggar -Paléoprotérozoïque - Néoprotérozoïque.

I- INTRODUCTION

Granulite facies metamorphism represents one of the highest grade of regional metamorphism, typically occurring at temperatures exceeding 700-750 °C and pressures ranging from 6 to 12 kbar (Harley, 1989; Bucher & Grapes, 2011). It is characterized by the development of anhydrous mineral assemblages, such as orthopyroxene + plagioclase ± garnet in mafic compositions and sillimanite + K-feldspar + quartz ± garnet in pelitic rocks (Spear, 1993; Pattison *et al.*, 2003). These mineral assemblages reflect extreme crustal conditions commonly associated with deep crustal heating, fluid-absent melting, and prolonged residence in the lower continental crust.

Granulite facies terranes are crucial for understanding crustal evolution, as they provide direct insights into processes such as crustal thickening, high-temperature re-equilibration, partial melting, and exhumation (Brown, 2007; Kelsey, 2008). The mineralogical and chemical record preserved in granulites can be used to constrain the pressure-temperature-time (P-T-t) histories of metamorphic belts, particularly when combined with diffusion modeling and geochronological data (Harley & Kelly, 2007; Caddick *et al.*, 2010). In addition, granulite

facies metamorphism is often linked to tectonothermal events such as continental collision, lithospheric delamination, or underplating by mantle-derived magmas, all of which can generate the necessary heat flux to drive metamorphism at these conditions (Clark *et al.*, 2011; Palin *et al.*, 2016).

Importantly, the study of granulites contributes to a better understanding of crust-mantle interac-tions, the secular cooling of the Earth, and the stabilization of continental lithosphere. Their occurrence in ancient metamorphic provinces offers key constraints on the thermal structure and tectonic dynamics of the deep crust over geological timescales (Harley, 1989; Bucher & Grapes, 2011).

In the Hoggar (southern Algeria), granulite facies rocks are widely exposed and form an essential component of the Precambrian basement. These rocks, particularly those from the In Ouzzal terrane (Western Hoggar, fig.1b) preserve clear evidence of ultra-high-temperature metamorphism associated with Paleoproterozoic tectonometamorphic event (Boumaza & Ouzegane, 1996, Ouzegane *et al.*, 2003a, b, Adjerid *et al.*, 2008; 2013; Doukkari *et al.*, 2018, Harouz *et al.*, 2024). The granulites rec-ord peak metamorphic conditions exceeding 900 °C at pressures of 8-10 kbar, often accompanied by partial melting and the development of anatectic leucosomes (Ouzegane *et al.*, 2003a; Aït Djafer *et al.*, 2009). On the other hand, granulite-facies metamorphism, of lower temperature, in the Central Hoggar (Tidjenouine, Tamanrasset, Gour Oumelellen; fig. 1c) is considered of Paleoproterozoic age (c. 1.9 Ga, Gour Oumelalen, Peucat *et al.*, 2003; c. 2.0 Ga, Tidjénouine, Bendaoud *et al.*, 2003, 2008) or of Neoproterozoic age where the anatexis that involved granodioritic migmatites from the Aleksod area is dated at c. 607 Ma (Barbey *et al.*, 1989).

The granulites of Hoggar thus offer a unique opportunity to investigate the thermal architecture and tectonic evolution of lower crustal domains in a context of long-lived crustal reactivation. Their preservation provides key insights into deep crustal processes, the secular evolution of continental lithosphere, and the interplay between Paleoproterozoic crustal stabilization and Neoproterozoic reworking. In this contribution,we provide a general review of the granulite facies metamorphism of the Hoggar showing the raised questions and the evolution of the ideas during the last three decades.

II- GEOLOGICAL SETTING

The Hoggar, constituting the central part of the Tuareg Shield, is a large Precambrian massif located in southern Algeria and forms part of the Trans-Saharan Belt. This belt extends from the West Afri-can Craton (WAC) in the southwest to the Saharan Metacraton (SmC) in the northeast and represents a key zone of the Pan-African orogenic system (Black *et al.,* 1979; Caby *et al.,* 1981; Liégeois *et al.,* 2003; Liégeois, 2019; Ouzegane *et al.*, 2023; Berrahmane *et al.*, 2025). The present-day morphology of the Tuareg Shield corresponds to a Cenozoic topographic swell (~550,000 km²), exhumed during the Eocene (Rougier *et al.,* 2013; English *et al.,* 2017) and subsequently affected by intraplate volcanism from 35 Ma to recent times (Liégeois *et al.,* 2005).

The Hoggar comprises a mosaic of 25 tectonic terranes, separated by subvertical shear zones or thrusts, and characterized by contrasting lithologies, metamorphic histories, and geodynamic evolutions ((Black *et al.,* 1994; Liégeois, 2019). These terranes include both juvenile Neoproterozoic island arcs (870-635 Ma) bearing ophiolites (Caby *et al.,* 1982, 1989; Béchiri-Benmerzoug *et al.,* 2011), and reworked Archean to Paleoproterozoic basement domains variably affected during the Pan-African orogeny (Bendaoud *et al.,* 2008).

A major structural unit is the LATEA metacraton, located in central Hoggar, which comprises the Laouni, Azrou n'Fad, Tefedest,

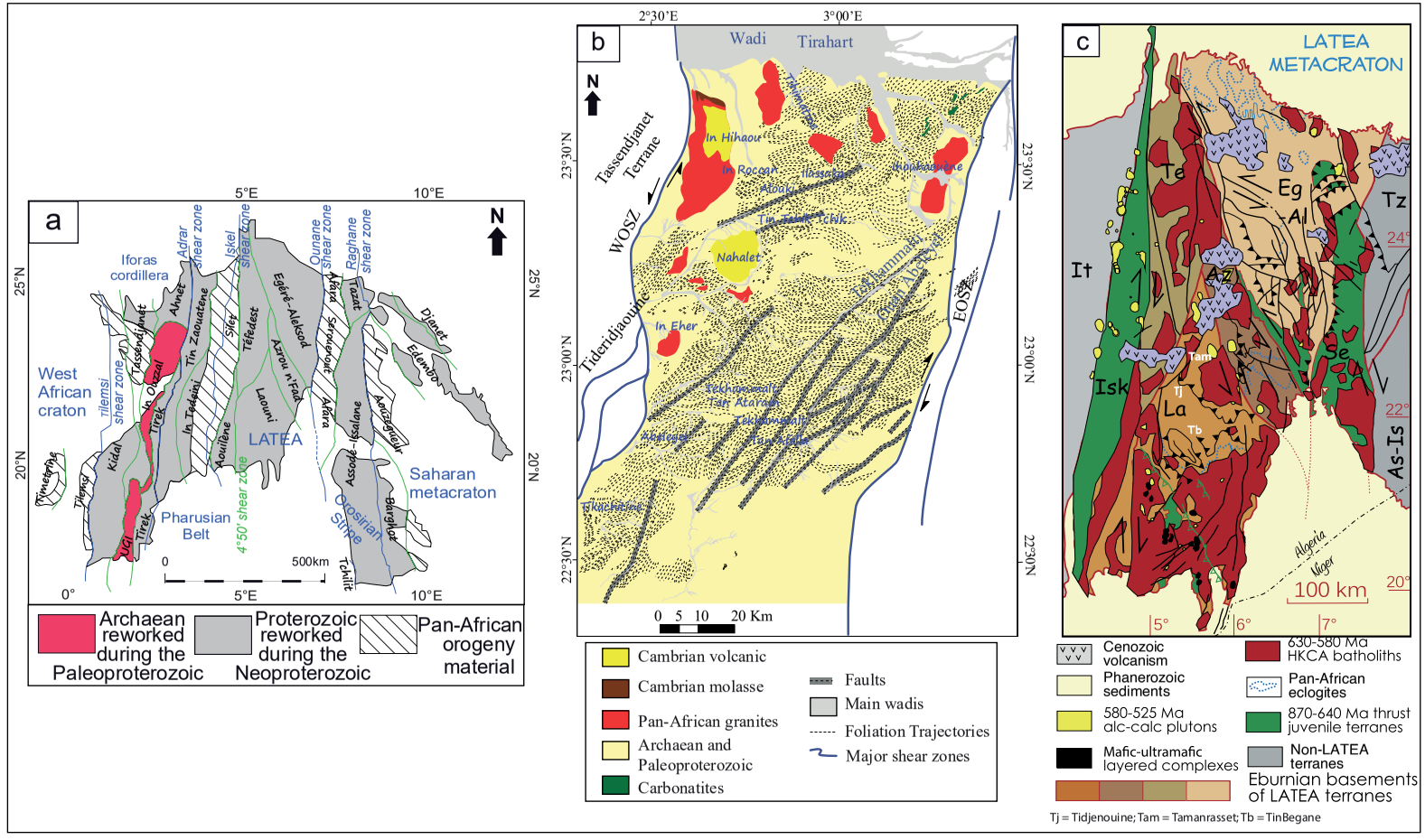


Fig. 1- (a) Simplified geological map of the Tuareg Shield after Liégeois (2019). **(b)** Geological sketch map of the northern part of the In Ouzzal terrane after Caby (1996). **(c)** Geological map of the LATEA metacraton after Liégeois *et al.* (2003).

(a) Carte géologique simplifiée du Bouclier Touareg (d'après Liégeois, 2019). (b) Carte géologique et schématique de la partie septentrionale du terrane d'In Ouzzal (d'après Caby, 1996). (c) Carte géologique du métacraton LATEA (d'après Liégeois et al., 2003).

Egéré- Aleksod and Aouilène terranes. These domains share a Paleoproterozoic granulite- to amphibolite-facies basement (2.1-1.9 Ga) with local Archean relicts (Peucat *et al.,* 2003; Bendaoud *et al.,* 2008), and underwent intense reactivation during the Pan-African orogeny (Liégeois *et al.,* 2003; Abdallah *et al.,* 2007). Metamorphic overprinting included high-temperature amphibolite or granulite to eclogite-facies conditions (Sautter, 1986; Zetoutou *et al.,* 2004, Bitam-Derridj *et al.,* 2010; Berger *et al.,* 2014; Doukkari *et al.,* 2014, 2015; Arab *et al.,* 2015, 2020).

To the west of LATEA lies the Pharusian Belt, composed of juvenile Neoproterozoic terranes (Iskel, In Tedeini, Tin Zaouatene), while further west, the In Ouzzal terrane contains a mainly Archean basement affected by ultra-high-temperature (UHT) metamorphism at ca. 2.0 Ga (Peucat *et al.,* 1996; Ouzegane *et al.,* 2003; Bosch *et al.,* 2016), and is considered a metacraton reactivated during the Pan-African orogeny (Fezaa *et al.,* 2018).

To the east of LATEA, the Serouenout terrane is interpreted as a metamorphosed ophiolitic mélange, displaying eclogite-facies assemblages (Bitam-Derridj *et al.,* 2010; Adjerid *et al.,* 2012). The Assodé-Issalane terrane, further east, underwent high-temperature amphibolite-facies metamorphism and crustal melting, related to lithospheric delamination and intrusion of Renatt-type leucogranites (~600 Ma; Liégeois *et al.,* 1994, 1998; Dahmani *et al.*, 2025).

The Hoggar Shield was intruded by multiple generations of magmatic rocks, including pre-collisional TTG batholiths (870-640 Ma),syn-collisional batholiths (615-580 Ma) and post-collisional plutons (580-520 Ma). Moreover, late Cenozoic volcanic rocks are associated with deep-seated lithospheric structures (Liégeois *et al.,* 1991, 2005; Derder *et al.,* 2016; Bouzid *et al.,* 2015). These magmatic pulses mark successive stages of lithospheric evolution and post-orogenic tectonic reactivation across the Tuareg Shield.

The Hoggar hosts two distinct granulite-facies domains that record contrasting metamorphic conditions and tectonometamorphic histories. The In Ouzzal terrane, located in western Hoggar, is renowned for preserving ultrahigh-temperature (UHT) metamorphism, with peak conditions estimated at 900-1050 °C and 8-12 kbar (Peucat *et al.*, 1996; Ouzegane *et al.*, 2003; Adjerid *et al.*, 2008; Doukkari *et al.*, 2018; Harouz *et al.*, 2024). These UHT conditions, which developed around 2.0 Ga, are associated with a regional granulite belt comprising orthopyroxene,sillimanite garnet, sapphirine, spinel, osumilite and quartz bearing assemblages, indicating extreme thermal gradients typical of high heat flow environments, possibly related to mantle upwelling during Paleoproterozoic crustal stabilization. In contrast, In the Tidjenouine area (Central Hoggar), granulite-facies metamorphism reached high-temperature (HT) conditions, with peak estimates at 860 ± 50 °C at 7-8 kbar, followed by decompression to around 700 °C and 4.3 ± 1 kbar, and later cooling to 650 °C at 3-4 kbar (Bendaoud *et al.*, 2008). These metamorphic conditions are consistent with a Paleoproterozoic high-grade event dated at ~2.06 Ga based on U-Pb zircon geochronology, attributed to the Eburnean orogeny. A later Pan-African overprint, marked by reheating and deformation localized in shear zones, is dated at ~615 Ma, but remained largely restricted to structurally weakened domains (Bendaoud *et al.*, 2008). This evolution indicates a complex, polyorogenic history involving deep crustal metamorphism followed by partial reactivation during Panafrican orogeny (Liégeois *et al.,* 2003; Liégeois, 2019). On the other hand, metabasites from Tin Begane area have experienced a clockwise P-T path, with a decompression from peak conditions estimated at 13-15 kbar and 750 ± 50 ◦C down to 7-4.5 kbar

and 810 ± 50 ◦C. The clockwise PT path can be interpreted in terms of crustal thickening followed by exhumation, most likely during the Pan African orogenesis (Derridj *et al.*, 2003; Arab *et al.,* 2025). The other area that has recorded the granulite facies metamorphism in the LATEA is the Tamanrasset region which shows a clockwise P-T path witha pre-peak stage (M1) at 11.50 ± 1.0 kbar and 735 ± 50 °C to peak metamorphic stage (M2) at 10.25 ± 1.5 kbar and 820 ± 50 °C, and finally post-peak stage (M3) at 6.75 ±1.0 kbar and 770 ± 50 °C conditions (Ouzegane *et al.*, 2025).

III- THE UHT METAMORPHISM OF IN OUZZAL TERRANE

The In Ouzzal terrane, located in northwestern Algeria, represents a complex assemblage of Archean to Paleoproterozoic high-grade metamorphic rocks that have undergone granulite-facies metamorphism (Ouzegane, 1987; Kienast *et al.*,1996). The lithological diversity within this terrane is particularly striking, and it is best described by considering the major rock units and their geochemical and geochronological characteristics.

The infracrustal orthogneisses

The orthogneisses are largely composed of enderbitic and charnockitic gneisses, and forms the dominant structural and lithological component of the terrane (fig. 2a). These orthogneisses are typically organized into dome-shaped massifs, which are separated by synformal basins occupied with supracrustal metasediments (Haddoum *et al.*, 1994). Based on petrographic, geochemical, structural, and geochronological criteria, three principal magmatic suites can be distinguished:

The Archean TTG suite consists of banded enderbitic orthogneisses with trondhjemitic and tonalitic compositions. Geochemically, this suite is characterized by low K_2O/Na_2O ratios (<0.5) and by primitive mantle-normalized trace element patterns marked by negative anomalies in Ta, Nb, P, and Ti, as well as a positive Pb anomaly (Barker, 1979). These features, including low Y, Yb, Nb, and Ta contents, suggest derivation from a garnet-amphibolite source (Peucat *et al.*, 1996). Zircon U-Pb geochronology reveals magmatic emplacement ages of approximately 3.2 Ga and 2.7 Ga, with TDM ages clustering around 3.2 Ga and εNd values ranging from +0.4 to +5.3, indicating a depleted mantle source.

The second suite corresponds to a group of alkali-rich orthogneisses emplaced around 2650 Ma. Chemically, they exhibit high SiO_2 contents (69-75 wt.%), high K_2O (>6 wt.%), and low Na_2O (<2.9 wt.%). Trace element data show enrichment in Ba, Zr, Hf, and Nb. Their REE patterns are flat to weakly fractionated consistent with intraplate granites (Peucat *et al.*, 1996). The Negative εNd values (-6.5) and high $\delta^{18}O$ values (5.95-7.7‰) indicate a protolith formed in rift zones (Liégeois *et al.*, 1998; Peucat *et al.*, 1996).

The third magmatic suite is characterized by calc-alkaline orthogneisses emplaced at 2500 Ma and is subdivided into two distinct units. The first unit comprises granodioritic to monzogranitic gneisses that are slightly peraluminous (A/CNK = 1.01-1.08) and display moderate XMg consistent with the characteristics of Archean calc-alkaline granites as defined by Sylvester (1994). Their trace element patterns, normalized to the primitive mantle, show negative anomalies in Ba, Ta, Nb, Sr, P, and Ti, similar to those observed in orogenic suites and are thought to derive from the partial melting of tonalitic lower crust. The second unit consists of monzogranitic orthogneisses with a calc-alkaline trend and is interpreted as a post-orogenic, highly fractionated suite derived from melting of tonalites interlayered with metasedimentary rocks at shallower depths. The U-Pb zircon geochronology indicates that both units were emplaced at approximately 2.5 Ga, with the

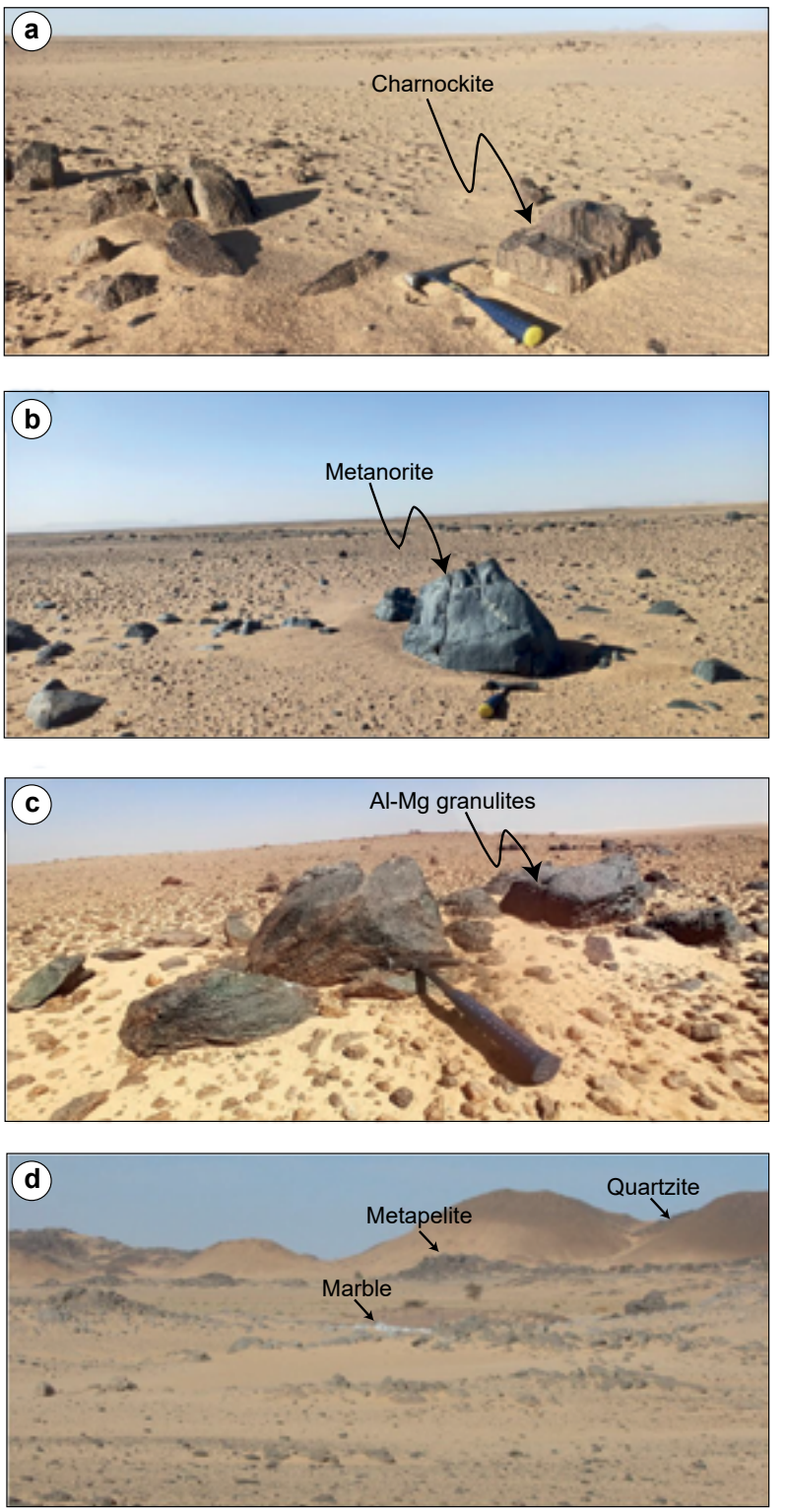


Fig. 2- Field outcrops of various lithologies in the northern part of In ouzzal terrane and LATEA.

Affleurements représentatifs des différentes lithologies du terrane d'In Ouzzal et du métacraton LATEA.

protoliths having a minimum age of 2.94 Ga (Peucat *et al.*, 1996).

The mafic and ultramafic meta-igneous granulites

The mafic and ultramafic meta-igneous granulites of the In Ouzzal terrane, primarily found around In Hihaou, Tekhamalt, Ihouhaouène, and Amesmessa, occur as boudinaged lenses (fig. 2b) aligned with regional foliation within UHT metamorphic lithologies (Peucat *et al.*, 1996, Bendaoud, 2008). These include metanorites and garnet pyroxenites, which respectively exhibit garnet-free and garnet-bearing assemblages. Peridotites, often serpentinized and associated with pyroxenites and anorthosites, are divided into lherzolites and harzburgites (Bendaoud *et al.*, 2001, Bendaoud, 2008), and exhibit equilibrium textures with Cr-rich spinel and high-Mg amphiboles. The geochemistry of these rocks indicates significant mobility of fluid-mobile elements (Rb, U, Th), as reflected in abnormal Rb/Sr, La/Th, and Th/U ratios (Peucat *et al.*, 1996). Samples with >20 wt.% of MgO are interpreted as komatiites (Bendaoud *et al.*, 2002). REE and spider diagrams are comparable to those of Archean tholeiites and high-Mg andesites. Isotopic data show elevated initial Sr ratios (0.7046-0.7072 at 3.2 Ga) and variable Nd model ages (3136-4193 Ma), suggesting strong disturbance from high-grade metamorphism, as commonly observed in Archean greenstone belts (Gruau *et al.*, 1992; Arndt, 1998).

Al-Mg and Al-Fe granulites

Al-Mg granulites are interlayered with banded iron formations and marbles (fig. 2c), and occur adjacent to metaigneous units. Two main field types are distinguished: quartz-rich granulites, which are massive and foliated, and quartz-free varieties, which often appear as blue sapphirine-rich lenses. The mineral assemblages typically include orthopyroxene-sillimanite associations, with cordierite, spinel, corundum, garnet, biotite, feldspars, and oxides (fig. 3; Bernard-Griffiths *et al.*, 1996; Ouzegane & Kienast, 1996, Ouzegane *et al.*, 2003a,b). Structural features such as grain elongation and orthopyroxene torsion reflect high-temperature ductile deformation via diffusion creep. Based on silica content and index minerals, these granulites are classified into five compositional groups: spinel-bearing (SiO_2 37-40%), corundum-bearing (40-45%), quartz-free (43-45%), quartz-bearing (46-63%), and quartzitic (65-85%) Al-Mg granulites (Bernard-Griffiths *et al.*, 1996, Ouzegane *et al.*, 2003a).

Al-Fe granulites, on the other hand, display migmatitic textures marked by quartz-feldspar veinlets (Ait Djafer, 1996; Ait Djafer & Ouzegane, 1998, Badani-Djebloun *et al.*, 2025). Their mineralogy includes garnet, sillimanite, spinel and cordierite, often forming symplectites indicative of decompression reactions (Ouzegane, 1987, Ouzegane & Boumaza 1996, Ouzegane *et al.*, 2003a, b, Doukkari *et al.*, 2018). The formation of cordierite and spinel from garnet and sillimanite reflects a high-temperature decompression path. Al-Fe quartzites, notably those containing hercynite and quartz show reaction textures like garnet-sillimanite coronas due to breakdown of hercynite, magnetite, and quartz (Badani-Djebloun *et al.*, 2000, Badani-Djebloun *et al.*, 2025), and in some cases, garnet develops from reactions involving sillimanite, quartz, and magnetite under oxidizing conditions (Helal, 1987).

Al-Mg and Al-Fe granulites are predominantly composed of SiO_2-Al_2O_3-FeO-MgO, accounting for over 90% of the total oxides. These granulites are chemically distinguishable based on their SiO_2 content and XMg. Al-Fe granulites have lower XMg values (0.3-0.48) and are quartz-rich, preventing the formation of orthopyroxene-sillimanite or sapphirine-bearing assemblages. In contrast, Al-Mg granulites, with higher XMg (>0.5), commonly contain these high-temperature mineral assemblages (Bernard-Griffiths *et al.*, 1996; Ouzegane *et al.*, 2003b).

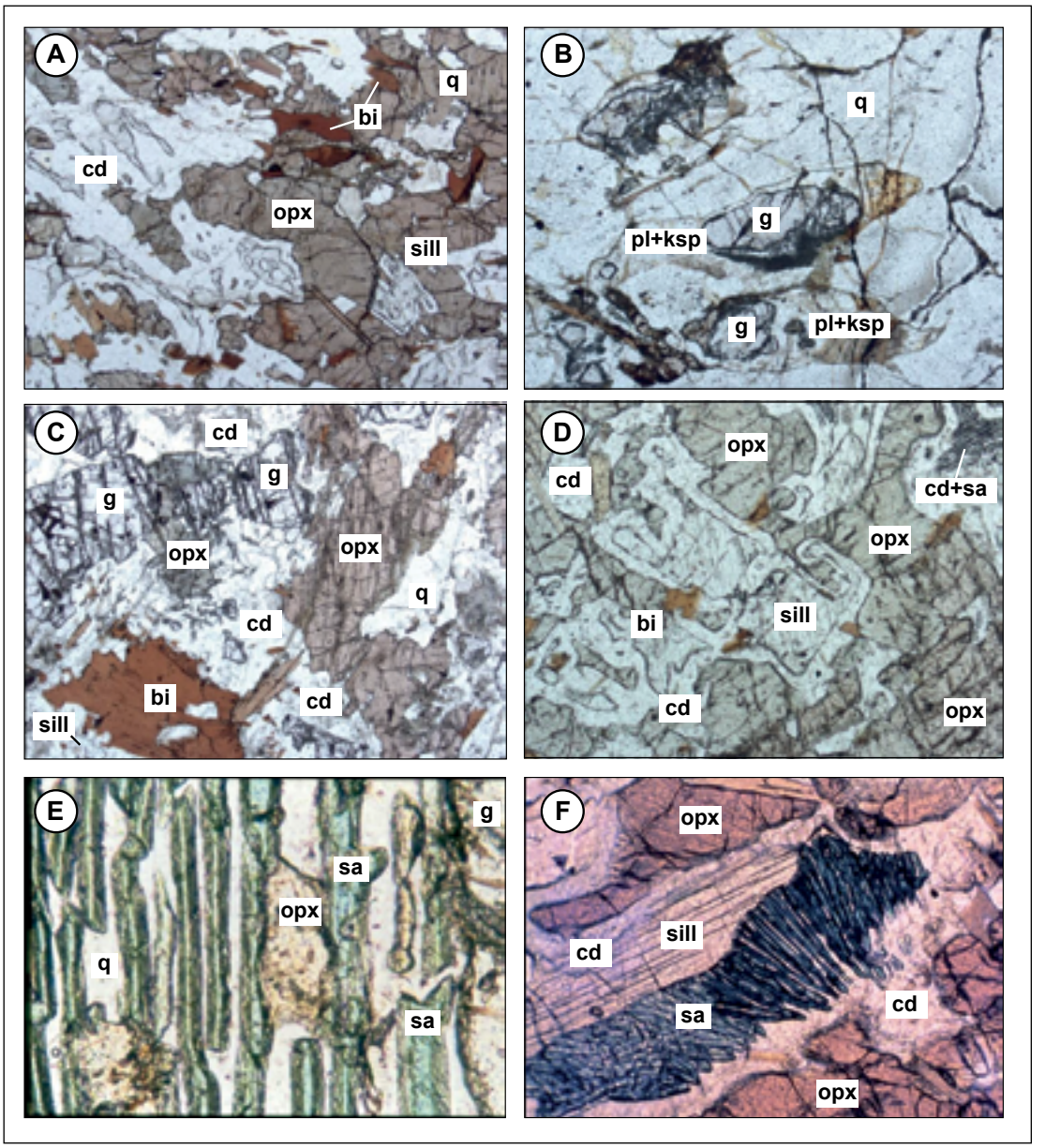


Fig. 3- Thin section microphotographs of the various mineral assemblages and reaction textures in Mg–Al granulites (from Doukkari *et al.*, 2018 and Harouz *et al.*, 2024)

Microphotographies en lame mince des différents assemblages minéralogiques et des textures réactionnelles observés dans les granulites magnésio-alumineuses (Mg–Al) (d'après Doukkari et al., 2018, et Harouz et al., 2024).

The trace element chemistry of Al-Mg granulites, including very high Cr, Ni, and Co, is incompatible with a partial melting origin. Instead, it suggests a pre-metamorphic hydrothermal alteration of mafic to ultramafic protoliths, forming chlorite-rich precursors, later mixed with quartz-rich detrital sediments. This dual origin is supported by $\delta^{18}O$ values (5-9.5‰), indicating a mixture of mature (granitic) and immature (chloritic) sources (Rahmani, 1992; Bernard-Griffiths *et al.*, 1996). Al-Fe granulites show similar compositional traits, supporting

a common mixed origin (Badani-Djebloun *et al.*, 2025).

Geochronological analyses of detrital zircons reveal that Al-Fe quartzites from Ihouhaouène contain inherited cores aged between 2700-3100 Ma, with metamorphic rims formed during granulite-facies metamorphism at ~2.0 Ga (Helal, 1987; Peucat *et al.*, 1996). Similarly, Al-Mg granulites host inherited zircons dated between 2700-3200 Ma, likely derived from the erosion of Archaean TTG complexes, suggesting a Neoarchaean source (Peucat *et al.*, 1996).

Metamorphic P-T path/conditions

The metamorphic evolution of the In Ouzzal terrane is firmly established within the timeframe of the Paleoproterozoic orogeny, as indicated by a range of isotopic dating methods. Rb/Sr dating on minerals (Allègre and Caby, 1972), U/Th/Pb dating on zircon (Lancelot *et al.*, 1976; Peucat *et al.*, 1996), and Sm/Nd dating on garnet (Ben Othman *et al.*, 1984; Peucat *et al.*, 1996) consistently yield ages between 2100 and 1950 Ma. These data confirm the acquisition of the granulitic metamorphic imprint during this major tectonothermal event.

The granulites of In Ouzzal offer exceptional conditions for reconstructing metamorphic histories through mineral and whole-rock chemistry. Numerous studies have used this approach to track variations in pressure, temperature, and water activity (XH_2O). Petrological estimations of P-T conditions have been based on a variety of lithologies, including Al-Mg granulites (Ouzegane, 1987; Kienast and Ouzegane, 1987; Bertrand *et al.*, 1992; Ait Djafer, 1996; Boumaza, 1996; Mouri *et al.*, 1996; Ouzegane and Boumaza, 1996; Adjerid, 2002), Al-Fe granulites (Ait Djafer, 1996; Djemai, 1996; Ouzegane *et al.*, 1996), corundum-magnetite quartzites (Guiraud *et al.*, 1996), calc-silicate granulites (Benyahia, 1996, Harrouz *et al.*, 2024), and garnet pyroxenites (Ouzegane, 1987; Kienast and Ouzegane, 1987; Djemai, 1996; Bendaoud, 2008).

Among these, the Al-Mg granulites contain the most complete reaction sequences, recording a prograde metamorphic evolution under extreme granulite-facies temperatures. Despite the general continuity in the mineral parageneses, the metamorphic evolution of the In Ouzzal terrane can be subdivided into two principal stages (fig. 4): a prograde isobaric heating stage at pressures of 10-11 kbar with increasing temperatures from 800 to 1050 °C, followed by a decompression stage down to 5 kbar while maintaining high temperatures around 900-1000 °C (Ouzegane, 1987; Bertrand *et al.*, 1992; Ouzegane and Boumaza, 1996; Ouzegane *et al.*, 2003a, b).

During the prograde stage, extreme high-temperature conditions led to the growth of UHT mineral assemblages, notably sapphirine-quartz and sapphirine-spinel-quartz (Adjerid *et al.*, 2008), indicative of the peak metamorphism conditions. This stage is well represented in the FMAS system, where equilibrium assemblages such as orthopyroxene-corundum-garnet, orthopyroxene-corundum, garnet-spinel-corundum, garnet-quartz-sillimanite-orthopyroxene, and orthopyroxene-sillimanite-quartz are documented. More complex systems include biotite, K-feldspar, plagioclase, and rutile. In quartz-bearing Al-Mg granulites, reactions were modelled to produce P-T diagrams with invariant points that match experimental constraints (Ackermand *et al.*, 1975; Hensen and Green, 1973; Bertrand *et al.*, 1991; Harley and Motoyoshi, 2000).

The earliest reaction in quartz-bearing Al-Mg granulites is garnet + quartz → orthopyroxene + sillimanite, with estimated equilibrium conditions at 9.5-11.5 kbar and approximately 1000 °C (Bertrand *et al.*, 1992). The associa-

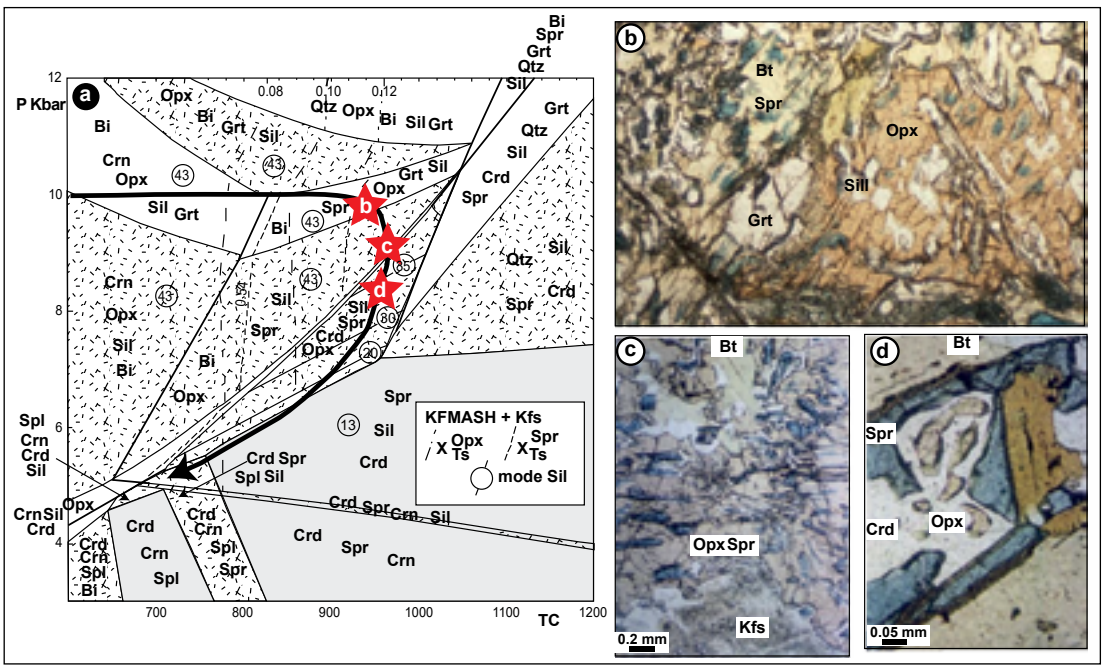


Fig. 4- P-T pseudosection and microphotographs of Al-Mg granulites from In Ouzzal terrane showing the evolution of mineral assemblages during the P-T path (from Ouzegane *et al.*, 2003b).

Pseudosection P–T et microphotographies en lame mince de granulites magnésio-alumineuses (Al–Mg) du terrane d'In Ouzzal, illustrant l'évolution des assemblages minéralogiques au cours du trajet pression–température (P–T) (d'après Ouzegane et al., 2003b).

tion sapphirine-quartz, which becomes stable above 1050 °C, marks the metamorphic peak and forms through reactions such as orthopyroxene + sillimanite → garnet + sapphirine + quartz. Symplectites involving orthopyroxene-quartz-sapphirine around garnet are noted in the quartzites of Tekhamalt, with evidence for divariant reactions specific to Fe-rich microdomains (Ouzegane *et al.*, 2003a).

Compositional changes support this P-T evolution: garnet becomes enriched in Fe (XMg decreases from 0.64 to 0.50), the Al_2O_3 content of orthopyroxene increases, and that of sapphirine decreases through Mg-Si→Al-Al substitution. These trends, along with thermodynamic modeling, indicate isobaric heating from 800 to 1050 °C at pressures around 10-11 kbar.

During decompression, the high-pressure mineral assemblages become destabilized, with pressure dropping to around 5 kbar. In Al-Mg granulites, orthopyroxene + sillimanite + quartz is replaced by cordierite via the reaction orthopyroxene + sillimanite + quartz → cordierite, occurring near 9 kbar and 950 °C. In more Fe-rich rocks (XMg ≈ 0.20), garnet-sapphirine-sillimanite-quartz assemblages are stable during decompression, with subsequent reactions such as garnet + sillimanite → sapphirine + cordierite, and finally, orthopyroxene + sapphirine → cordierite + spinel near 5-6 kbar. In Al-Fe granulites, decompression textures with cordierite coronas and spinel symplectites reflect reactions like garnet + sillimanite + quartz → cordierite or garnet + sillimanite → cordierite + spinel. The terminal stages are marked by cordierite replacing spinel-quartz, with temperatures falling to about 750 °C at 5-6 kbar (Kienast and Ouzegane, 1987; Ouzegane *et al.*, 2003).

In the light of the recent advances in the thermodynamic modelling, Doukkari *et al.* (2018)

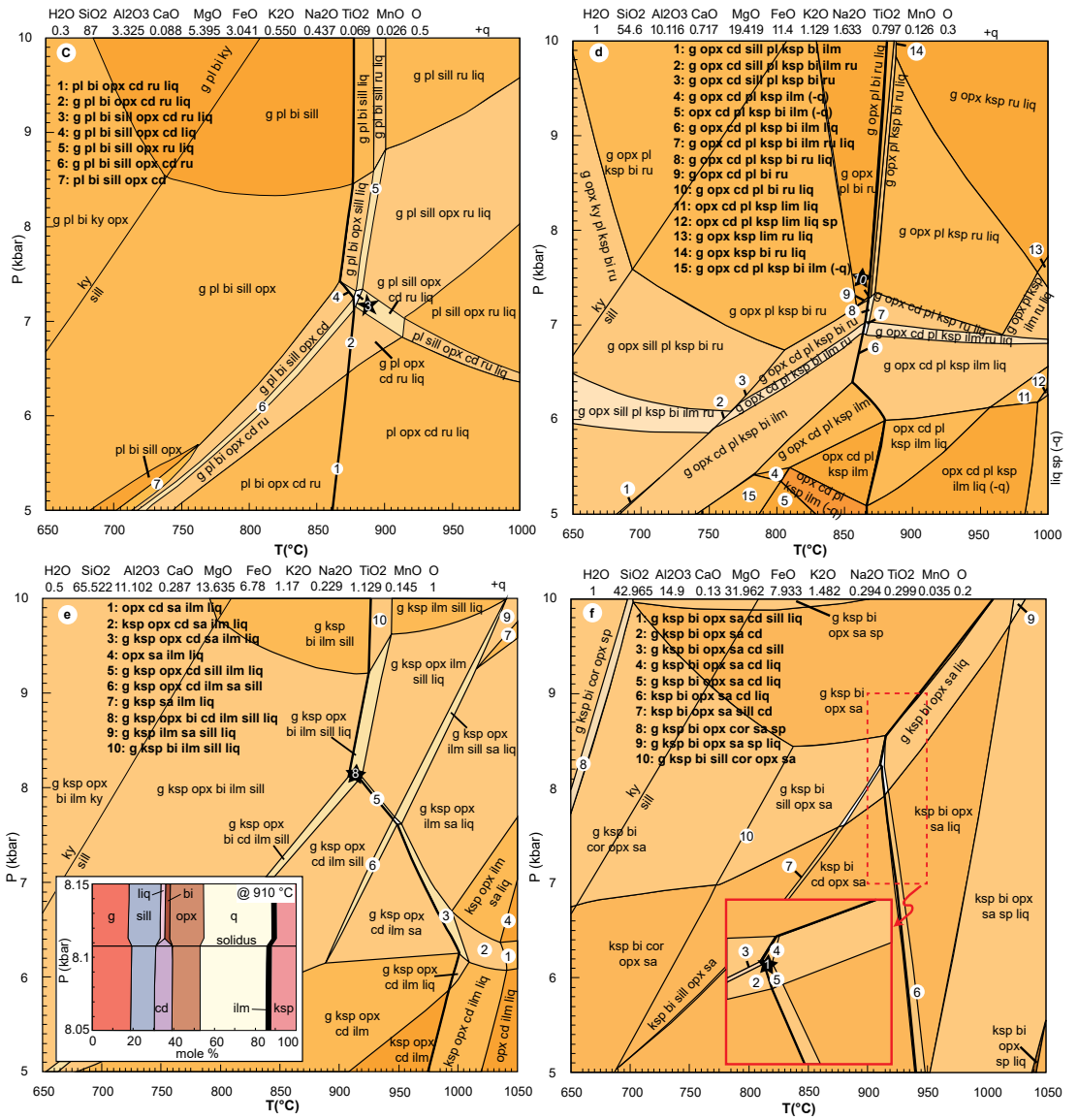


Fig. 5- P–T pseudosections in the MnNCKFMASHTO system for Al–Mg granulites from the In Ouzzal terrane (from Doukkari *et al*., 2018).

Pseudosection P–T calculée dans le système MnNCKFMASHTO pour les granulites magnésio-alumineuses (Al–Mg) du terrane d' In Ouzzal (d'après Doukkari et al., 2018).

have used calculated pseudosections to re-evaluate the previously estimated P-T conditions in Al-Mg granulites. Re-evaluated peak-conditions were estimated at 8.5 ± 1 kbar and 900 ± 20°C (fig. 5). These results have been supported by recent independent estimates of 900-1050°C for peak UHT conditions derived from ternary feldspar thermometry (Benbatta *et al.*, 2017), but are significantly lower than estimates of more than 1050-1100°C and 10 kbar previously suggested (Ouzegane & Boumaza, 1996; Ouzegane *et al.*, 2003b). The interpretation of the mineral assemblages and textures largely follows that of the previous works, and the difference is exclusively due to the updated methodologies used to quantify P-T conditions. However, the

estimation of peak P-T is conservative, as the modelling ignores F in biotite and CO_2 in cordierite, which will respectively increase the upper temperature and pressure limits of biotite and cordierite stability by up to 50-100°C and 1-2 kbar (Dooley & Patino- Douce, 1996; Harley & Thompson, 2004; Harley *et al.*, 2002; Hensen & Osanai, 1994; Icenhower & London, 1997; Kurepin, 2010).

Ideas evolution through time and geodynamic implication of the UHT metamorphism

Initial investigations in the In Ouzzal terrane aimed to identify evidence of Archean metamorphism, particularly through the study of late Archean granites (ca. 2.5 Ga), interpreted as products of partial melting of ancient crust during high-grade metamorphism (Peucat *et al.*, 1996; Ouzegane *et al.*, 2003b). These granitic bodies, along with associated granulitic parageneses, were thought to reflect deep crustal reworking during the stabilization of the Archean lithosphere. However, more recent studies combining detailed petrography, and thermobarometry have revealed that a major Paleoproterozoic tectonometamorphic event at ca. 2.0-1.9 Ga, associated with the Eburnean orogeny, has profoundly overprinted the earlier Archean record (Ouzegane & Boumaza, 1996; Ouzegane *et al.*, 2003a; Aït Djafer *et al.*, 2009; Doukkari *et al.*, 2018; and Harouz *et al.*, 2024). This UHT event locally exceeded 1000 °C as recorded by sapphirine-quartz and orthopyroxene-sillimanite-bearing assemblages, is now widely accepted to obliterate most of the mineralogical and isotopic evidence of the Archean metamorphism, with zircon and monazite ages overwhelmingly reflecting Paleoproterozoic crystallization or recrystallization (Doukkari *et al.*, *In* preparation).

As a result, the scientific focus has shifted away from identifying Archean signatures toward unravelling the complexity of the Paleoproterozoic overprint. Current research questions are now centred on understanding the duration and thermal evolution of the UHT-metamorphism whether it was short-lived and associated with rapid tectonic processes or prolonged over tens of millions of years, suggesting sustained crustal heat input possibly linked to deep crustal insulation or mantle-derived magmatism. Resolving this issue is critical for constraining the geodynamic context of the Eburnean orogeny and for understanding the longevity of UHT conditions in lower continental crust.

The In Ouzzal granulitic unit (IOGU) presents a unique high-grade metamorphic evolution that diverges from the typical model of continental collision belts observed in modern orogens. Instead of a classic subduction-related metamorphic belt, the IOGU is characterized by ultra-high-temperature (UHT) metamorphism reaching up to 900 °C/1100 °C (Kienast *et al.*, 1996; Guiraud *et al.*, 1996; Ouzegane and Boumaza, 1996; Harley, 1998; Doukkari *et al.*, 2018), yet it records only limited partial melting despite such extreme thermal conditions. The deformation style resembles that of Archaean cratons involving dome and basin structures and vertical foliations (Haddoum *et al.*, 1994). Syn-metamorphic emplacement of carbonatites with distinctive geochemical signatures and the presence of anorthosites imply a mantle-derived contribution.

The metamorphic evolution follows a clockwise P-T path beginning with crustal thickening and pressure increase during Paleoproterozoic tectonics (~2.06-2.0 Ga), reaching conditions of 800-1050 °C at 10-11 kbar (fig. 4). This first stage reflects the continuation and intensification of Archaean tectonic regimes, involving regional NW-SE shortening and reactivation of vertical Archaean fabrics. The second stage is marked by a significant heat influx without a notable pressure increase, interpreted as evidence for asthenospheric upwelling and lithospheric mantle delamination. Due to prior crustal dehydration during Archaean anatexis, melt buffering was minimal, allowing unimpeded heat diffusion and resulting in extreme

thermal conditions (Vielzeuf *et al.*, 1990).The third stage corresponds to isothermal decompression (down to 5-6 kbar), likely related to post-orogenic extension. This extension may reflect asthenospheric rebound and isostatic re-equilibration, ultimately leading to thermal stabilization of the lithosphere. This re-stabilized cratonic architecture is what preserved the In Ouzzal terrane from extensive reworking during the Pan-African orogeny (Black & Liégeois, 1993; Ouzegane *et al.*, 2003).

IV- THE HT METAMORPHISM OF LATEA (CENTRAL HOGGAR)

Several studies suggest that granulite-facies metamorphism in the Central Hoggar occurred during the Paleoproterozoic (fig. 1c), with reported ages of approximately 1.9 Ga at Gour Oumelalen (Peucat *et al.*, 2003) and around 2.0 Ga at Tidjénouine (Bendaoud *et al.*, 2003, 2008). According to some authors, the Pan-African orogeny led only to greenschist- or amphibolite-facies metamorphism (Liégeois *et al.*, 2003; Peucat *et al.*, 2003). However, Ouzegane *et al.* (2025), argue that granulite-facies metamorphism also occurred during the Pan-African event based on U-Pb dating of 200 zircon grains of metapelites from Tamanrasset area.

The Tidjenouine area, situated in the central Hoggar, lies within the north western part of the Laouni terrane. Structurally, the Laouni terrane is characterized by a granulite- to amphibolite-facies basement that is tectonically juxtaposed against Pan-African lithologies through major thrust systems. These include remnants of oceanic crust such as the Tessalit ophiolite to the south and high-pressure granulite in the Tin Begane region (Derridj *et al.*, 2003; Arab *et al.*, 2025). Together with the Azrou-n-Fad, Tefedest, and Egéré-Aleksod terranes, Laouni forms the LATEA microcontinent, an Archaean to Paleoproterozoic block that was fragmented and intruded by granitic batholiths during the Pan-African tectonothermal event (Bendaoud *et al.*, 2008).

The granulite-facies rocks of Tidjénouine are complex and diverse, comprising migmatitic gneisses that contain metapelitic and metabasic inclusions, along with biotite-garnet-sillimanite-rich migmatitic metapelites. These metapelites are interlayered with olivine-spinel marbles, sillimanite-bearing quartzites, and mafic layers. Structurally, the quartzites form thick folded ridges, and the marbles occur as aligned boudins. All of these lithologies are crosscut by younger Pan-African granites, and skarn formation is observed at the contacts between carbonate-rich marbles and intrusive granites (fig. 2d; Bouammar, 1991). The granulite-facies metamorphism that affects these rocks is associated with subhorizontal foliation, indicative of tangential tectonics typical of deep crustal settings.

Geochronological data in the Laouni terrane remain limited but informative. The emplacement of the Pan-African Anfeg granitic batholith is dated at 608 ± 7 Ma based on U-Pb zircon ages (Bertrand *et al.*, 1986; recalculated by Liégeois *et al.*, 2003), while the thrust-bound oceanic material at Tin Begane experienced amphibolite-facies metamorphism around 685 ± 20 Ma, based on Sm-Nd mineral isochrones (Liégeois et *al.,* 2003). However, some rocks in Tidjenouine, including granulites and migmatitic granites, yield older U-Pb zircon ages around 1979 ± 33 Ma and 2038 ± 15 Ma, suggesting an earlier Paleoproterozoic (Eburnean) high-grade metamorphic event (Bertrand *et al.*, 1986; recalculated by Liégeois *et al.*, 2003). A migmatite from the neighboring Azrou-n-Fad terrane produced discordant zircon ages with an upper intercept of 2131 ± 12 Ma and a lower intercept at 609 ± 17 Ma, reflecting the complex metamorphic and tectonic history of the region.

The interpretation of the age of granulite-facies metamorphism in Tidjenouine is debated. Some researchers consider the ~2.0 Ga ages as evidence of Eburnean high-grade metamorphism, unaffected by Pan-African overprinting (Bertrand & Jardim de Sá, 1990; Ouzegane *et*

al., 2001; Liégeois *et al.*, 2003; Bendaoud *et al.*, 2008). Others argue that these ages only represent the protoliths, and that the granulite-facies metamorphism is in fact Pan-African in age (Barbey *et al.*, 1989; Caby, 2003). There is also a third position acknowledging the uncertainty and suggesting that current data are insufficient to decisively confirm either hypothesis (Bendaoud *et al.*, 2004; Benyahia *et al.*, 2005).

The Tin Begane region (Laouni terrane) is notable for its complex tectonic architecture dominated by large-scale megathrusts. This region is broadly divided into two distinct geological domains. First, extensive Pan-African granitic batholiths, emplaced during the late stages of the orogeny (Bettioui *et al.*, 2022). Second, highly migmatitized metamorphic rocks interspersed with ultramafic to mafic lithologies, including serpentinites, peridotites, garnet-bearing micaschists, and Mn-rich pods. These assemblages are interpreted as fragments of ancient oceanic lithosphere, or ophiolitic remnants, tectonically emplaced during neoproterozoic subduction-collision processes (Black *et al.*, 1994; Liégeois *et al.*, 2003). Tin Begane metabasites display striking reaction textures, most notably symplectites, which led Boughrara (1999) and Liégeois *et al.* (2003) to interpret them as retrogressed eclogites, now preserved as garnet amphibolites. The observed microstructures and mineral assemblages suggest an early evolution under intermediate-pressure conditions, likely within the eclogite facies, followed by overprinting under lower-pressure, amphibolite- to granulite-facies conditions. The pervasive development of symplectitic textures, particularly involving the breakdown of garnet and clinopyroxene, points to high-temperature decompression processes affecting all lithologies. This evolution is consistent with a clockwise P-T path involving crustal thickening and subsequent exhumation. Numerous studies have confirmed this metamorphic trajectory, highlighting the role of high-temperature decompression in the retrogression of eclogitic assemblages and the stabilization of amphibolitic mineral parageneses (Latouche, 1985; Boughrara, 1999; Ouzegane *et al.*, 2001; Liégeois *et al.*, 2003; Bendaoud *et al.*, 2008; Bitam-Derridj *et al.*, 2010; Ayad *et al.*, 2016; Fettous, 2016; Arab *et al.,* 2025). The Tamanrasset area hosts remarkably well-preserved garnet pyroxenites and metapelites that have enabled detailed reconstructions of the metamorphic history. Peak metamorphic conditions are estimated at approximately 820 °C and 10 kbar, indicating high-temperature, moderate-pressure metamorphism. Subsequent retrogression led to the development of lower-grade assemblages under conditions of around 750 °C and 6.5 kbar (Ouzegane *et al.*, 2001; Ouzegane *et al.*, 2025).

Metamorphic P-T path/conditions

In several parts of the Laouni terrane, granulite-facies rocks are commonly associated with extensive migmatitic activity, which began during the prograde segment of a clockwise metamorphic evolution. Textural observations and P-T estimates in the Tidjénouine area indicate that partial melting commenced and was sustained during the M1 metamorphic stage, peaking at approximately 850 °C and 7.5 kbar. Even during the early stages of the retrograde M2 evolution, down to 700 °C and 4 kbar, the rocks remained within granulite-facies conditions. Strongly restitic early granulites especially corundum-bearing metapelites suggest that significant melting had already occurred before the M1 climax, with additional melt generated during biotite breakdown in the M2 stage (Bendaoud *et al.,* 2008). The subsequent M2' stage reached amphibolite-facies conditions around 600 °C, marked by the development of late-stage minerals like anthophyllite, cummingtonite, and secondary biotite (fig. 6b). The granulitic metamorphism is dated to the Eburnean orogeny at approximately 2062 ± 39 Ma (Bendaoud *et al.* 2008). This metamorphic history also reflects a progres-

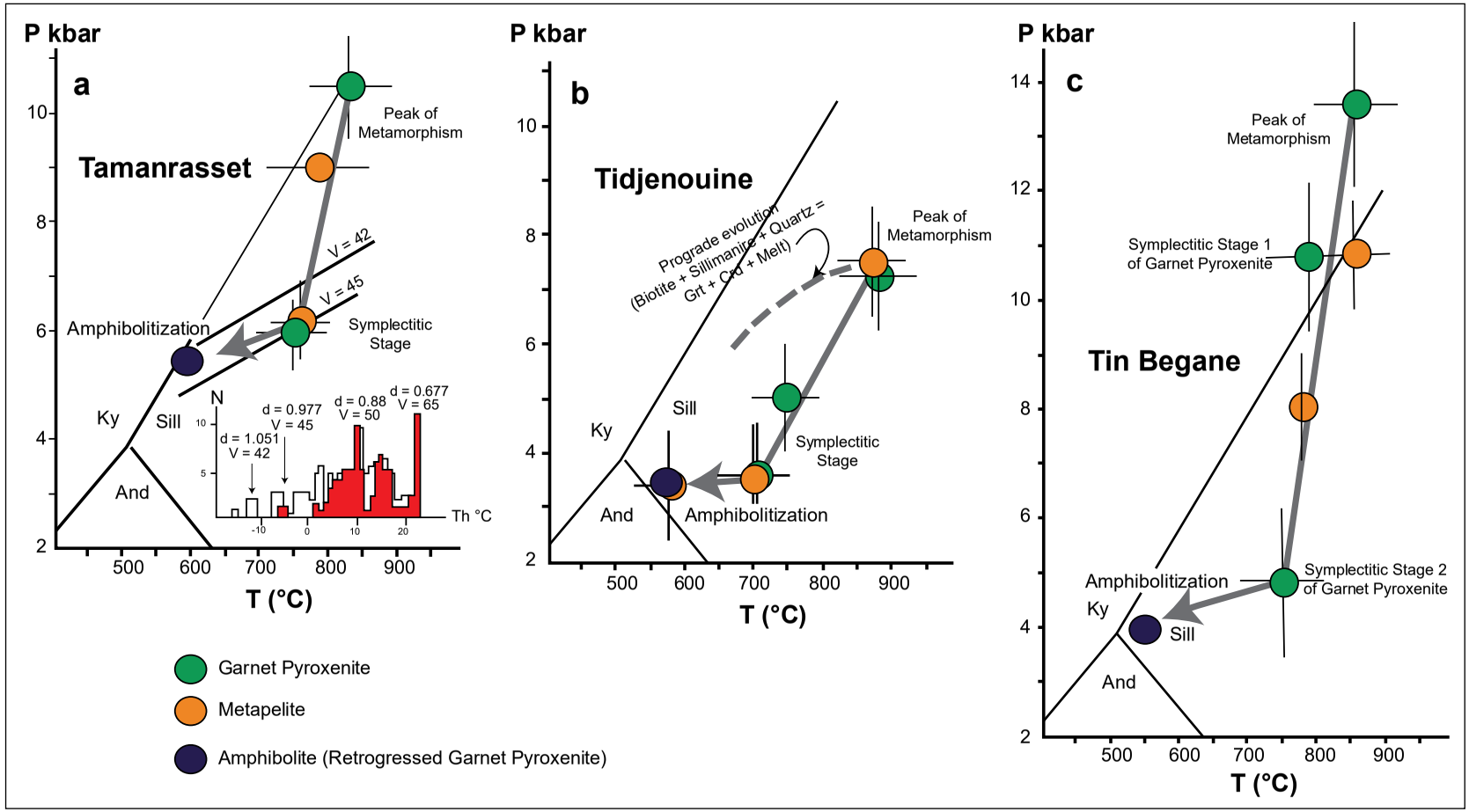


Fig. 6- P-T paths of H-T terranes from the LATEA metacraton (from Ouzegane *et al.*, 2001).

Trajets pression–température (P–T) des terranes de haute température (HT) du métacraton LATEA (d'après Ouzegane et al., 2001).

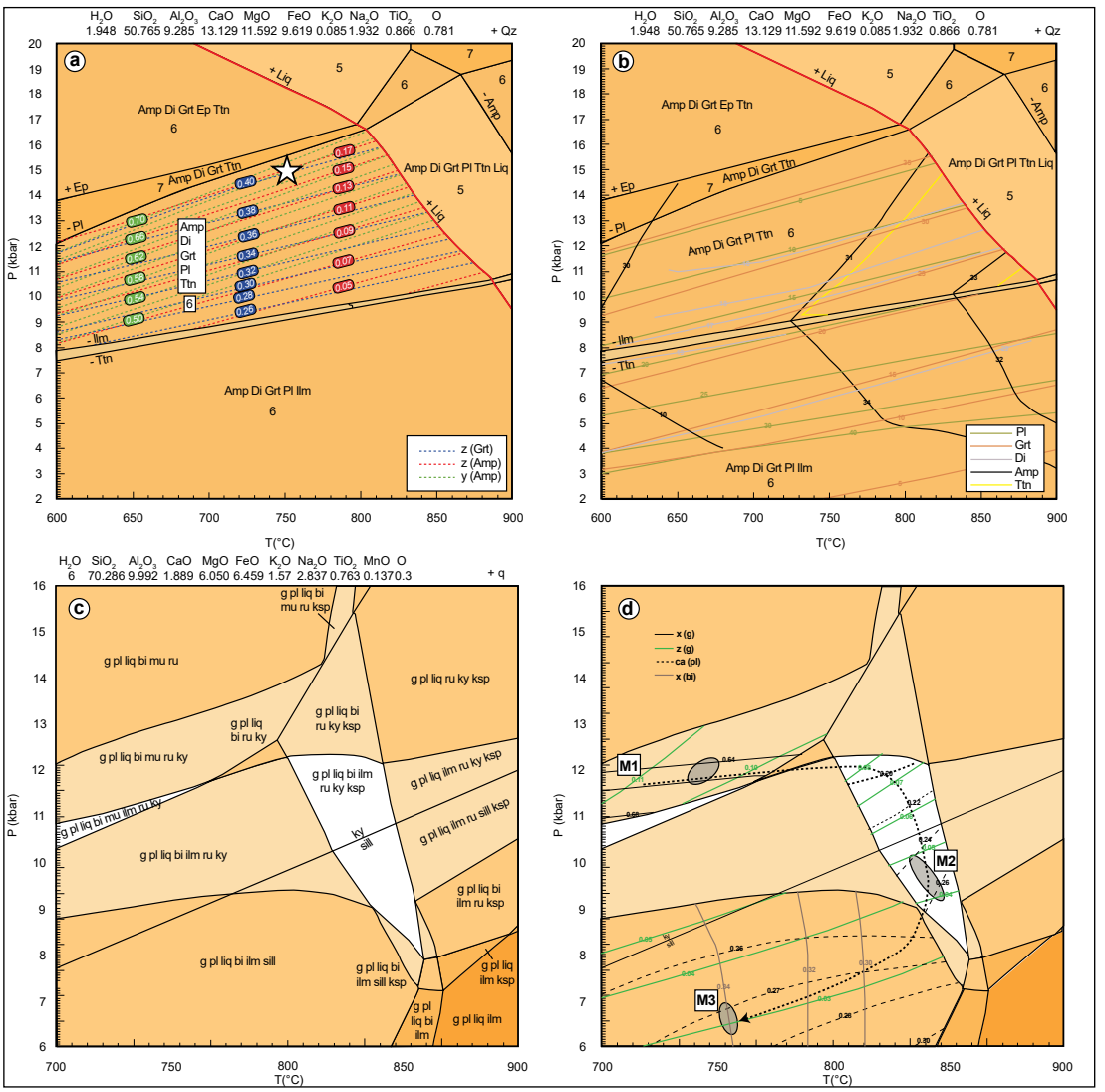


Fig. 7- (a, b) P-T pseudosection of a Tin Begane metabasite (from Arab *et al.*, 2025). **(c, d)** P-T pseudosection of a Tamanrasset metapelites (from Ouzegane *et al.*, 2025).

(a, b) Pseudosection P–T d'une métabasite de Tin Begane (d'après Arab et al., 2025). (c, d) Pseudosection P–T d'une métapélite de Tamanrasset (d'après Ouzegane et al., 2025).

sive decrease in water activity, likely due to H_2O sequestration into anatectic melts, thereby preserving high-grade assemblages; amphibolite-facies overprinting remains localized (Bendaoud *et al.*, 2008).On the other hand, The succession of mineral assemblages in the Tamanrasset region, indicates a neoproterozoic clockwise P-T path starting with a pre-peak stage (M1) at approximately 11.50 ± 1.0 kbar and 735 ± 50 °C, progresses to peak metamorphic conditions (M2) at around 10.25 ± 1.5 kbar and 820 ± 50 °C, and concludes with a post-peak stage (M3) marked by nearly isothermal decompression to 6.75 ± 1.0 kbar and 770 ± 50 °C (fig. 6a; fig. 7 a, b; Ouzegane *et al.*, 2025). The Tin Begane area has also recorded a granulite-facies metamorphism characterized also by a clockwise P-T path with decompression from peak conditions of 13-15 kbar and 750 ± 50 °C to 7-4.5 kbar

and 810 ± 50 °C (fig. 6c, fig. 7 a, b; Arab *et al.*, 2025).

Ideas evolution through time and geodynamic implication of the HT metamorphism

The understanding of the LATEA has undergone a significant evolution over the past two decades. Early models, notably those proposed by Liégeois *et al.* (2003), portrayed LATEA as a metacraton an ancient, structurally coherent crustal block that had largely escaped significant reworking during the Neoproterozoic Pan-African orogeny. In this framework, LATEA was considered a stable Archean to Paleoproterozoic crustal domain that acted as a rigid backstop during the Pan-African collision, only marginally affected by orogenic processes. However, recent studies have fundamentally revised this interpretation. High-resolution structural, geochronological, and petrological data along with mapping and geochemical investigations provide compelling evidence that the Pan-African orogeny deeply affected the LATEA (Bettioui *et al.*, 2022; Ouzegane *et al.*, 2023, 2025; Arab *et al.*, 2025). These works document pervasive deformation, widespread magmatic intrusions, and extensive high- to medium-grade metamorphism (e.g., garnulite-facies metamorphism in Tamanrasset dated at c. 660-632 Ma; Ouzegane *et al.*, 2025), linked to the Pan-African event. This evolving view suggests that LATEA, far from being a passive relict, was actively involved in the Neoproterozoic orogenic dynamics of the Tuareg Shield.

The Pan-African orogeny had a profound thermal and structural impact in the LATEA. A zircon age of 614 ± 11 Ma from unzoned grains, and the observed discordance of older Eburnean zircons, reflects this overprint. Comparable Pan-African ages (e.g., 609 ± 17 Ma) have been recorded in Telohat migmatites (Barbey *et al.* 1989). The M3 metamorphic event (ca. 650 °C, 3–4 kbar) facilitated amphibole breakdown in metabasic rocks and biotite destabilization in metapelites, leading to the crystallization of a new generation of sillimanite, unrelated to M1–M2 (Caby 2003). This M3 phase correlates with the emplacement of major Pan-African batholiths such as the Anfeg pluton (608 ± 7 Ma; Bertrand *et al.* 1986, recalculated by Liégeois *et al.* 2003), rooted in steep shear zones and emplaced along reactivated horizontal structures (Acef *et al.* 2003; Liégeois *et al.* 2003). These results confirm the Eburnean origin of subhorizontal shear zones, which were reused during the Pan-African event—though direct geochronological constraints on these structures remain lacking.

These insights contribute significantly to our understanding of LATEA as a metacraton, as proposed by Liégeois *et al.* (2003). The LATEA microcontinent experienced a major granulite-facies Eburnean orogeny that led to lithospheric thickening and stabilization (Black & Liégeois, 1993), with little Mesoproterozoic activity recorded in central Hoggar (Ouzegane *et al.*, 2023). During the Neoproterozoic, LATEA served as a docking site for island arc terranes like Iskel (870–850 Ma; Caby *et al.,* 1982) and Tin Begane (~685 Ma; Liégeois *et al.,* 2003), although these events left no imprint in the Tidjenouine granulites. The principal Pan-African phase (620–580 Ma) was marked by large-scale shearing and granitoid intrusions (Bertrand *et al.,* 1986; Caby & Andreopoulos-Renaud, 1989; Black *et al.,* 1994; Liégeois *et al.,* 1994, 2003). This dual orogenic overprint fits the definition of a metacraton (Abdelsalam *et al.,* 2002). Although LATEA is geographically limited, it was likely part of a more extensive craton before the Pan-African orogeny. Whether it represents the eastern edge of the West African craton or the western limit of the Saharan craton remains debated. The Tidjenouine region exemplifies the tectono-metamorphic complexity of metacratonic domains shaped by successive orogenies on a once-rigid lithospheric block. As such, these regions remain among the most compelling

targets for future high-resolution structural, geochronological, and petrological investigations.

V- CONCLUSION

Granulite-facies metamorphism in the Hoggar, particularly within the In Ouzzal terrane and the LATEA, has long been a subject of scientific debate, shaped by evolving interpretations and new analytical tools. In the In Ouzzal terrane, early studies emphasized the presence of Archean metamorphism, inferred from the formation of calc-alkaline granites around 2.5 Ga (Peucat *et al.*, 1996). However, more recent investigations, notably by Ouzegane *et al.* (2003) and Aït Djafer *et al.* (2009), have shown that the Paleoproterozoic Eburnean metamorphism at ca. 1.9–2.0 Ga profoundly overprinted these Archean signatures. The intense thermal overprint, marked by ultrahigh-temperature (UHT) conditions, reset most isotopic systems and mineralogical records, leaving only vestigial evidence of any earlier metamorphic history. Today, the consensus holds that the observed granulite-facies assemblages in In Ouzzal reflect extensive Paleoproterozoic crustal reworking, not preserved Archean metamorphism.

Similarly, the LATEA terrane in Central Hoggar was initially viewed as a stable metacratonic block only weakly affected by the Pan-African orogeny (Liégeois *et al.*, 2003). However, recent contributions by Ouzegane *et al.* (2023, 2025) and Bettioui *et al.* (2022) have overturned this view, demonstrating that LATEA was in fact deeply reworked during the Neoproterozoic. Structural and metamorphic data now reveal that the terrane experienced significant Pan-African tectonometamorphic overprinting, including pervasive deformation, magmatic intrusions, and partial melting.

Future research should aim to further quantify the duration and thermal evolution of granulite- and UHT-facies metamorphism in the Hoggar, particularly through high-resolution in-situ geochronology (e.g., U–Pb in zircon, monazite and Lu–Hf in garnet). Deciphering whether the UHT conditions recorded in In Ouzzal were short-lived or sustained over tens of millions of years is key to constraining the geodynamic environment of the Eburnean orogeny. In the LATEA terrane, continued structural and petrological investigations are essential to fully map the extent and timing of Pan-African reworking. Integrated geochronological, thermodynamic, and geophysical approaches will be vital for reconstructing the deeper crustal architecture and metamorphic history of this complex orogenic belt, allowing for refined models of crustal reworking in Precambrian shields worldwide.

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REFERENCES

ABDELSALAM, M.-G., LIÉGEOIS, J.-P. AND STERN, R.-J. 2002. The saharan metacraton. *Journal of African Earth Sciences, 34*(3-4), 119-136.

ACEF, K., LIÉGEOIS, J.-P., OUABADI, A. AND LATOUCHE, L. 2003. The Anfeg post-collisional Pan-African high-K calc-alkaline batholith (Central Hoggar, Algeria), result of the LATEA microcontinent metacratonization. *Journal of African Earth Sciences, 37*(3-4), 295-311.

ACKERMAND, D., SEIFERT, F. AND SCHREYER, W. 1975. Instability of sapphirine at high pressures. *Contributions to Mineralogy and Petrology, 50*(2), 79-92.

ADJERID, Z., GODARD, G., OUZEGANE, K.-H. AND KIENAST, J.-R. 2013. Multistage progressive evolution of rare osumilite-bearing

assemblages preserved in ultrahigh-temperature granulites from In Ouzzal (Hoggar, Algeria). *Journal of Metamorphic Geology, 31*(5), 505-524.

Adjerid, Z., Ouzegane, K., Godard, G., Bitam-Derridj, A. and Kienast, J.-R. 2012. Le Sérouènout: un fragment de lithosphère océanique subducté à haute pression, exhumé puis granulitisé à haute température. *Bulletin du Service Géologique National, 23*(3), 199-217.

Adjerid, Z., Ouzegane, K., Godard, G., Kienast, J.-R. 2008. Reactional History and Phase Relationships in Ultrahigh-Temperature Sapphirine-Spinel-Quartz Al-Mg Granulites from the Khanfous Area *in* "The Boundaries of the West African Craton", Ennih, N. Liégeois, J-P. Eds, J. Geol. Soc. London, 297. Spe. Pub.

Ait Djafer, S. 1996. Relation cristallisation fusion et cheminement pression température dans les migmatites de l'In Ouzzal NW Hoggar. *Unpublished Magister, USTHB, Alger, Algérie*.

Ait-djafer, S. and Ouzegane, K. 1998. Fusion partielle et relation de phases dans les granulites Al-Fe à Hercynite-Quartz de la région d Ihouhaouène (In Ouzzal, Nord-Ouest Hoggar). *Bulletin du Service Géologique de l'Algérie, 9(*1), 43-67.

Aït-Djafer, S., Adjerid, Z., Badani, A., Ouzegane, K. and Kienast, J.-R. 2009. Spinel–quartz high temperature paragenesis in Al–Fe granulites from the Ihouhaouene area (NW Hoggar, Algeria). *Journal of African Earth Sciences, 55*(1-2), 79-91.

Allègre, C.-J. and Caby, R. 1972. Chronologie absolue du Précambrien de l'Ahaggar occidental. *CR Acad. Sci. Paris, 275*(D), 2095-2098.

Arab, A., Bitam-Derridj, A., Ouzegane, K., Godard, G. and Doukkari, S. 2025. Petrology and PT evolution of high-grade garnet metabasites from the Tin Begane area (Laouni terrane, South Algeria). *Geochemistry, 126260*.

Arab, A., Godard, G., Ouzegane, K., Acosta-Vigil, A., Kiénast, J.-R., Román-Alpiste, M.-J., & Drareni, A. 2021. Partial melting and PT evolution of eclogite-facies metapelitic migmatites from the Egere terrane (Central Hoggar, South Algeria). *American Mineralogist, 106*(8), 1209-1224.

Arab, A., Ouzegane, K., Drareni, A., Doukkari, S., Zetoutou, S. and Kienast, J.-R. 2015. Phase equilibria modeling of kyanite-bearing eclogitic metapelites in the NCKFMASHTO system from the Egere terrane (Central Hoggar, South Algeria). *Arabian Journal of Geosciences, 8*(5), 2443-2455.

Ayad, B., Fettous, E.-H. and Ouabadi, A. 2016. Isothermal decompression of garnet metabasites from Laouni terrane in the LATEA, Central Hoggar, Algeria. *Arabian Journal of Geosciences, 9*(3), 238.

Badani, A., Aït Djafer, S., Adjerid, Z., Ouzegane, K., Kienast, J.-R. and Boureghda, N. 2025. Mineralogical and geochemical characteristics of AlFe granulites and banded iron formations in the Archean supracrustal unit of the In Ouzzal terrane (NW Hoggar, Algeria). *Geochemistry, 126261*.

Barbey, P., Bertrand, J.-M., Angoua, S. and Dautel, D. 1989. Petrology and U/Pb geochronology of the Telohat migmatites, Aleksod, central Hoggar, Algeria. *Contributions to Mineralogy and Petrology, 101*(2), 207-219.

Barker, F. 1979. Trondhjemite: definition, environment and hypotheses of origin. *In* Developments in petrology (Vol. 6, pp. 1-12). *Elsevier*.

BECHIRI-BENMERZOUG, F., LIÉGEOIS, J.-P., BONIN, B., AZZOUNI-SEKKAL, A., BECHIRI, H., KHELOUI, R. AND SERGEEV, S.-A. 2011. The plutons from the Cryogenian Iskel composite oceanic island arc (Hoggar, Tuareg Shield, Algeria): U-Pb on zircon SHRIMP geochronology and geodynamic setting. Abstract 17-18. *In* 7th Hutton Symposition on Granites and Related Rocks.

BEN OTHMAN, D., POLVÉ, M. AND ALLÈGRE, C.-J. 1984. Nd-Sr isotopic composition of granulites and constraints on the evolution of the lower continental crust. *Nature, 307*(5951), 510-515.

BENBATTA, A., BENDAOUD, A., CENKI-TOK, B., ADJERID, Z., LACENE, K. AND OUZEGANE, K. 2017. Ternary feldspar thermometry of Paleoproterozoic granulites from In-Ouzzal terrane (Western Hoggar, southern Algeria). *Journal of African Earth Sciences, 127*, 51-61.

BENDAOUD, A. 2008. Pétrologie et géochimie des séries basiques et ultrabasiques précambriennes de l'In Ouzzal et du Hoggar Central et leur relation avec l'encaissant (*Doctoral dissertation, Alger*).

BENDAOUD, A., DERRIDJ, A., OUZEGANE, K. AND KIENAST, J.-R. 2004. Granulitic metamorphism in the Laouni terrane (central hoggar, tuareg shield, algeria). *Journal of African Earth Sciences, 39*(3-5), 187-192.

BENDAOUD, A., OUZEGANE, K. AND KIENAST, J.-R. 2003. Textures and phase relationships in ferrous granulites from Tidjenouine (Hoggar, Algeria): fayalite–ferrossilite–quartz secondary assemblage. *Journal of African Earth Sciences, 37*(3-4), 241-255.

BENDAOUD, A., OUZEGANE, K., GODARD, G., LIEGEOIS, J.-P., KIENAST, J.-R., BRUGUIER, O., AND DRARENI, A. 2008. . Geochronology and metamorphic PTX evolution of the Eburnean granulite-facies metapelites of Tidjenouine (Central Hoggar, Algeria): witness of the LATEA metacratonic evolution. *Geol. Soc. Lond., Spec. Publ. 297*, 111–146.

BENDAOUD, A., OUZEGANE, K., KIENAST, AND J.-R. 2001. The Archaean basic and ultrabasic rocks of the In Ouzzal granulitic Unit Western Hoggar, Algeria. *Special Abstract Issue, EUG XI Strasbourg, France 570*.

BENDAOUD, A., OUZEGANE, K., AND KIENAST, J.-R. 2002. Mise en evidence d'une serie komatiitique de type Munro dans la region d'In Hihaou In Ouzzal, Hoggar Occidental, Algerie. *20ème Reunion des Sciences de la Terre Nantes, France 63*.

BENYAHIA, O. 1996. Les granulites à silicates calciques du môle In Ouzzal NW Hoggar: Minéralogie, géochimie et relation de phases. *Unpublished Magister, USTHB, Alger, Algérie*.

BENYAHIA, O., HADDOUM, H., OUZEGANE, K., BENDAOUD, A., DJEMAI, S. & KIENAST, J.-R. 2005. Fonctionnement et rôle des méga zones de cisaillement dans la structuration du métacraton éburnéen du LATEA au panafricain puis au phanérozoıque (région de Tamanrasset, Hoggar, Algérie). *African Geosciences Review, 12*, 261-274.

BERGER, J., OUZEGANE, K., BENDAOUD, A., LIÉGEOIS, J.-P., KIÉNAST, J.-R., BRUGUIER, O. AND CABY, R. 2014. Continental subduction recorded by Neoproterozoic eclogite and garnet amphibolites from Western Hoggar (Tassendjanet terrane, Tuareg Shield, Algeria). *Precambrian Research, 247*, 139-158.

BERNARD-GRIFFITHS, J., FOURCADE, S., KIENAST, J.-R., PEUCAT, J.-J., MARTINEAU, F. AND RAHMANI, A. 1996. Geochemistry and isotope (Sr, Nd, O) study of Al–Mg granulites from the In Ouzzal Archaean block (Hoggar, Algeria). *Journal of Metamorphic Geology, 14*(6), 709-724.

Berrahmane, N., Fettous, E.-H., Bendaoud, A., Doukkari, S.-A., Zoheir, B. and Zeh, A. 2025. Neoproterozoic arc-magmatism of the Silet Terrane, Western Hoggar (Algeria), new constraints from zircon U-Pb-Hf isotope analyses and whole rock geochemistry. *Gondwana Research, 137*, 234-254.

Bertrand, J.-M. and Jardim de Sá, E.-F. 1990. Where are the Eburnian–Transamazonian collisional belts?. *Canadian Journal of Earth Sciences, 27*(10), 1382-1393.

Bertrand, J.-M., Michard, A., Boullier, A.-M. and Dautel, D. 1986. Structure and U/Pb geochronology of Central Hoggar (Algeria): A reappraisal of its Pan-African evolution. *Tectonics, 5*(7), 955-972.

Bertrand, P., Ellis, D.-J. and Green, D.-H. 1991. The stability of sapphirine-quartz and hypersthene-sillimanite-quartz assemblages: an experimental investigation in the system FeO- MgO- Al_2O_3- SiO_2 under H_2O and CO_2 conditions. *Contributions to Mineralogy and Petrology, 108*(1), 55-71.

Bertrand, P., Ouzegane, K. and Kienast, J.-R. 1992. P–T–X relationships in the Precambrian Al–Mg-rich granulites from In Ouzzal, Hoggar, Algeria. *Journal of Metamorphic Geology, 10*(1), 17-31.

Bettioui, D., Liégeois, J.-P., Fettous, E.-H., Fezaa, N. and Bruguier, O. 2022. Syn-kinematic emplacement of granitic batholith and leucogranite along the extensional detachment shear zone system of the Tin Begane area, Laouni terrane (LATEA metacraton, Central Hoggar, Algeria). *Precambrian Research, 368*, 106484.

Bitam-Derridj, A., Ouzegane, K., Adjerid, Z., Godard, G. and Kienast, J.-R. 2010. Les éclogites granulitisées de Ti-N-Eggoleh (terrane du Sérouènout, Hoggar central): étude métamorphique et conséquence géodynamique. *Bulletin du Service Géologique National, 21*(2), 117-136.

Black, R. and Liegeois, J.-P. 1993. Cratons, mobile belts, alkaline rocks and continental lithospheric mantle: the Pan-African testimony. *Journal of the Geological Society, 150*(1), 89-98.

Black, R., Latouche, L., Liégeois, J.-P., Caby, R. and Bertrand, J.-M. 1994. Pan-African displaced terranes in the Tuareg shield (central Sahara). *Geology, 22*(7), 641-644.

Bosch, D., Bruguier, O., Caby, R., Buscail, F. and Hammor, D. 2016. Orogenic development of the Adrar des Iforas (Tuareg Shield, NE Mali): New geochemical and geochronological data and geodynamic implications. *Journal of Geodynamics, 96*, 104-130.

Boughrara, M. 1999. Analyse pétrologique et géochronologique de la région de Tin Begane (Hoggar, Algérie): un exemple de la datation d'une série métamorphique en contexte polycyclique. *Doctoral dissertation, Paris, Muséum national d'histoire naturelle*.

Boumaza, S., 1996. Petrologie d'un nodule migmatitique à saphirine d'In Hihaou In Ouzzal, Hoggar occidental: diffusion chimique et comparaison avec les granulites Al–Mg de l'encaissant. *Unpublished Magister, U.S.T.H.B., Alger, Algerie*, 200 p.

Bouzid, A., Bayou, B., Liégeois, J.-P., Bourouis, S., Bougchiche, S.-S., Bendekken, A. and Ouabadi, A. 2015. Lithospheric structure of the Atakor metacratonic volcanic swell (Hoggar, Tuareg Shield, southern Algeria): electrical constraints from magnetotelluric data.

Bucher, K. and Grapes, R. 2011. Metamorphism of pelitic rocks (metapelites). In Pe-

trogenesis of metamorphic rocks (pp. 257-313). *Berlin, Heidelberg: Springer Berlin Heidelberg*.

CABY, R. 2003. Terrane assembly and geodynamic evolution of central–western Hoggar: a synthesis. *Journal of African Earth Sciences, 37*(3-4), 133-159.

CABY, R., ANDREOPOULOS-RENAUD, U. AND PIN, C. 1989. Late Proterozoic arc–continent and continent–continent collision in the Pan-African Trans-Saharan Belt of Mali. *Canadian Journal of Earth Sciences, 26*(6), 1136-1146.

CABY, R., BERTRAND, J.-M.-L. AND BLACK, R. 1981. Pan-African ocean closure and continental collision in the Hoggar-Iforas segment, central Sahara. *In* Developments in Precambrian geology (Vol. 4, pp. 407-434). Elsevier.

CADDICK, M.-J., KONOPÁSEK, J. AND THOMPSON, A.-B. 2010. Preservation of garnet growth zoning and the duration of prograde metamorphism. *Journal of Petrology, 51*(11), 2327-2347.

DAHMANI, S., OUZEGANE, K., DRARENI, A., GARRIDO, C.-J., ROMÁN-ALPISTE, M.- J. AND DOUKKARI, S. 2025. Zircon and Titanite U-Pb geochronology, petrology and PT path of garnet-bearing amphibolites from Tadoumet area (Assodé-Issalane terrane, Central Hoggar, Algeria). *Journal of African Earth Sciences, 105675*.

DJEMAI, S. 1996. Les pyrigarnites et les granulites alumineuses d'Amesmessa, Môle. Relations de phases et déformation. *These de Magister USTHB, Alger, Algérie*, 210.

DOOLEY, D.-F. AND PATINO DOUCE, A.-E. 1996. Fluid-absent melting of F-rich phlogopite+ rutile+ quartz. *American Mineralogist, 81*(1-2), 202-212.

DOUKKARI, S.-A., DIENER, J.-F., OUZEGANE, K. AND KIENAST, J.-R. 2018. Mineral equilibrium modelling and calculated chemical potential relations of reaction textures in the ultrahigh-temperature In Ouzzal terrane (In Hihaou area, Western Hoggar, Algeria). *Journal of Metamorphic Geology, 36*(9), 1175-1198.

DOUKKARI, S.-A., OUZEGANE, K., ARAB, A., KIENAST, J.-R., GODARD, G., DRARENI, A. AND LIÉGEOIS, J.-P. 2014. Phase relationships and P–T path in NCFMASHTO system of the eclogite from the Tighsi area (Egere terrane, Central Hoggar, Algeria). Journal of African Earth Sciences, 99, 276-286.

DOUKKARI, S.-A., OUZEGANE, K., GODARD, G., DIENER, J.-F., KIENAST, J.-R., LIÉGEOIS, J.-P., & DRARENI, A. 2015. Prograde and retrograde evolution of eclogite from Adrar Izzilatène (Egéré-Aleksod terrane, Hoggar, Algeria) determined from chemical zoning and pseudosections, with geodynamic implications. *Lithos, 226*, 217-232.

ENGLISH, K.-L., REDFERN, J., BERTOTTI, G., ENGLISH, J.-M. AND CHERIF, R.-Y. 2017. Intraplate uplift: new constraints on the Hoggar dome from the Illizi basin (Algeria). *Basin Research, 29*(3), 377-393.

FETTOUS, E.-H. 2016. Le Paléoprotérozoïque dans le Hoggar Occidental et central et son évolution post-éburnéenne. *Thèse de Doctorat, Faculté des Sciences de la Terre, de la Géographie et de l'Aménagement du Territoire*.

FEZAA, N., LIÉGEOIS, J.-P., ABDALLAH, N., BRUGUIER, O., DE WAELE, B. AND OUABADI, A. 2018. The 600 Ma-old Pan-African magmatism in the In Ouzzal terrane (Tuareg Shield, Algeria): witness of the metacratonisation of a rigid block. In The Geology of the Arab World---An Overview (pp. 109-148). Cham: *Springer International Publishing*.

Gruau, G., Tourpin, S., Fourcade, S. and Blais, S. 1992. Loss of isotopic (Nd, O) and chemical (REE) memory during metamorphism of komatiites: new evidence from eastern Finland. *Contributions to Mineralogy and Petrology, 112*(1), 66-82.

Guiraud, M., Kienast, J.-R. and Ouzegane, K. 1996. Corundum-quartz-bearing assemblage in the Ihouhaouene area (In Ouzzal, Algeria). *Journal of Metamorphic Geology, 14*(6), 755-761.

Haddoum, H., Choukroune, P. and Peucat, J.-J. 1994. Evolution of the Precambrian In-Ouzzal block (Central Sahara, Algeria). *Precambrian Research, 65*(1-4), 155-166.

Harley, S.-L. 1989. The origins of granulites: a metamorphic perspective. *Geological Magazine, 126*(3), 215-247.

Harley, S.-L. and Kelly, N.-M. 2007. Zircon tiny but timely. *Elements, 3*(1), 13-18.

Harley, S.-L. and Motoyoshi, Y. 2000. Al zoning in orthopyroxene in a sapphirine quartzite: evidence for> 1120 C UHT metamorphism in the Napier Complex, Antarctica, and implications for the entropy of sapphirine. *Contributions to Mineralogy and Petrology, 138*(4), 293-307.

Harley, S.-L. and Thompson, P. 2004. The influence of cordierite on melting and mineral-melt equilibria in ultra-high-temperature metamorphism.

Harley, S.-L., Thompson, P., Hensen, B.-J. and Buick, I.-S. 2002. Cordierite as a sensor of fluid conditions in high-grade metamorphism and crustal anatexis. *Journal of metamorphic Geology, 20*(1), 71-86.

Harouz, C., Ouzegane, K., Doukkari, S., Adjerid, Z. and Aït-djafer, S. 2024. Metamorphic evolution and mineral assemblages of fassaite calc-silicate and sapphirine-quartz Al-Mg granulites from the Tekhamalt area (In Ouzzal terrane, Western Hoggar): Implications for ultra-high-temperature conditions and petrogeneses. *Journal of African Earth Sciences, 211*, 105184.

Hensen, B.-J. and Green, D.-H. 1973. Experimental study of the stability of cordierite and garnet in pelitic compositions at high pressures and temperatures: III. Synthesis of experimental data and geological applications. *Contributions to Mineralogy and Petrology, 38*(2), 151-166.

Hensen, B.-J. and Osanai, Y. 1994. Experimental study of dehydration melting of F-bearing biotite in model pelitic compositions. *Mineralogical Magazine A, 58*, 410-411.

Icenhower, J.-P. and London, D. 1997. Partitioning of fluorine and chlorine between biotite and granitic melt: experimental calibration at 200 MPa H_2O. *Contributions to Mineralogy and Petrology, 127*(1), 17-29.

Kelsey, D.-E. 2008. On ultrahigh-temperature crustal metamorphism. *Gondwana Research, 13*(1), 1-29.

Kienast, J.-R. and Ouzegane, K. 1987. Polymetamorphic Al, Mg-rich granulites with orthopyroxene–sillimanite and sapphirine parageneses in Archaean rocks from the Hoggar, Algeria. *Geological Journal, 22*(S2), 57-79.

Lancelot, J., Vitrac, A. and Allegre, C.-J. 1976. Uranium and lead isotopic dating with grain-by-grain zircon analysis: a study of complex geological history with a single rock. *Earth and Planetary Science Letters, 29*(2), 357-366.

Latouche, L. 1985. Les collisions intracratoniques et la tectonique tangentielle dans le Pan-Africain du Hoggar central.

LIÉGEOIS, J.-P. 2018. A new synthetic geological map of the Tuareg Shield: an overview of its global structure and geological evolution. The Geology of the Arab World---An Overview, 83-107.

LIÉGEOIS, J.-P., BENHALLOU, A., AZZOUNI-SEKKAL, A., YAHIAOUI, R. AND BONIN, B. 2005. The Hoggar swell and volcanism: reactivation of the Precambrian Tuareg shield during Alpine convergence and West African Cenozoic volcanism.

LIÉGEOIS, J.-P., BLACK, R., NAVEZ, J. AND LATOUCHE, L. 1994. Early and late Pan-African orogenies in the Aïr assembly of terranes (Tuareg shield, Niger). *Precambrian research, 67*(1-2), 59-88.

LIÉGEOIS, J.-P., CLAESSENS, W., CAMARA, D. AND KLERKX, J. 1991. Short-lived Eburnian orogeny in southern Mali. Geology, tectonics, U-Pb and Rb-Sr geochronology. *Precambrian Research, 50*(1-2), 111-136.

LIÉGEOIS, J.-P., LATOUCHE, L., BOUGHRARA, M., NAVEZ, J. AND GUIRAUD, M. 2003. The LATEA metacraton (Central Hoggar, Tuareg shield, Algeria): behaviour of an old passive margin during the Pan-African orogeny. *Journal of African Earth Sciences, 37*(3-4), 161-190.

LIEGEOIS, J.-P., NAVEZ, J., HERTOGEN, J. AND BLACK, R. 1998. Contrasting origin of post-collisional high-K calc-alkaline and shoshonitic versus alkaline and peralkaline granitoids. *The use of sliding normalization. Lithos, 45*(1-4), 1-28.

MOURI, H., GUIRAUD, M. AND HENSEN, B.-J. 1996. Petrology of phlogopite-sapphirine-bearing Al-Mg granulites from Ihouhaouene, In Ouzzal, Hoggar, Algeria: an example of phlogopite stability at high temperature. *Journal of metamorphic Geology, 14*(6), 725-738.

OUZEGANE, K. 1987. Les granulites Al-Mg et les carbonatites dans la série de l'In Ouzzal (NW Hoggar, Algérie): nature et évolution de la croûte continentale profonde pendant l'Archéen. *Doctoral dissertation, Atelier national de reproduction des thèses*.

OUZEGANE, K. AND BOUMAZA, S. 1996. An example of ultrahigh-temperature metamorphism: orthopyroxene–sillimanite–garnet, sapphirine–quartz and spinel–quartz parageneses in Al–Mg granulites from In Hihaou, In Ouzzal, Hoggar. *Journal of metamorphic Geology, 14*(6), 693-708.

OUZEGANE, K. AND KIENAST, J.-R. 1996. Nature et évolution des séries métamorphiques de très haute température de l'unité granulitique de l'In Ouzzal (Ouest Hoggar). *Bulletin du Service Géologique de l'Algérie, 7*(2), 133-157.

OUZEGANE, K., BENDAOUD, A., KIENAST, J. R. AND TOURET, J.-L. 2001. Pressure-temperature-fluid evolution in Eburnean metabasites and metapelites from Tamanrasset (Hoggar, Algeria). *The Journal of Geology, 109*(2), 247-263.

OUZEGANE, K., GUIRAUD, M. AND KIENAST, J.-R. 2003B. Prograde and retrograde evolution in high-temperature corundum granulites (FMAS and KFMASH systems) from In Ouzzal terrane (NW Hoggar, Algeria). *Journal of Petrology, 44*(3), 517-545.

OUZEGANE, K., KIENAST, J.-R., BENDAOUD, A. AND DRARENI, A. 2003A. A review of Archaean and Paleoproterozoic evolution of the In Ouzzal granulitic terrane (Western Hoggar, Algeria). *Journal of African Earth Sciences, 37*(3-4), 207-227.

OUZEGANE, K., LIÉGEOIS, J.-P., DOUKKARI, S., KIÉNAST, J.-R., ARAB, A., DRARENI, A., & LINNEMANN, U. 2023. The Egéré Paleo-Mesoproterozoic rifted passive margin of the

LATEA metacraton (Central Hoggar, Tuareg Shield, Algeria) subducted and exhumed during the Pan-African orogeny: U-Pb zircon ages, PTt paths, geochemistry and Sr-Nd isotopes. *Earth-Science Reviews, 236*, 104262.

Ouzegane, K., Linnemann, U., Gärtner, A., Doukkari, S., Arab, A., Drareni, A., & Bendaoud, A. 2025. Geochronology and PT Paths of Metapelites and Garnet Pyroxenites from Tamanrasset Block (Central Hoggar, Algeria): Evidence of a Neoproterozoic Deposition and High-Grade Metamorphism. In Lithospheric Architecture and Precambrian Geology of the Hoggar and Adjacent Areas: A Reference Case for Mapping and Modeling in Geosciences (pp. 51-72). Cham: *Springer Nature Switzerland*.

Palin, R.-M., White, R.-W., Green, E.-C., Diener, J.-F., Powell, R. and Holland, T.-J. 2016. High-grade metamorphism and partial melting of basic and intermediate rocks. *Journal of Metamorphic Geology, 34*(9), 871-892.

Pattison, D.-R., Chacko, T., Farquhar, J. and McFarlane, C.-R. 2003. Temperatures of granulite-facies metamorphism: constraints from experimental phase equilibria and thermobarometry corrected for retrograde exchange. *Journal of Petrology, 44*(5), 867-900.

Peucat, J.-J., Capdevila, R., Drareni, A., Choukroune, P., Fanning, C.-M., Bernard-Griffiths, J. and Fourcade, S. 1996. Major and trace element geochemistry and isotope (Sr, Nd, Pb, O) systematics of an Archaean basement involved in a 2.0 Ga very high-temperature (1000° C) metamorphic event: In Ouzzal Massif, Hoggar, Algeria. *Journal of metamorphic Geology, 14*(6), 667-692.

Peucat, J.-J., Drareni, A., Latouche, L., Deloule, E. and Vidal, P. 2003. U-Pb zircon (TIMS and SIMS) and Sm–Nd whole-rock geochronology of the Gour Oumelalen granulitic basement, Hoggar massif, Tuareg shield, Algeria. *Journal of African Earth Sciences, 37*(3-4), 229-239.

Rahmani, A. 1992. Pétrologie et géochimie de la série granulitique du massif du khanfous (In-Ouzzal, Hoggar, Algérie). *Doctorat de l'université ParisVI* P, 204.

Rougier, S., Missenard, Y., Gautheron, C., Barbarand, J., Zeyen, H., Pinna, R. and de Lamotte, D.-F. 2013. Eocene exhumation of the Tuareg Shield (Sahara Desert, Africa). *Geology, 41*(5), 615-618.

Sautter, V. 1986. Les éclogites de l'Aleksod (sud Algérien): des témoins in situ d'une collision intracontinental. *Journal of African Earth Sciences (1983), 5*(4), 345-357.

Vielzeuf, D., Clemens, J.-D., Pin, C. and Moinet, E. 1990. Granites, granulites, and crustal differentiation. In Granulites and crustal evolution (pp. 59-85). *Dordrecht: Springer Netherlands*.

Zetoutou, S., Ouzegane, K., Boubazine, S. and Kienast, J.-R. 2004. Azrou N'Fad (Central Hoggar, Algeria) one of the deepest terranes of LATEA: arguments based on P–T evolution in eclogite. *Journal of African Earth Sciences, 39*(3-5), 193-200.