



ex solo ad solem, वसुधैव कुटुम्बकम्
ex solo ad solem, Vasudhaiva Kutumbakam
from the earth to the sun, the world is one family



STRUCTURE AND GEODYNAMIC EVOLUTION OF THE HOGGAR SHIELD: CONSTRAINTS FROM PETROLOGICAL, GEOCHRONOLOGICAL AND GEOPHYSICAL STUDIES

Abderrahmane BENDAOUD

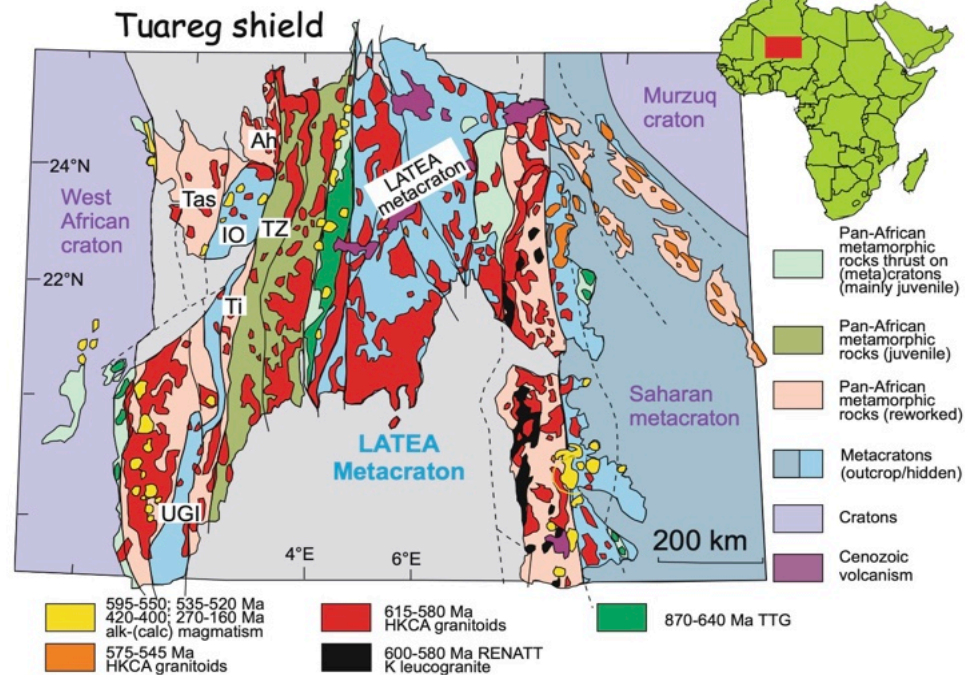
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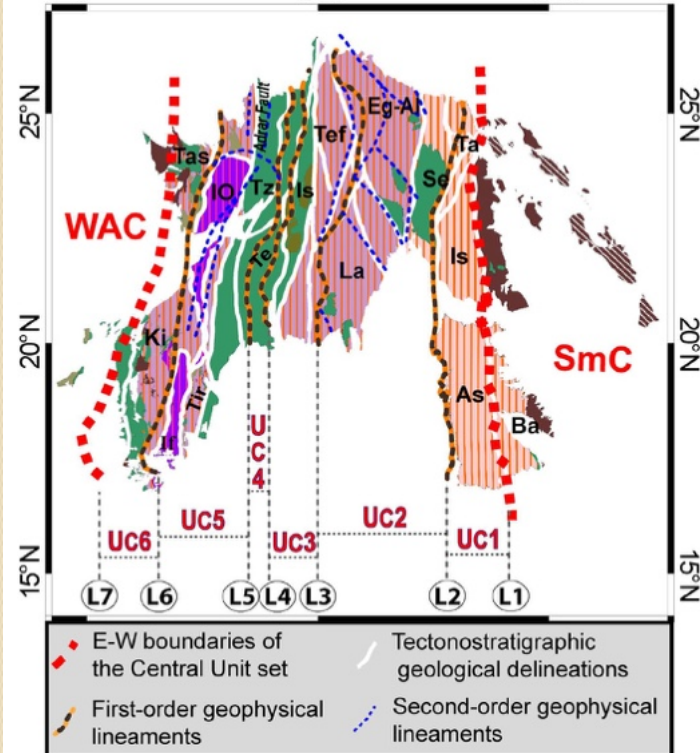
IASGT Conference 2026,
ACCRA, Ghana



The Tuareg Shield, is bounded: to the west, by the West African Craton and to the east, by the Saharan Metacraton. It corresponds to the assembly of around twenty terranes during the Pan-African Orogen. It is therefore considered to be a succession of juvenile Pan-African domains alternating with Archean and/or Paleoproterozoic terranes, more or less remobilised at Pan-African.

The Touareg shield with the Benino-Nigerian shield and the Central African Orogen constitute the African expression of the Trans-Saharan Orogenic Belt, one of the longest Neoproterozoic orogens on Earth (~4,000 km in Africa alone, extending to NE Brazil as the Brasiliano Belt).

The Hoggar, located in southern Algeria, represents the most extensive Precambrian basement exposure of the Tuareg Shield.



A: 630-635 Ma (Proto-Pan-African)

West African craton | Iforas Cordillera | Pharusion Belt | LATEA | Orosirian Stripe | Saharan craton

Timetrine | Tlemisi | Kidal | Tassendjanet | Tin Zaoua-tene | Silet & In Tedini | Ammas Ocean | Sérouénout | Enachet Ocean | Juvenile Aouzgueur | Sedid Ocean | Ao | Ed | Dj | Murzuq

B: 630-580 Ma (Pan-African)

West African craton | Iforas Cordillera | Pharusion Belt | LATEA | Orosirian Stripe | Saharan craton

Tlemisi | Timetrine | Kidal Tass. | In O. | Tin Z. | In T. | Si. | Se. | Al. | As-Is. | Ao | Ed | Dj | Murzuq

C: 575-520 Ma (Murzukian)

West African craton | Iforas alkaline province | Pharusion Belt | LATEA | Orosirian Stripe | Saharan metacraton

In O. | Taurit Province | Se. | As-Is. | Ao | Ed | Dj | Murzuq

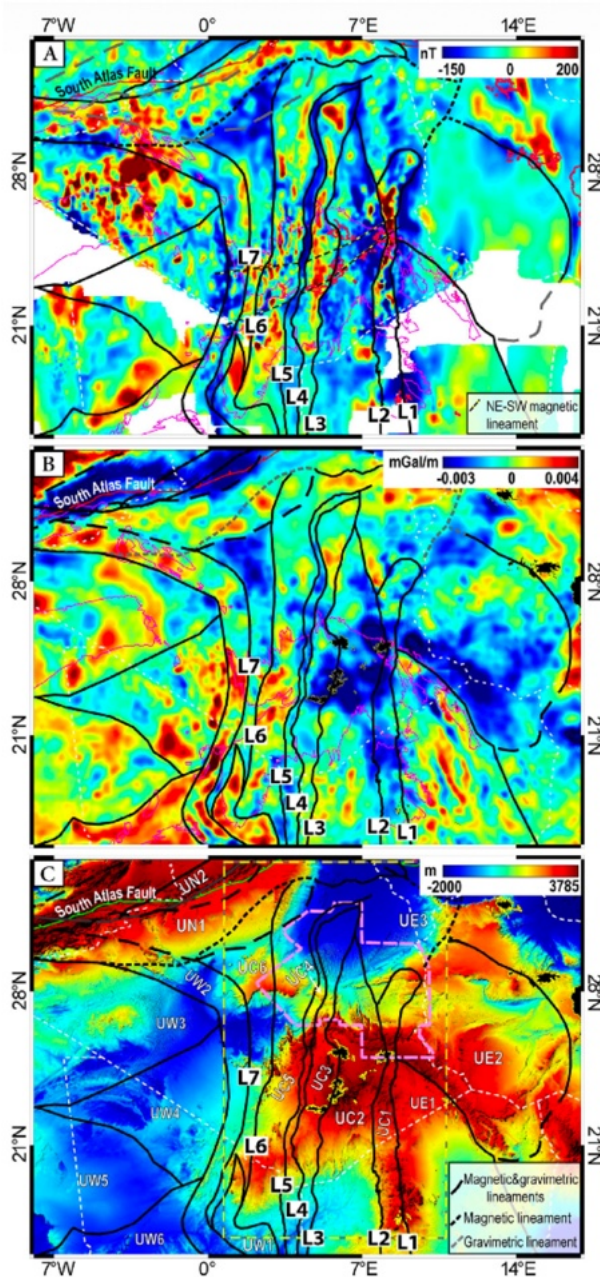
Legend:

- TTG batholiths
- HKCA batholiths
- Renatt granite
- Alcali-calcic & alkalic magmatism
- Murzukian crustal magmatism

Lithospheric mantle and crust for:

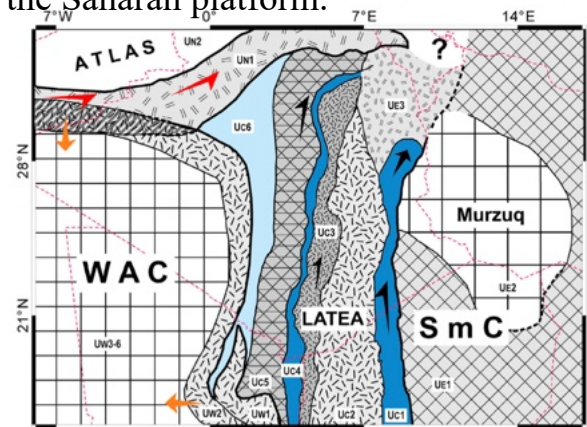
- West African craton
- Saharan (meta) craton
- LATEA and In Ouzzal (meta)craton
- Juvenile mostly oceanic terranes
- Iforas cordillera
- Orosirian Stripe

This makes it possible to group the 25 terranes that make up the Tuareg shield into half a dozen continental blocks.

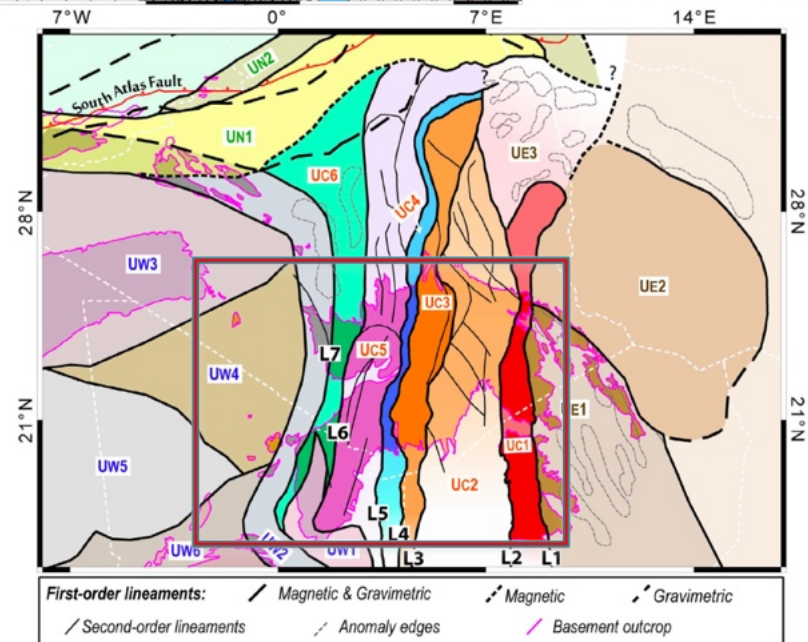


To define these boundaries, gravimetric and magnetic data were primarily used.

These geophysical data also make it possible to map the northward extension of these crustal blocks beneath the Paleozoic basins of the Saharan platform.



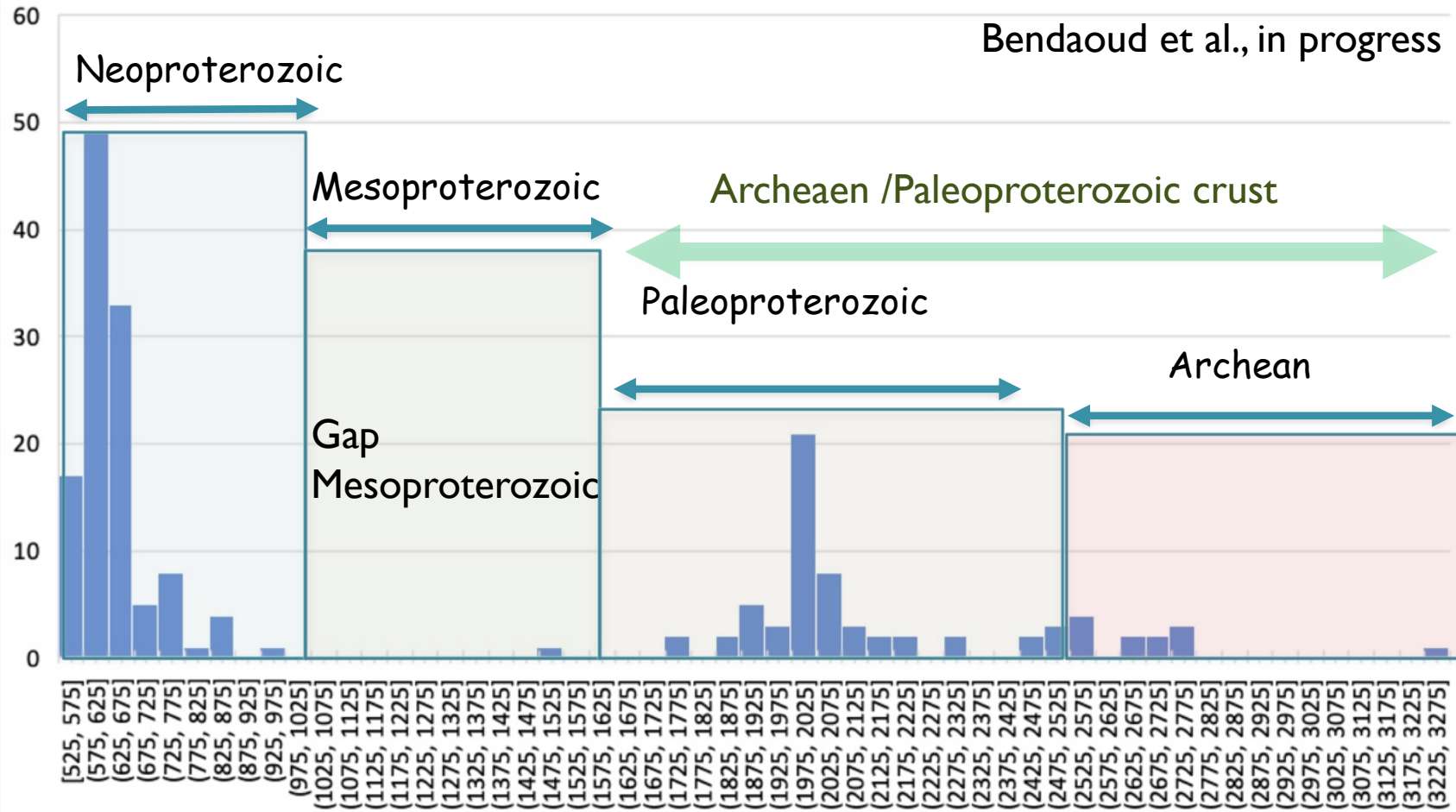
Brahimi et al., 2018



- (A) Magnetic anomaly map reduced to the pole from the Global Earth Magnetic Anomaly Grid (EMAG2);
 (B) Vertical derivative of the Bouguer anomalies from the World Gravity Map (WGM2012);
 (C) Digital Earth Model from the SRTM Digital Elevation Model database.

Age Histogram Touareg Shield (700.000 km²) N = 186

Bendaoud et al., in progress

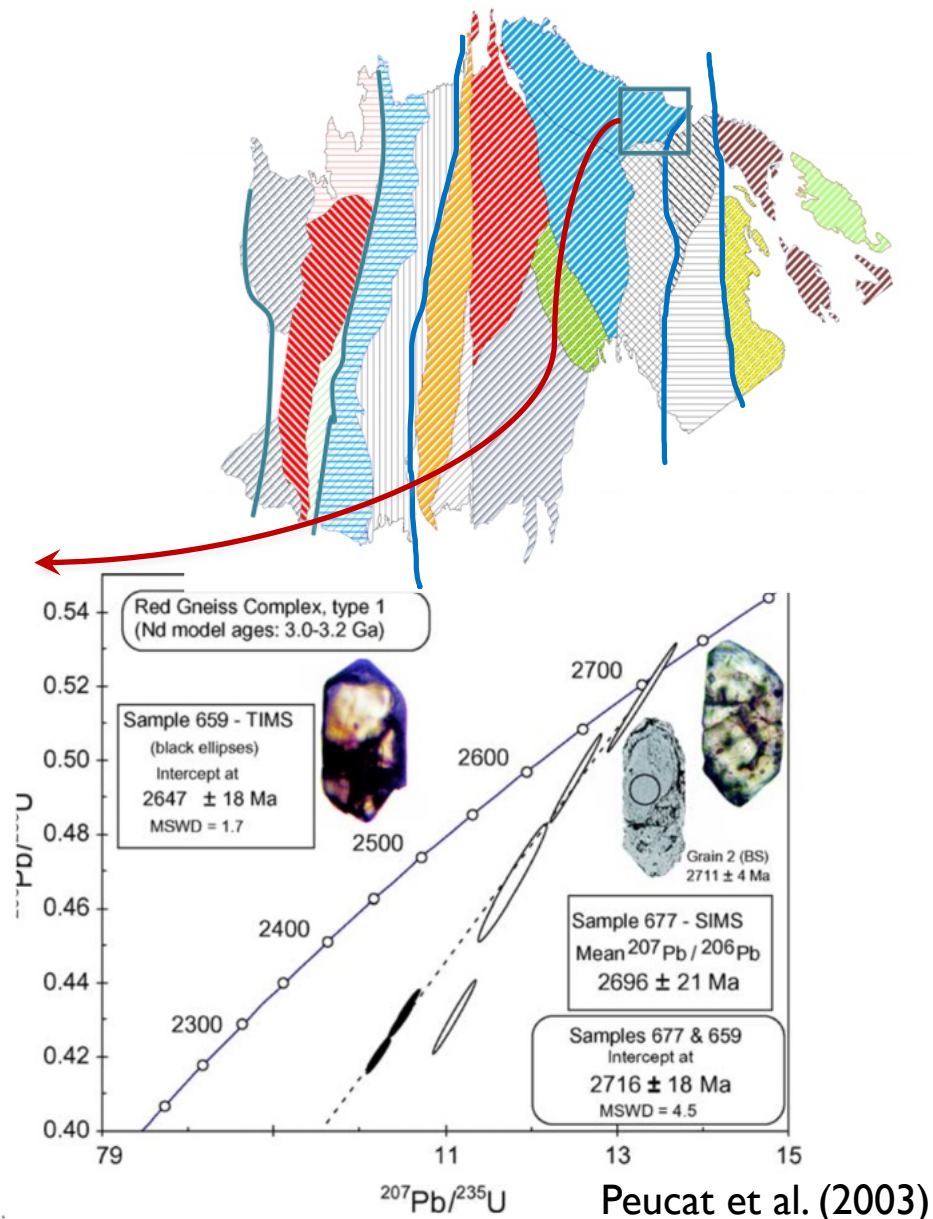
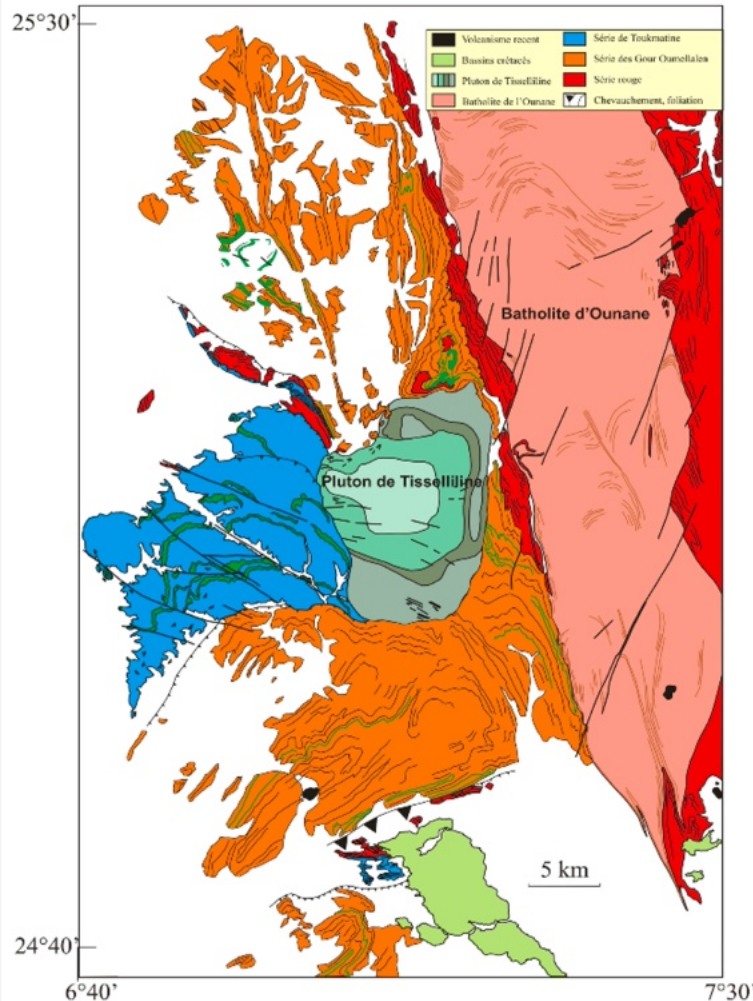


This histogram summarises all the zircon ages obtained from the Tuareg Shield. In detail, it shows the presence of an Archean and Palaeoproterozoic crust, a gap during the Mesoproterozoic, and a major Pan-African event.



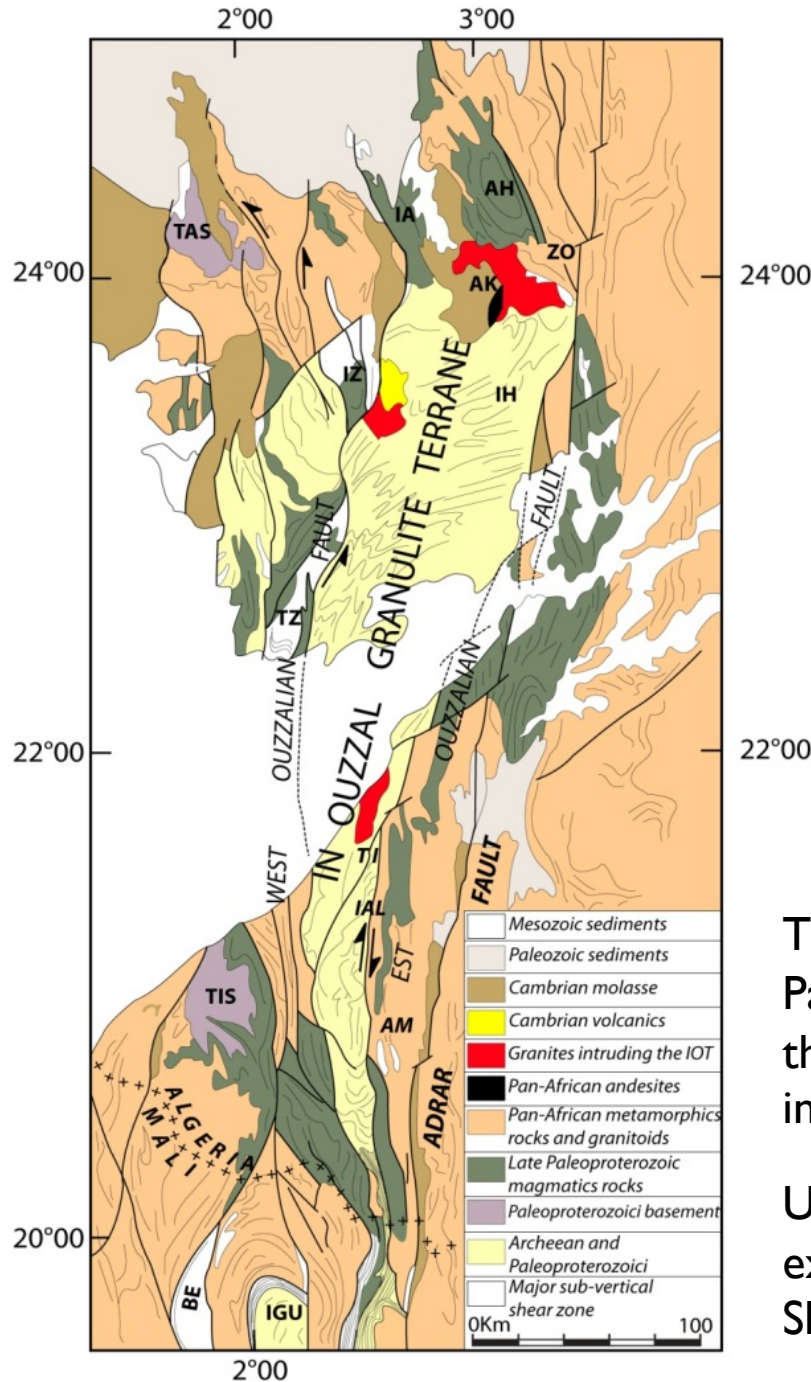
ARCHEAN

Gour Oumelalen (LATEA)

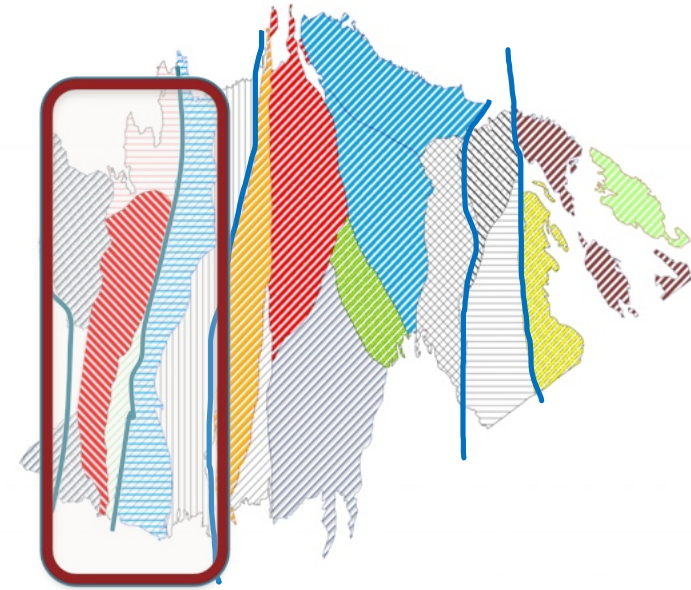


The only region in the central part of the Hoggar where Archaean rocks have been identified is the Gour Oumelalen. Here, orthogneisses – shown in red – are located along a major shear zone and have been dated to 2,700 million years (Ma). Little is known about these formations, their geochemistry or the context in which they were formed.

ARCHEAN



In Ouzzal Terrane



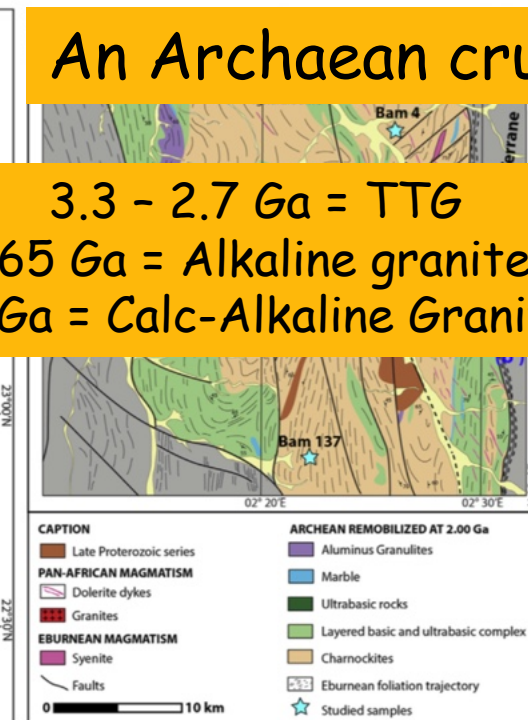
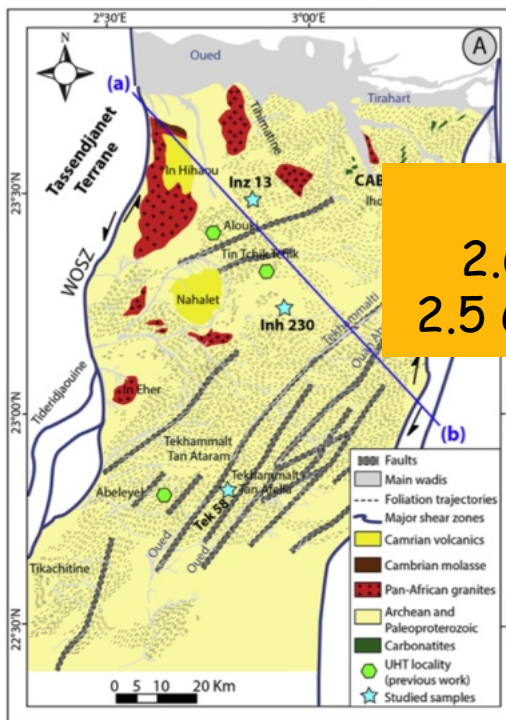
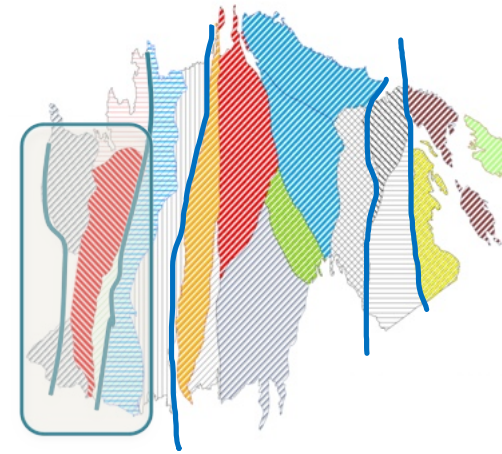
The In Ouzzal is an Archean-Paleoproterozoic terrane, considered to be the oldest in the Tuareg Shield. It is located in the western part of the Hoggar.

Until recently, it was considered to be an exotic terrane, integrated into the Tuareg Shield during the Neoproterozoic.

ARCHEAN

An Archaean crust

3.3 - 2.7 Ga = TTG
 2.65 Ga = Alkaline granites
 2.5 Ga = Calc-Alkaline Granites

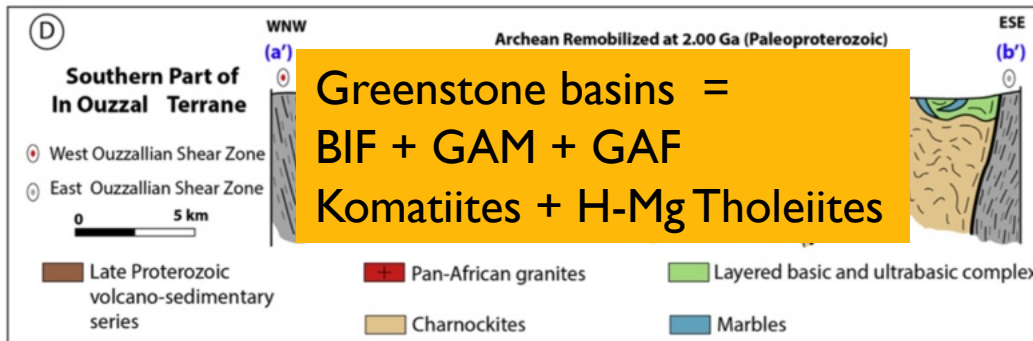
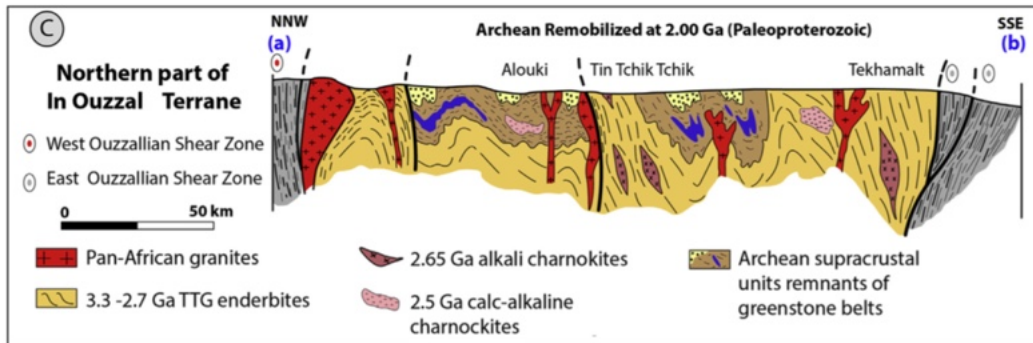


The Northern Ouzal consists of two major units

the first comprises Charnockite orthogneiss domes with TTG series geochemistry, dated between 3.2 and 2.7 Ga,

the second consists of metasedimentary basins commonly associated with basic (metanorites, pyrigarnites) and ultrabasic (komatiites) ortho-derived rocks.

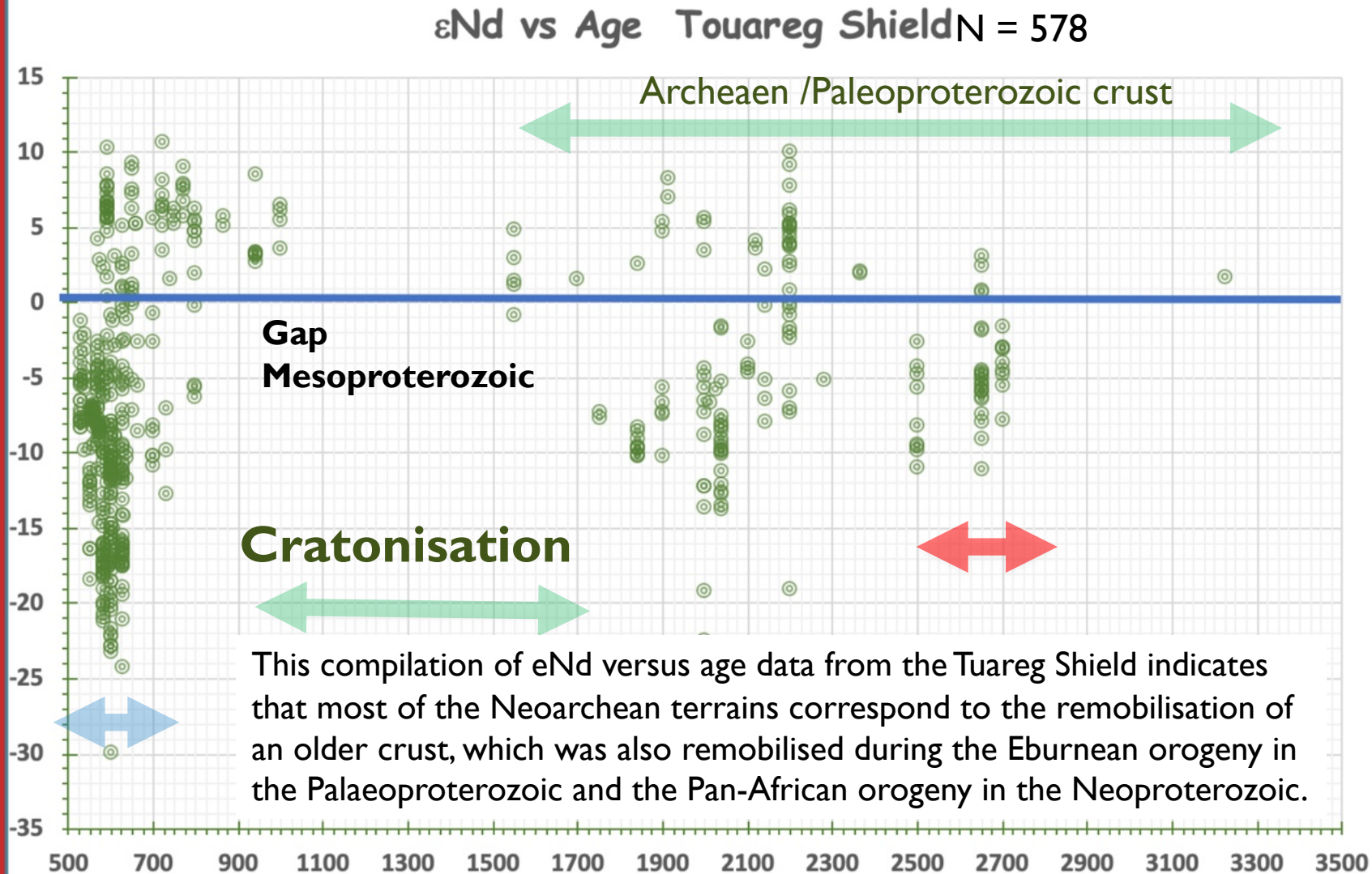
Both units are cut through by alkaline orthogneisses at 2.65 Ga and calc-alkaline orthogneisses at 2.5 Ga.

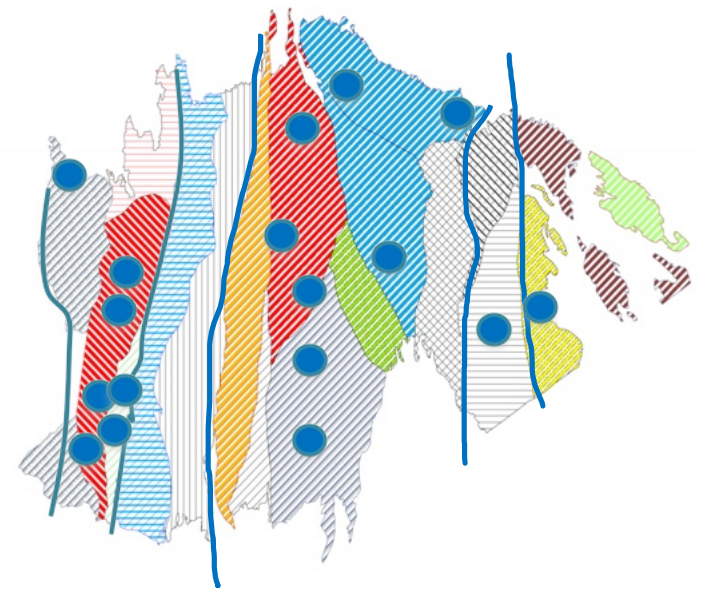


Greenstone basins =
 BIF + GAM + GAF
 Komatiites + H-Mg Tholeiites

Peucat et al., 1996
 Ouzegane et al., 2003

ARCHEAN

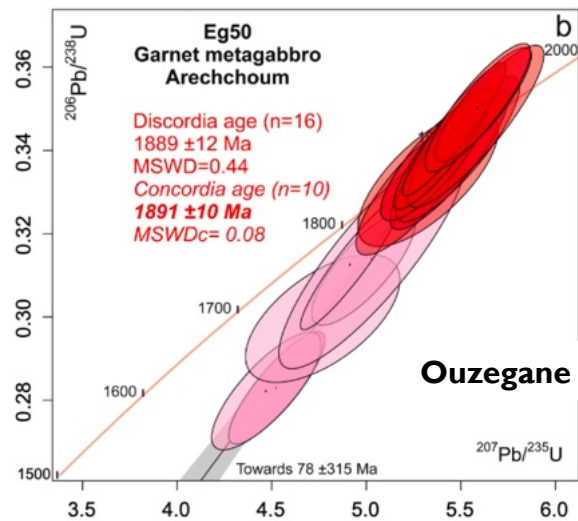
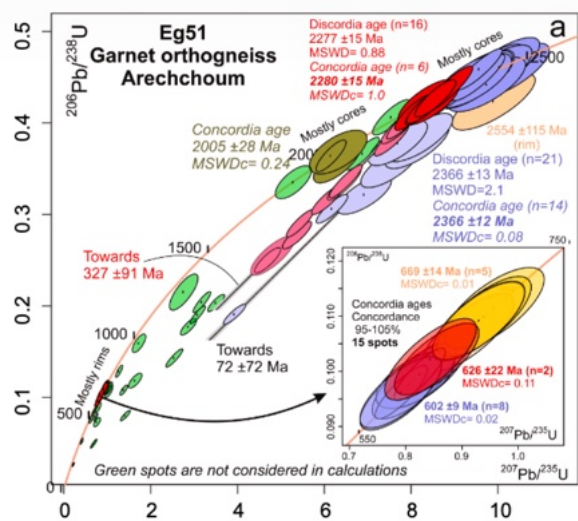




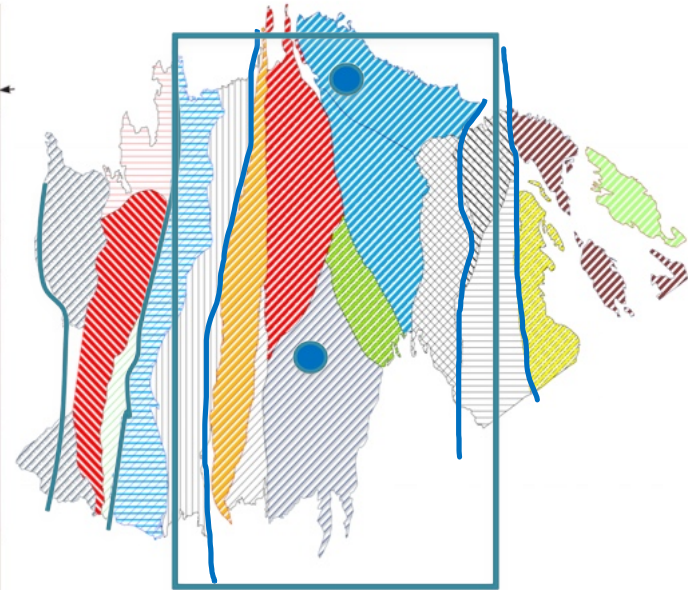
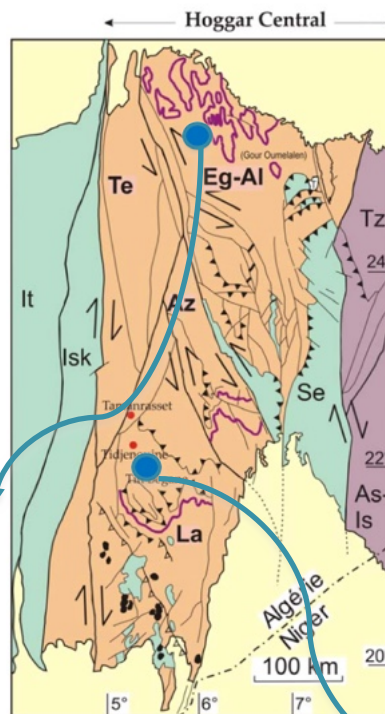
Paleoproterozoic

Palaeoproterozoic rocks are found almost everywhere within the various continental blocks of the Tuareg Shield. Even in the Tin Zaoutene terrane, which was previously considered to be a juvenile Neoproterozoic terrane, orthogneisses dating back to around 2000 Ma have been dated by Bosch et al. (2016) in the Malian part of the Massif.

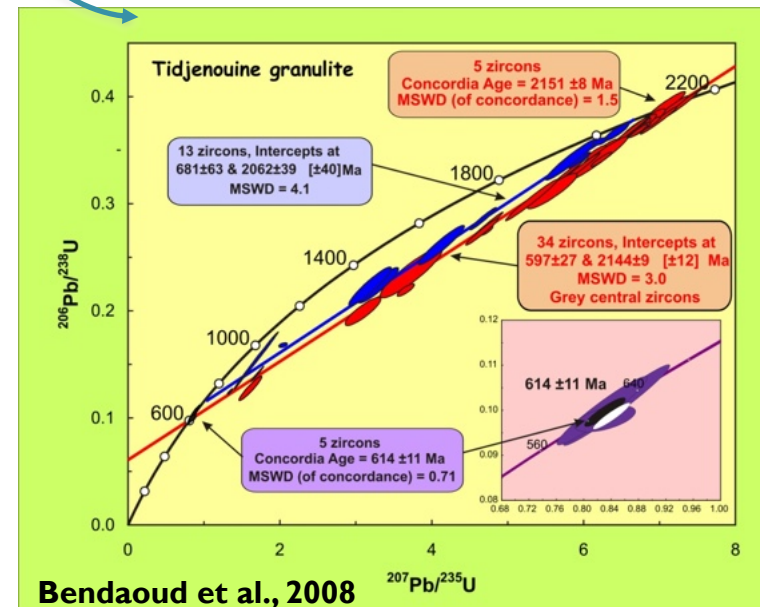
Paleoproterozoic



Ouzegane et al., 2023



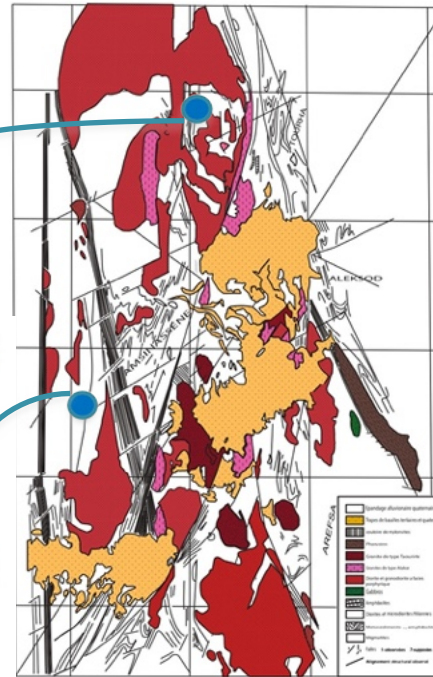
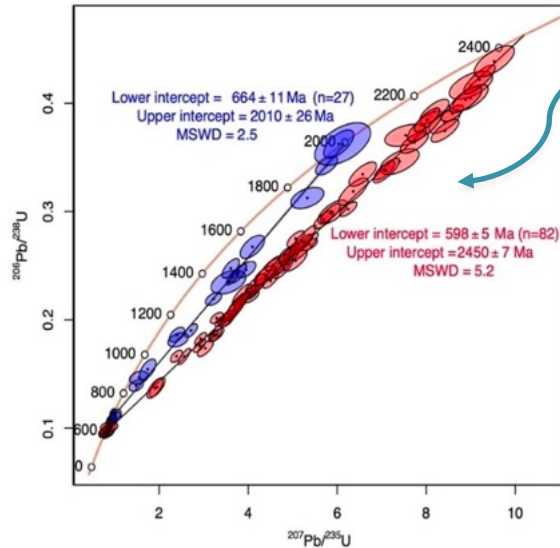
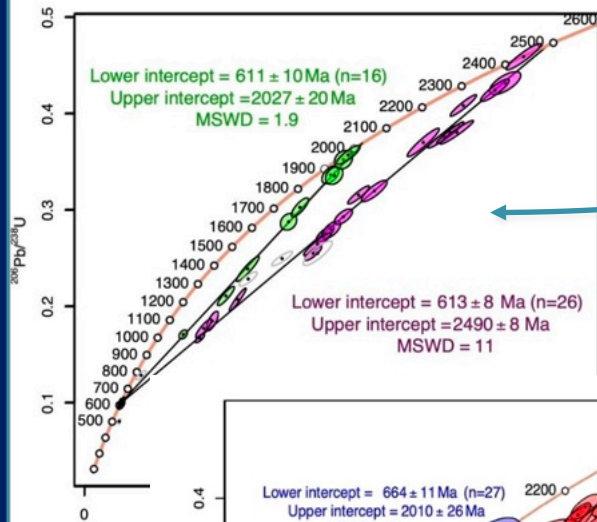
In the central block of the LATEA, the basement rocks are predominantly Palaeoproterozoic in age and consist primarily of K-rich orthogneisses dating from between 2.25 and 2.15 billion years. The basement experienced high-temperature metamorphism around 2 billion years (Ga) and was subsequently remobilised during the Neoproterozoic by the Pan-African orogeny.



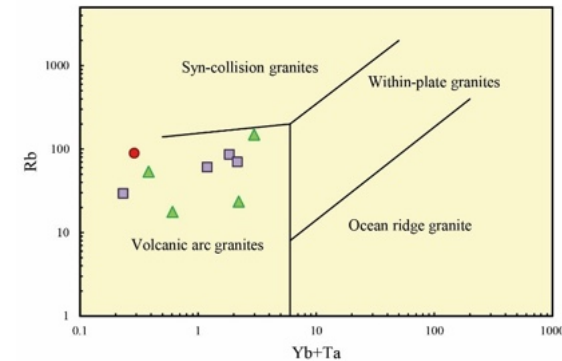
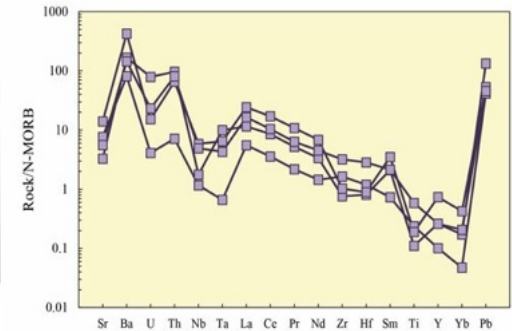
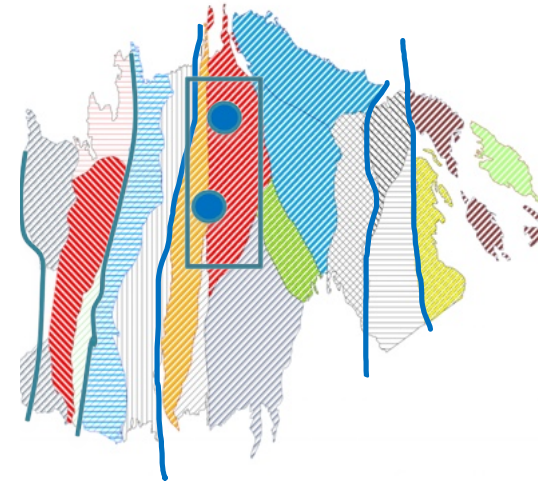
Bendaoud et al., 2008

Tefedest : a basement at 2.45 – 2.49 Ga

- Migmatitic orthogneiss with a tonalite composition (TTG)



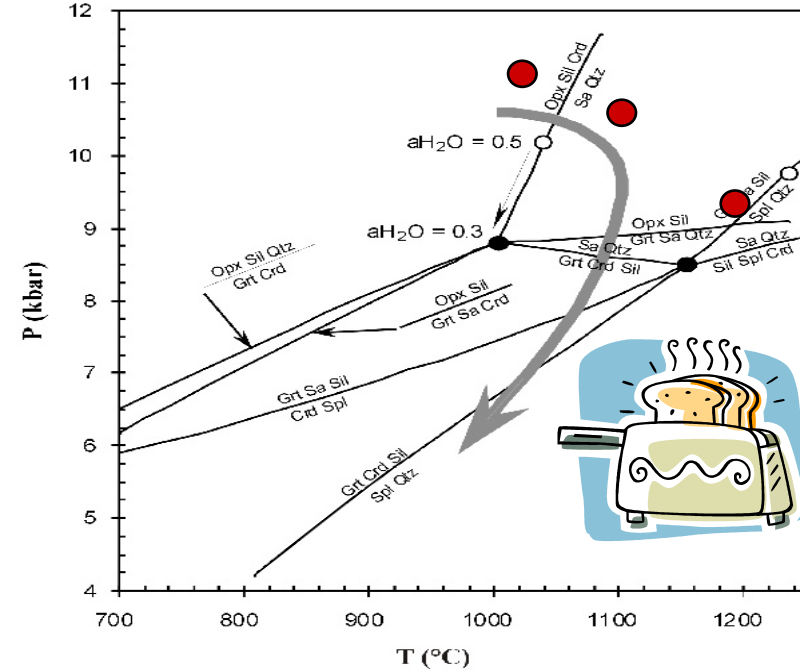
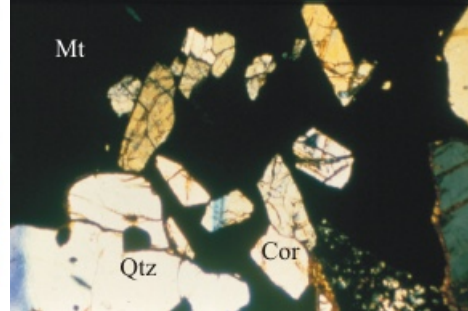
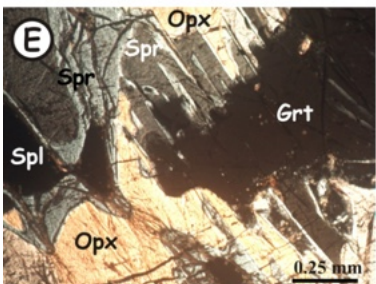
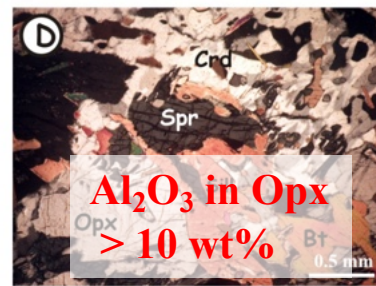
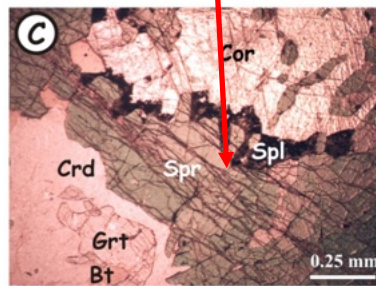
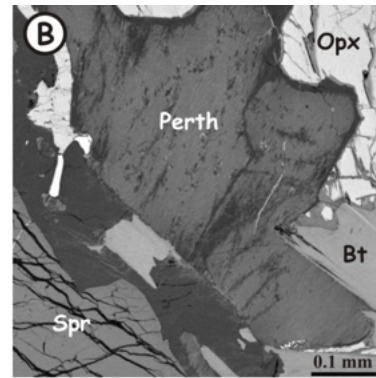
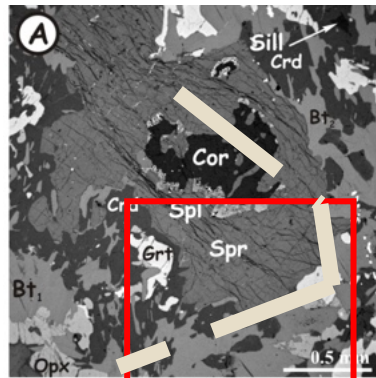
Amara et al.,(2024)



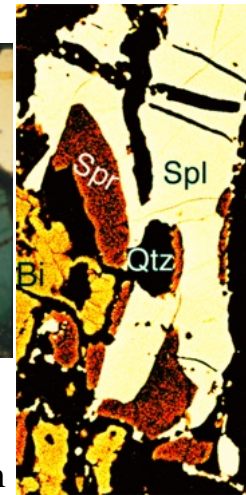
Recent studies of the Tefedest terrane within this same LATEA continental block have revealed an older basement dating from the Lower Palaeoproterozoic, at the boundary with the Archaean. These are migmatitic orthogneisses exhibiting TTG compositions and an affinity with arc magmatism.

In Ouzzal, one of the most extreme UHT metamorphisms in the world

Ouzegane et al., 2003
Bendaoud, 2008
Bendaoud et al. 2017



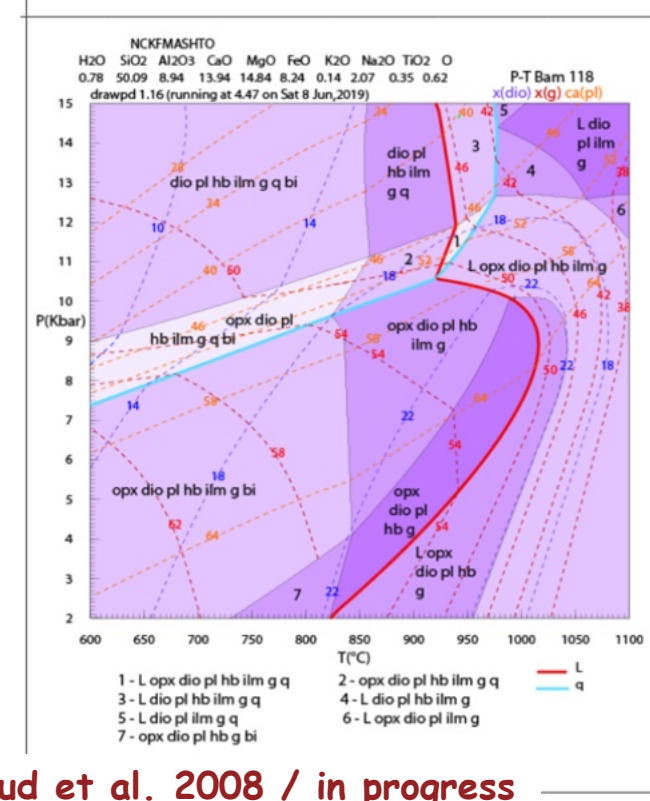
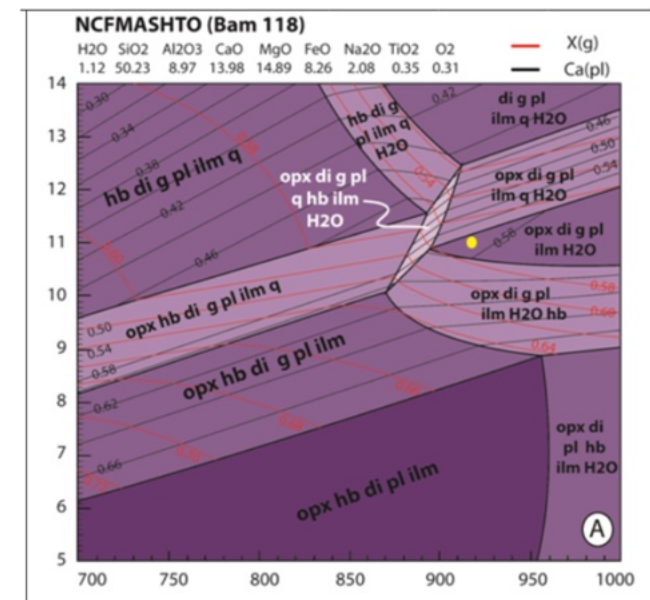
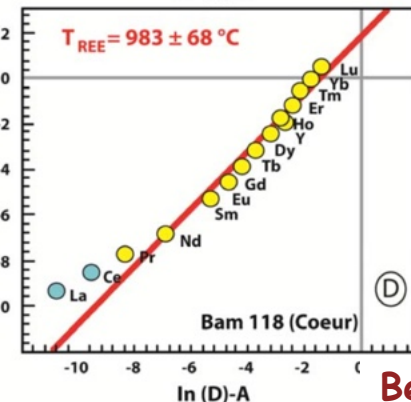
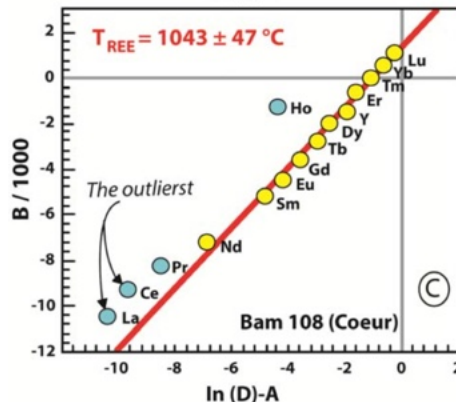
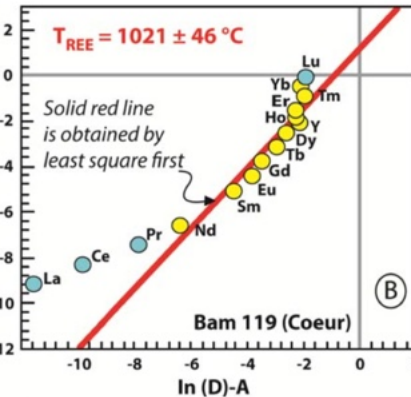
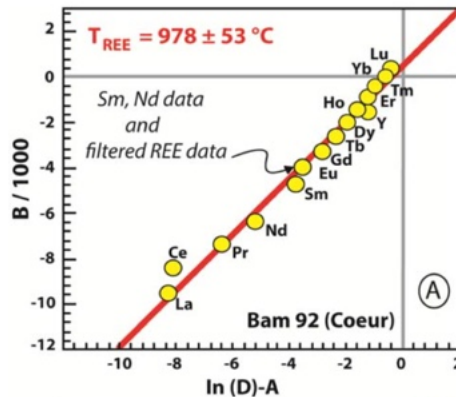
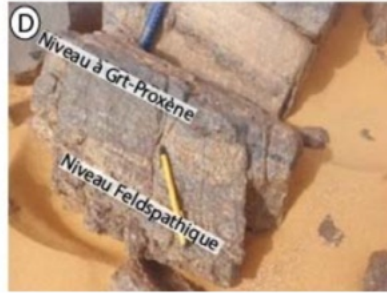
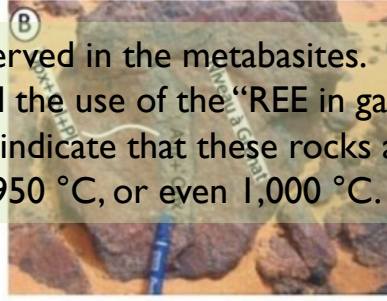
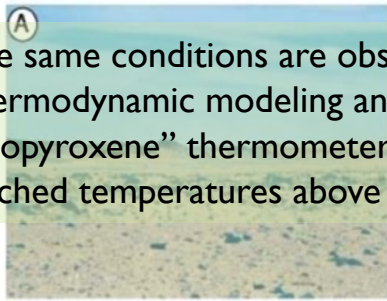
Equilibrium conditions are estimated at 1,100 °C and 12 kbar. The P-T trajectory begins with a gradual phase that peaks above 1,000 °C. This is followed by decompression at a relatively constant temperature, then an isobaric decrease in temperature.



But for this period, I've saved the best for last. The In Ouzzal terrane and the metamorphism affecting it, which is considered one of the most extreme metamorphic events known. This is evidenced by the presence of the Spl + Spr + Qtz assemblage, and Al_2O_3 contents exceeding 10% in orthopyroxene in the presence of garnet in Al-Mg granulites. And the corundum-quartz association in the BIF,

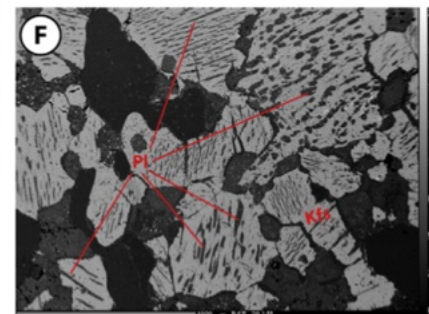
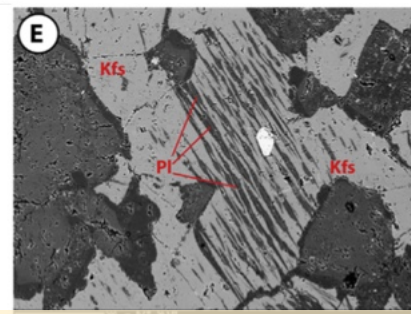
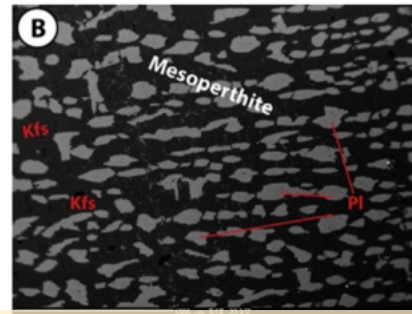
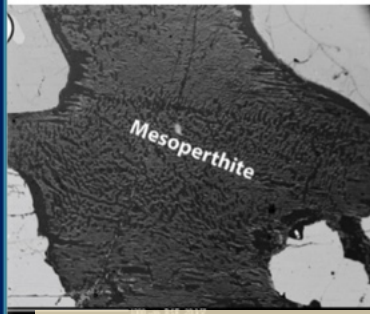
Paleoproterozoic

The same conditions are observed in the metabasites. Thermodynamic modeling and the use of the “REE in garnet-clinopyroxene” thermometer indicate that these rocks also reached temperatures above 950 °C, or even 1,000 °C.

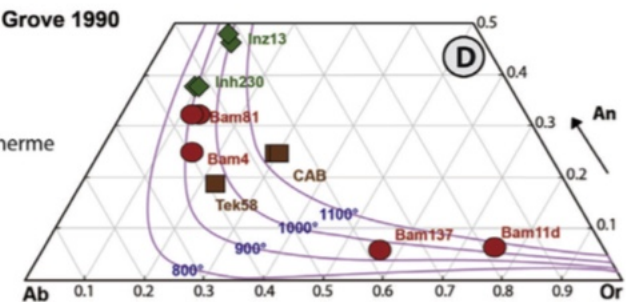
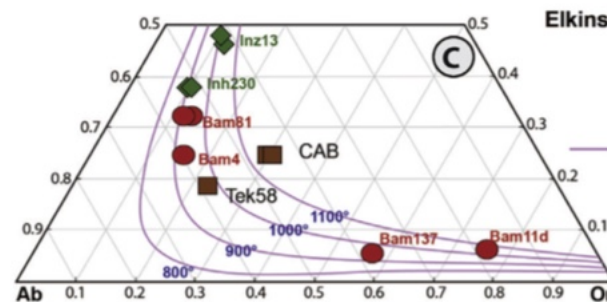
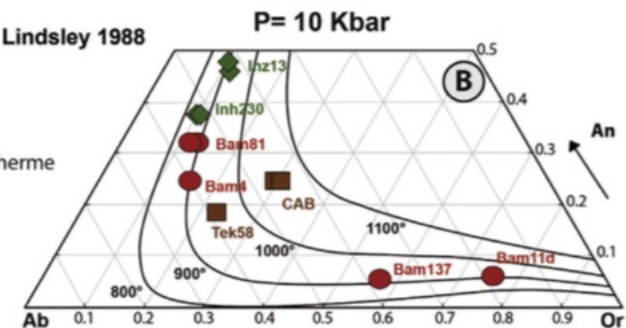
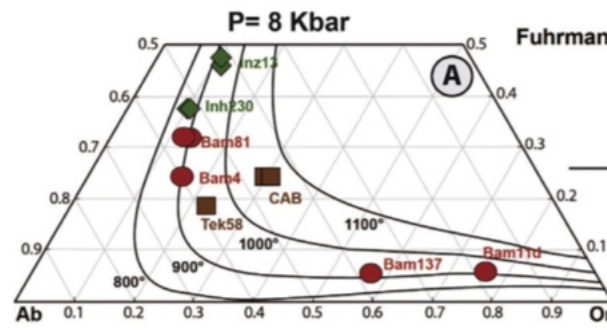
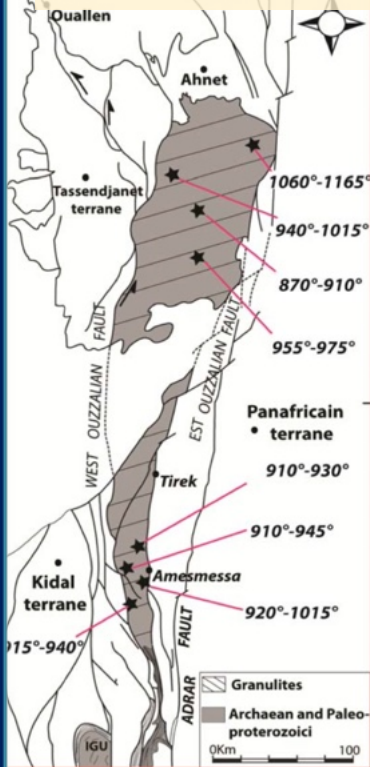
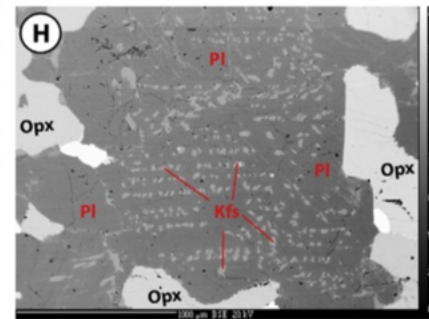


Bendaoud et al. 2008 / in progress

Paleoproterozoic

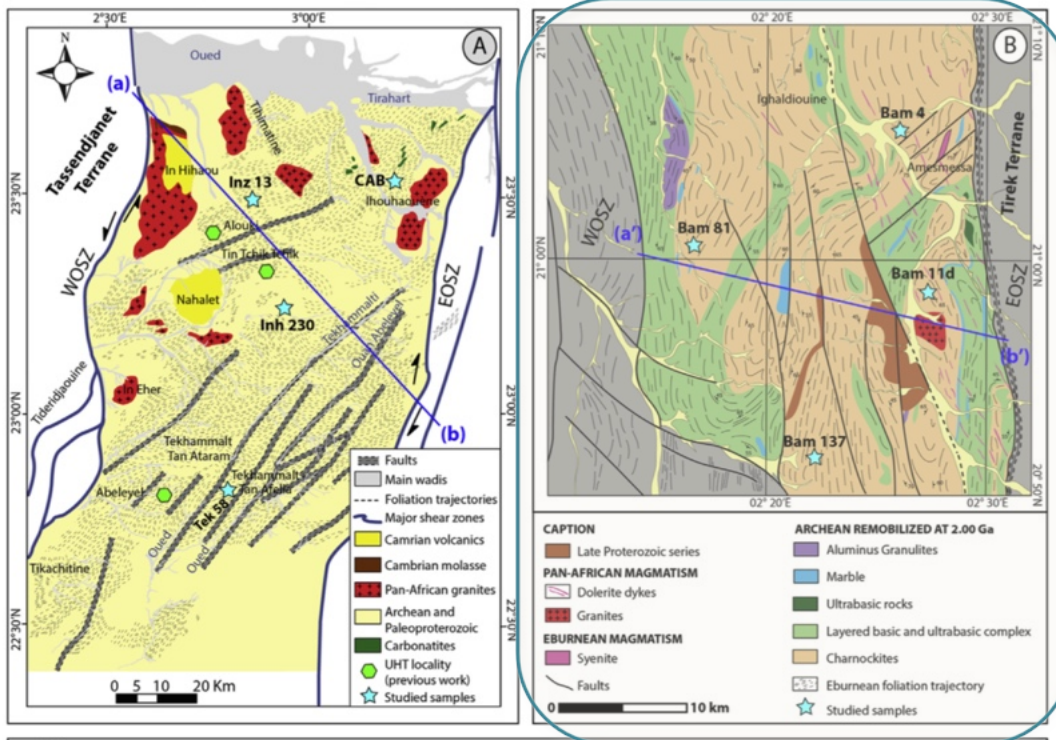


Another interesting outcome of our research is that we demonstrated that UHT metamorphism ($>900^{\circ}\text{C}$) affected the entire In Ouzzal crustal block. This result was obtained using ternary feldspar thermometry on various rock types (metanorite, Al-Mg granulite and orthogneiss) sampled from different regions of the In Ouzzal terrane.

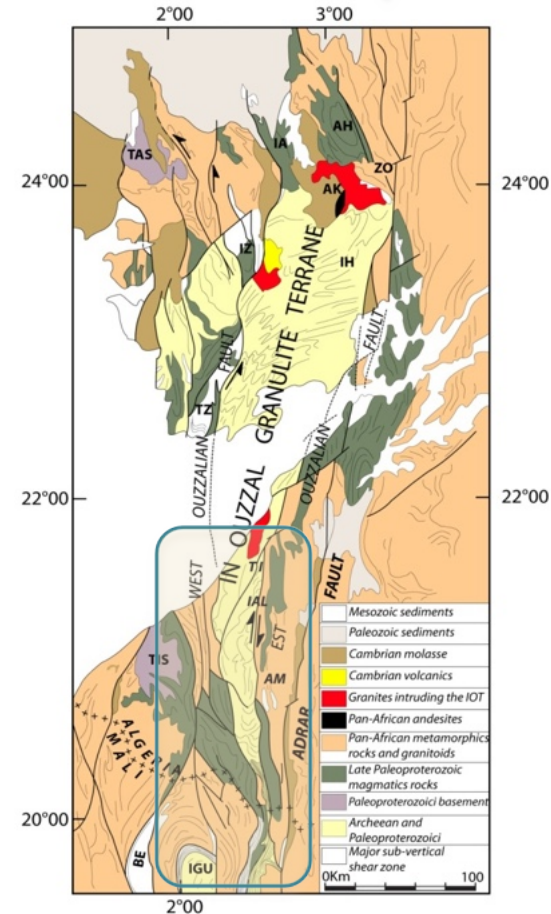
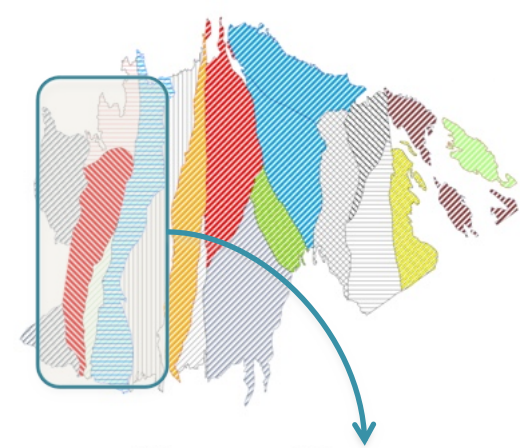
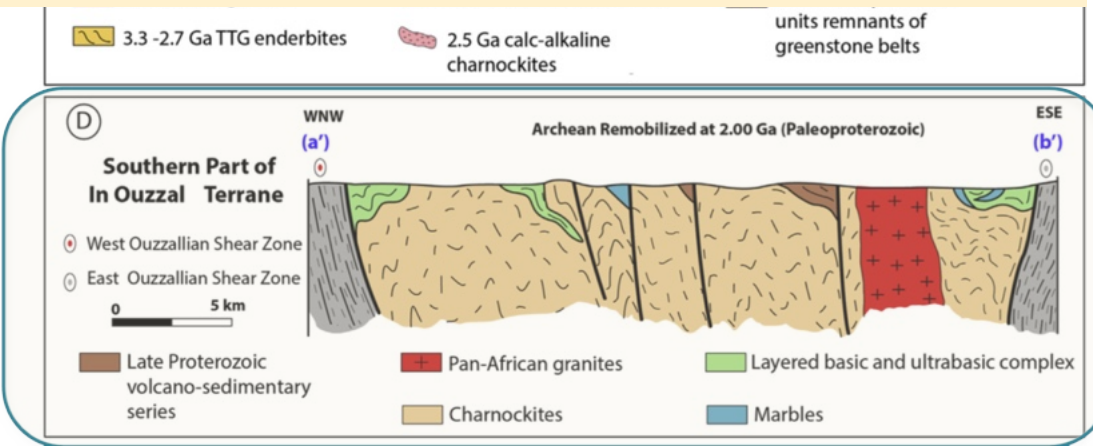


Benbatta et al., 2017 ● Orthogneisses ■ Al-Mg Granulites ◆ Metanorites

Paleoproterozoic

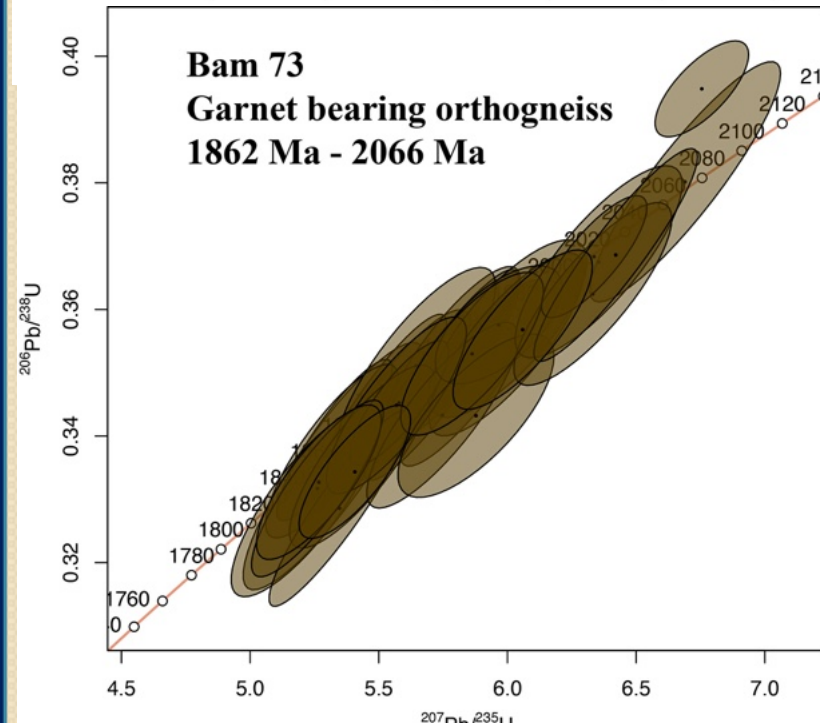
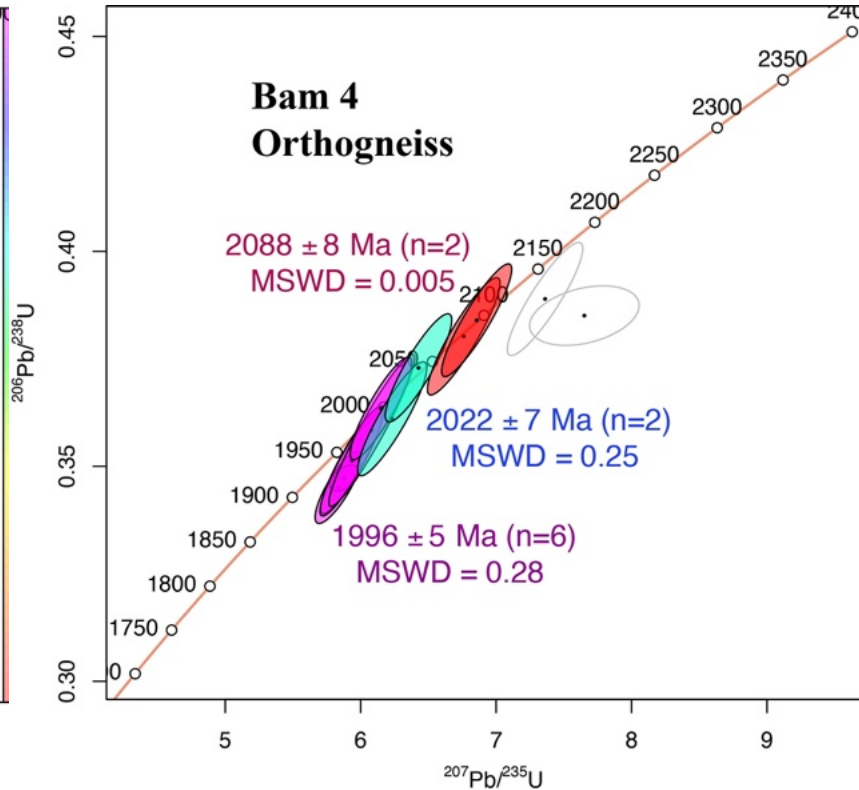
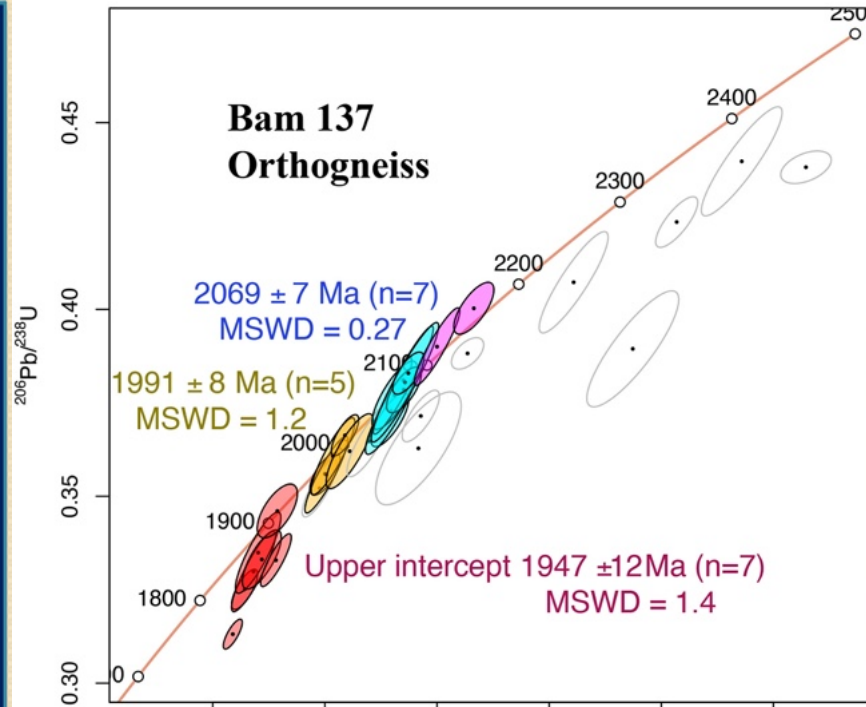


Recent studies have focused on the southern part of the In Ouzzal, where orthogneisses cut through the Archean crust and are associated with a layered basic-ultrabasic complex



Carte géologique de l'In Ouzzal et des terranes limitrophes (Caby, 1996)

Paleoproterozoic

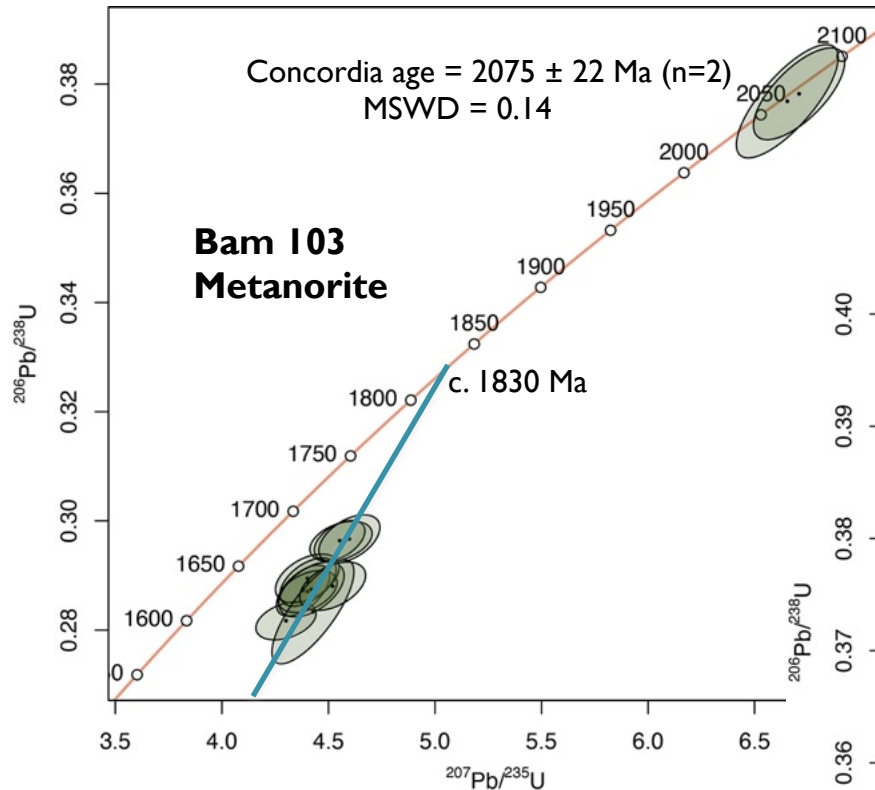


Paleoproterozoic arc magmatism

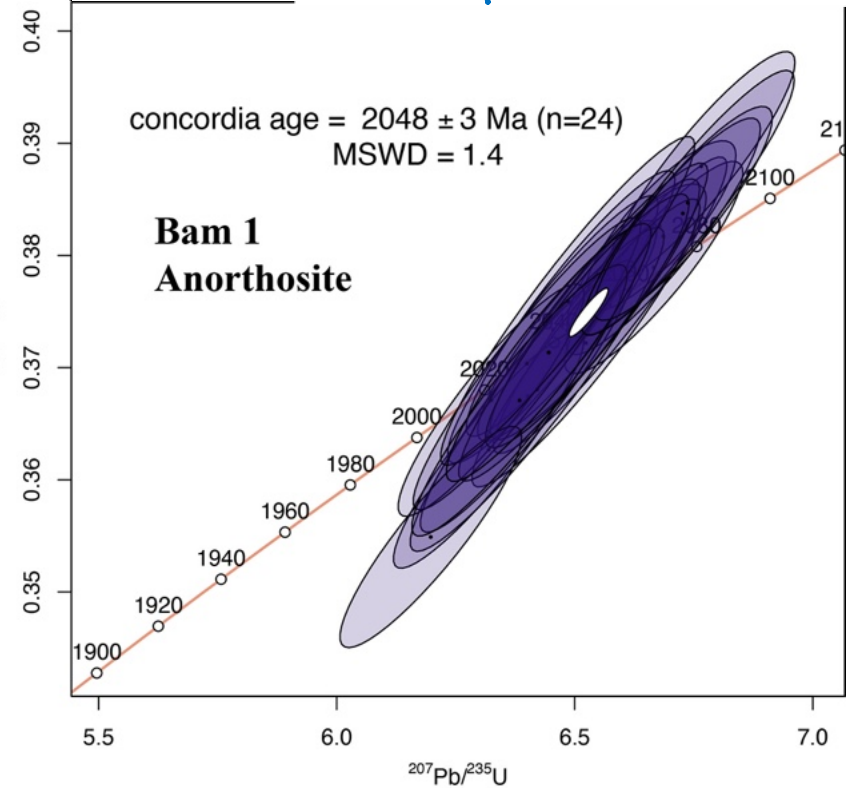
The protoliths of these orthogneisses correspond to arc magmatism dated between 2.07 and 2.1 Ga, while the metamorphic zircons yield ages ranging from 2.04 to 1.86 Ga. This suggests that the thermal event lasted a long time.

Bendaoud et al., in progress

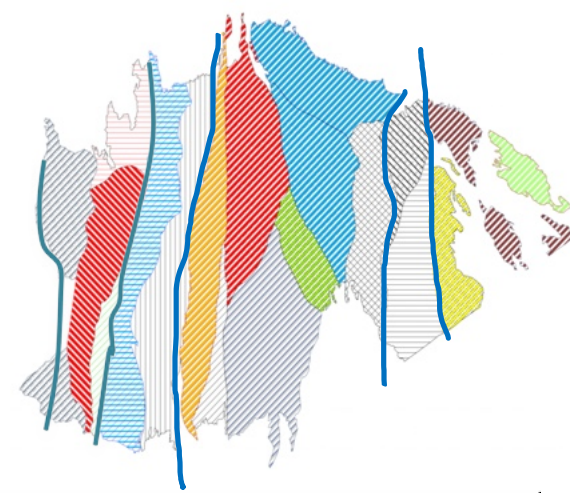
Metabasites.



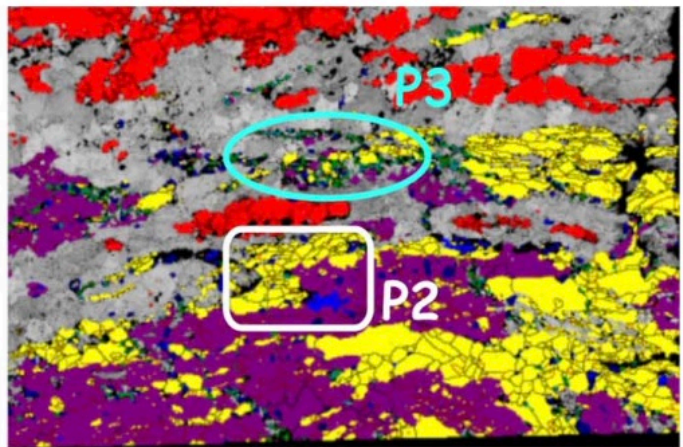
The layered basic-ultrabasic complex has been dated to between 2050 and 2070 Ma. It also appears to have been remobilized around 1830 Ma.



Bendaoud et al., in progress

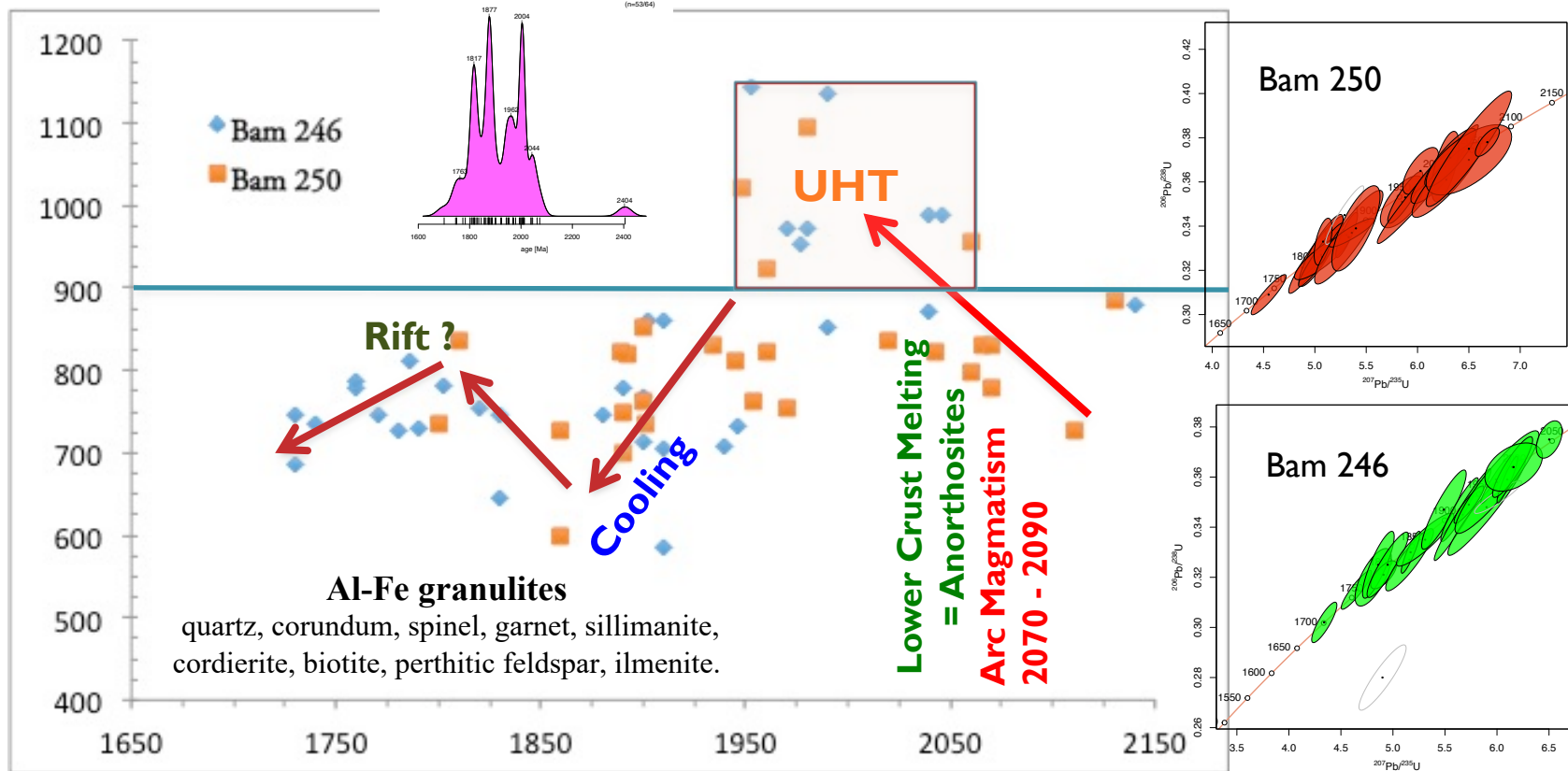


Bam 250 XFe Grenat ~~-0.68~~ XAn Plagioclase ~~-0.04~~ XFe Spinelle ~~-0.71~~



Benbatta et al.(submitted)

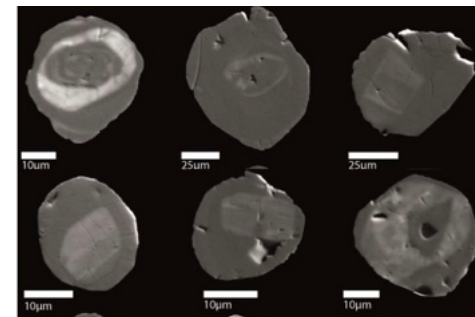
Combined Ti in Zircon Thermometry And U/Pb Geochronology



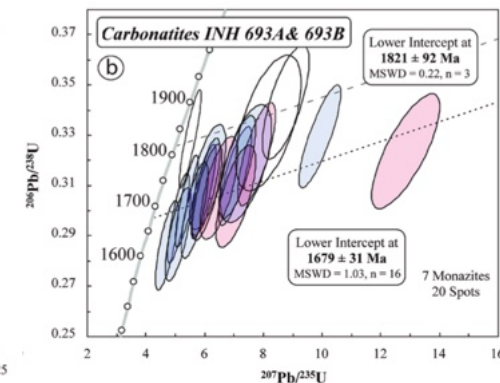
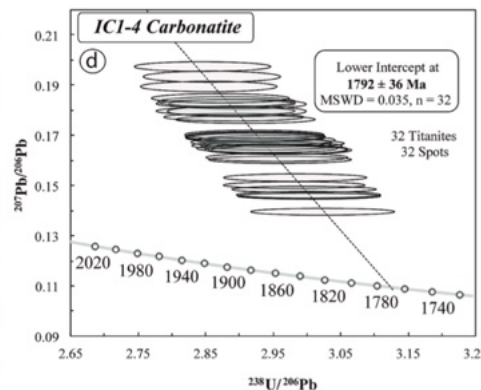
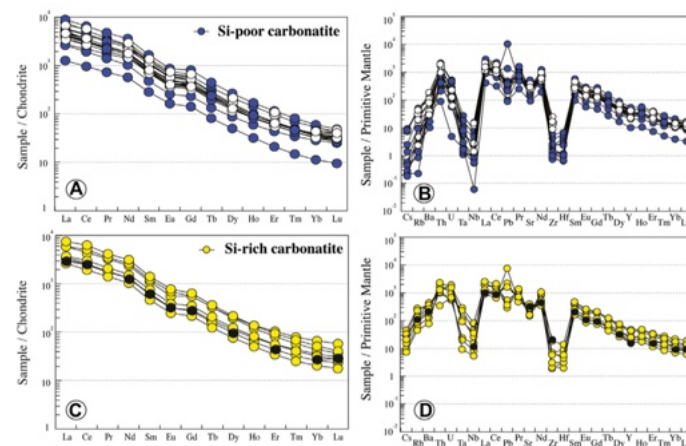
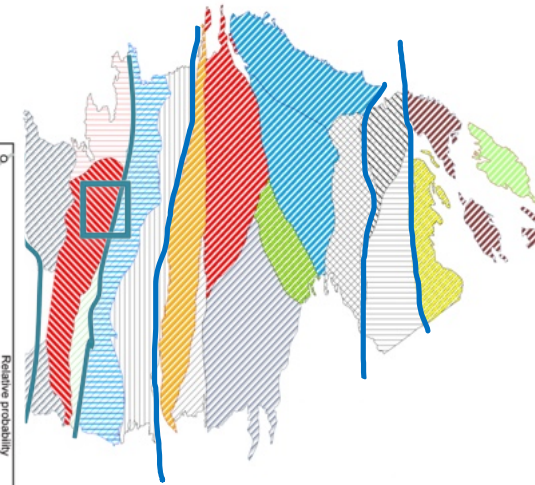
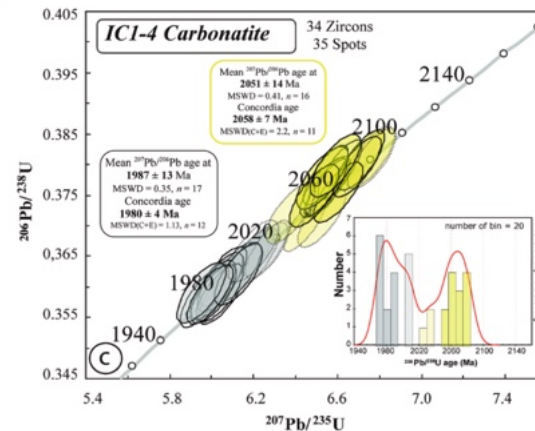
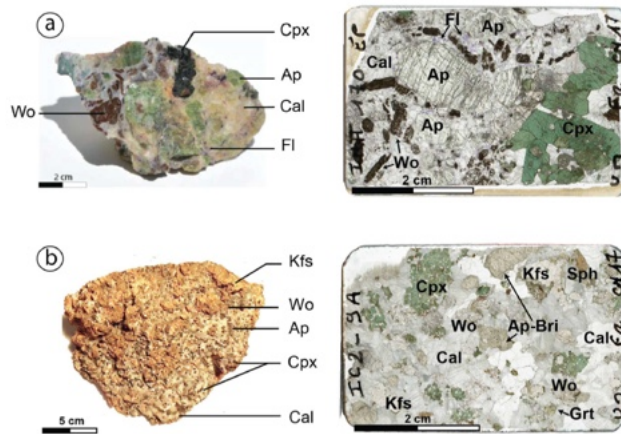
Benbatta et al., in submitted

U-Pb laser ablation dating of zircon, combined with titanium thermometry in zircon, performed on samples of these rocks, suggests two major events:

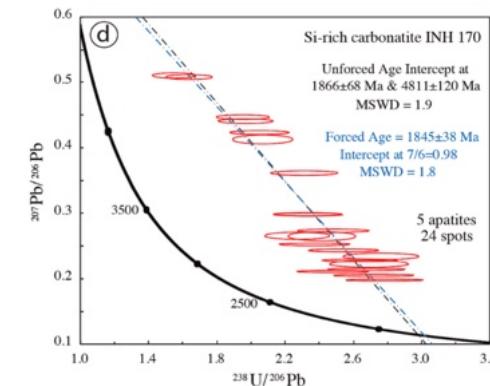
- 1- high-temperature metamorphism during the Paleoproterozoic, between 2.05 and 1.9 Ga, with a UHT thermal peak at 2 Ga followed by very slow cooling.
- 2- and a second high-temperature (HT) thermal event between 1.83 and 1.75 Ga, which is reported here for the first time.



Ihaouhaouine Carbonatites



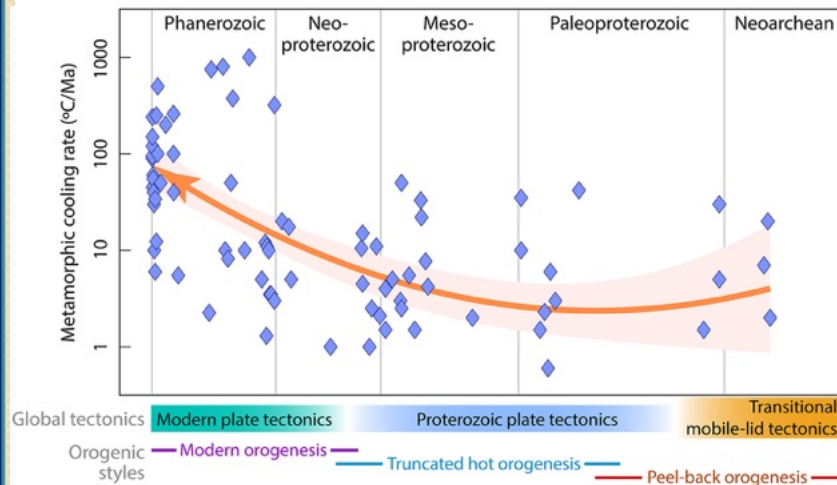
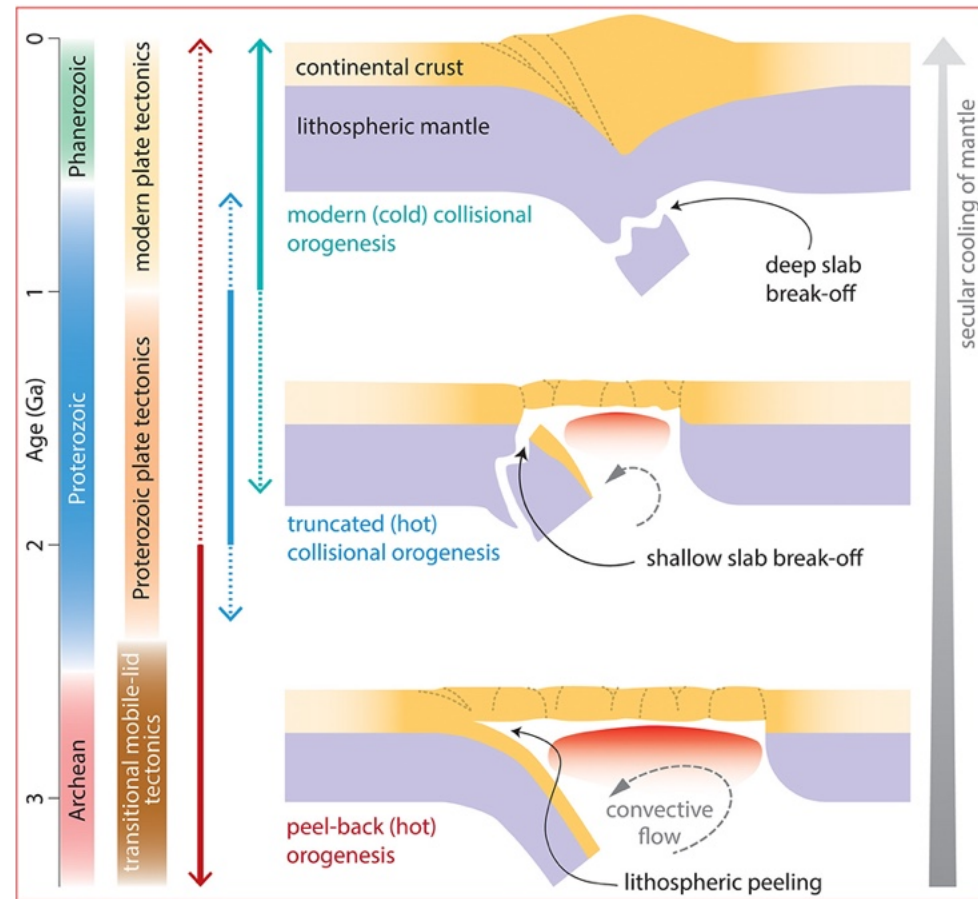
The In Ouzzal terrane is also known for the Ihaouhaouine carbonatite complex. This complex comprises various calcio-carbonatites closely associated with syenites emplaced within the Archean crust of In Ouzzal. These carbonatites have been dated to approximately 2,060 Ma and subsequently underwent the very high-temperature metamorphism I have just described. The use of apatite, monazite, and titanite geochronometers, combined with the LA-ICP-MS U-Th-Pb method, reveals a long and complex post-UHT history, with ages extending down to 1,650 Ma.



Paleoproterozoic

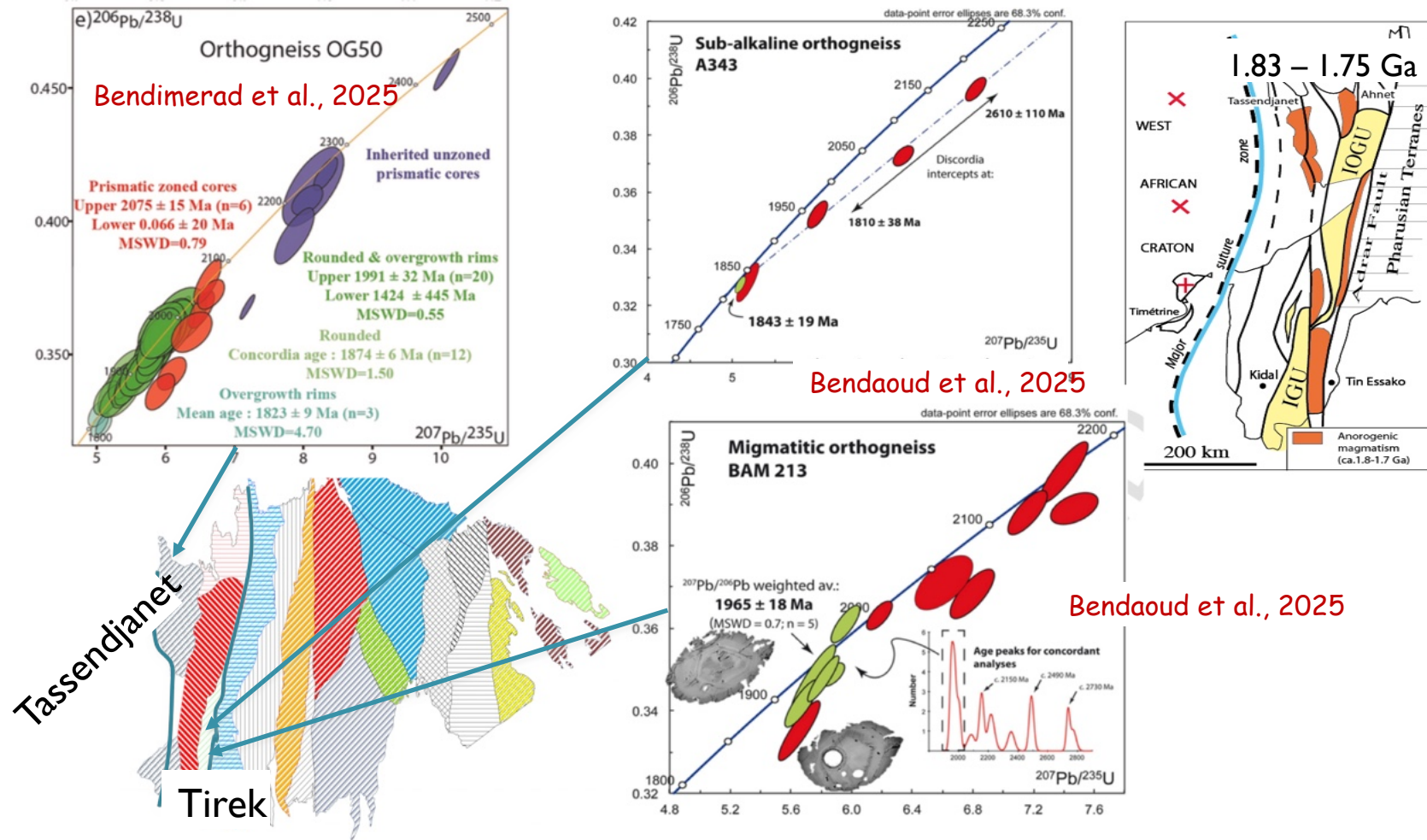
These data are consistent with the model proposed by Chowdhury et al (2021), according to which the Proterozoic, and in particular the Paleoproterozoic, is a period of transition marked by a change in the orogenic regime and, consequently, in plate tectonics over time.

This is a period of hot (collisional) orogenesis with very slow cooling rates, before the emergence, since the end of the Neoproterozoic, of modern-type orogenesis with faster cooling rates.



This explains the prolonged longevity (> 100 million years) of many Precambrian orogenic belts compared to those of the Phanerozoic.

Paleoproterozoic

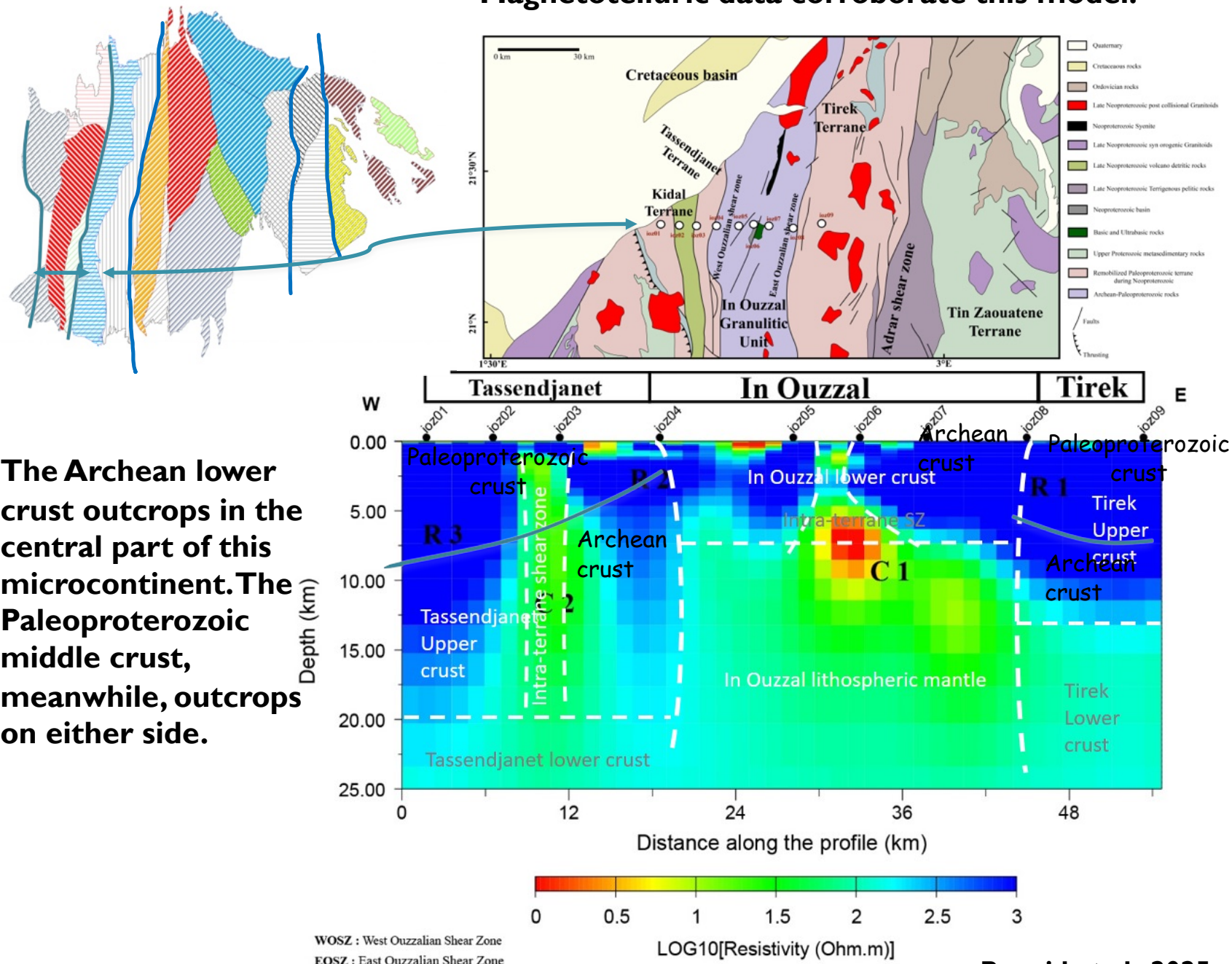


These results also link In Ouzzal to the surrounding terranes. Recently, Bendimerad et al. (2025) dated magmatic zircons from an orthogneiss located in the basement north of Tassendjanet, west of In Ouzzal, to 2075 Ma. The rims of these zircons and rounded crystals have ages ranging from 1990 Ma to 1830 Ma. Furthermore, in the Tirek terrane, east of In Ouzzal, the emplacement of an orthogneiss has been dated to 1965 Ma, with inherited zircons providing ages that correspond to the Archean lithologies of In Ouzzal. This basement is cut by subalkaline magmatism of the same age, 1840 Ma, as similar magmatism present in the terranes surrounding In Ouzzal. This suggests that all these terranes have formed the same microcontinent since the Archean.

Paleoproterozoic

The Archean lower crust outcrops in the central part of this microcontinent. The Paleoproterozoic middle crust, meanwhile, outcrops on either side.

Magnetotelluric data corroborate this model.

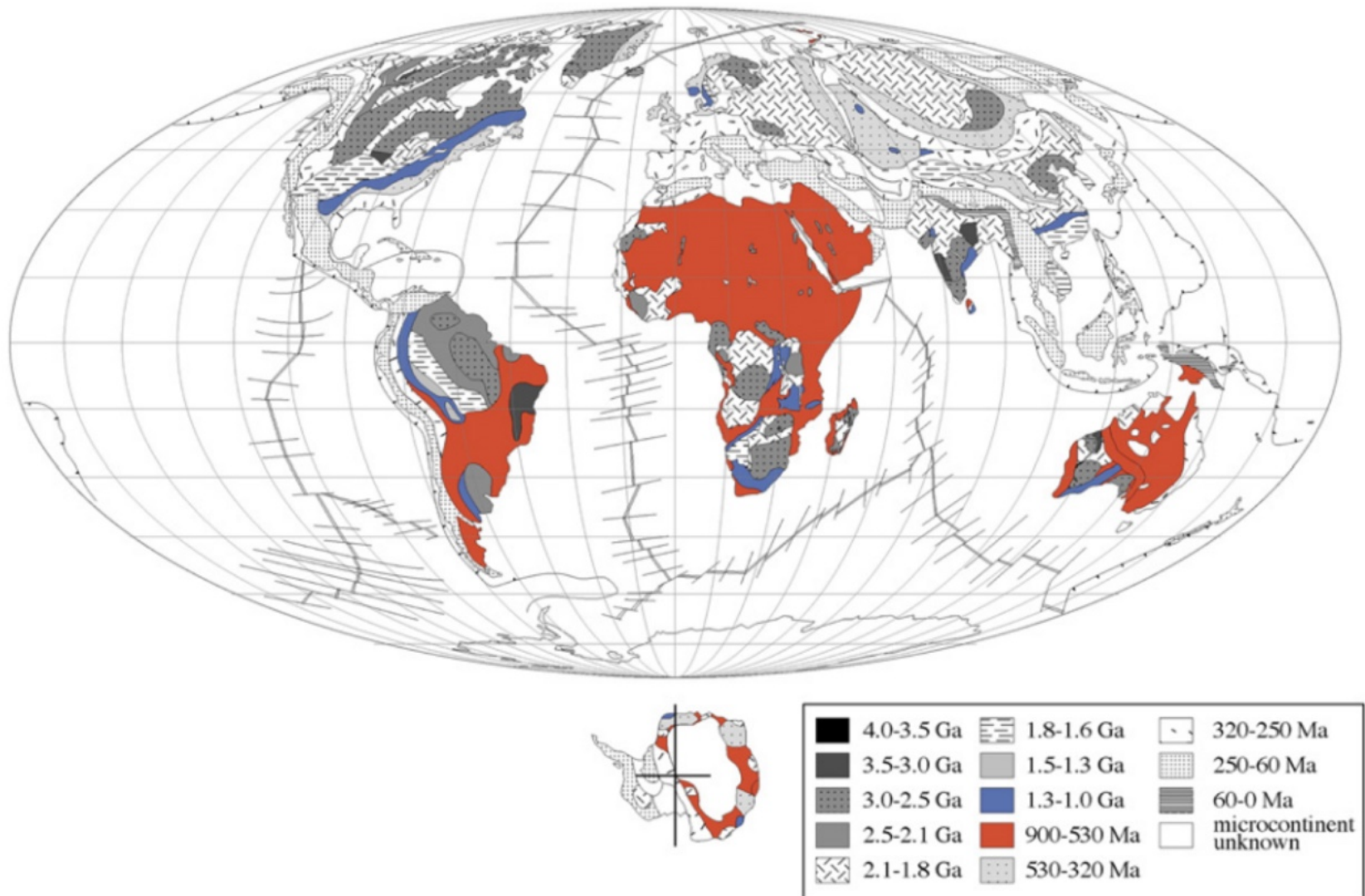




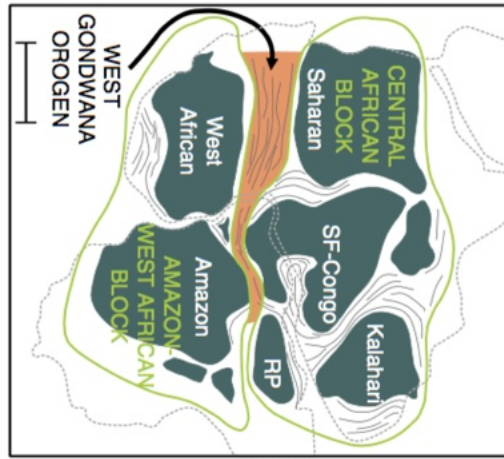
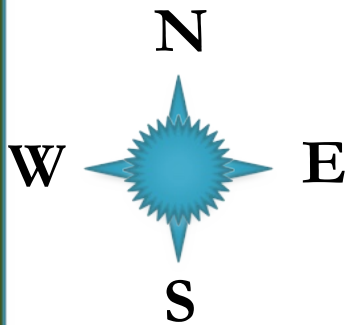
Neoproterozoic

We will now turn our attention to the Neoproterozoic and the Pan-African orogeny, which gave rise to the current structure of the Tuareg Shield and the Hoggar.

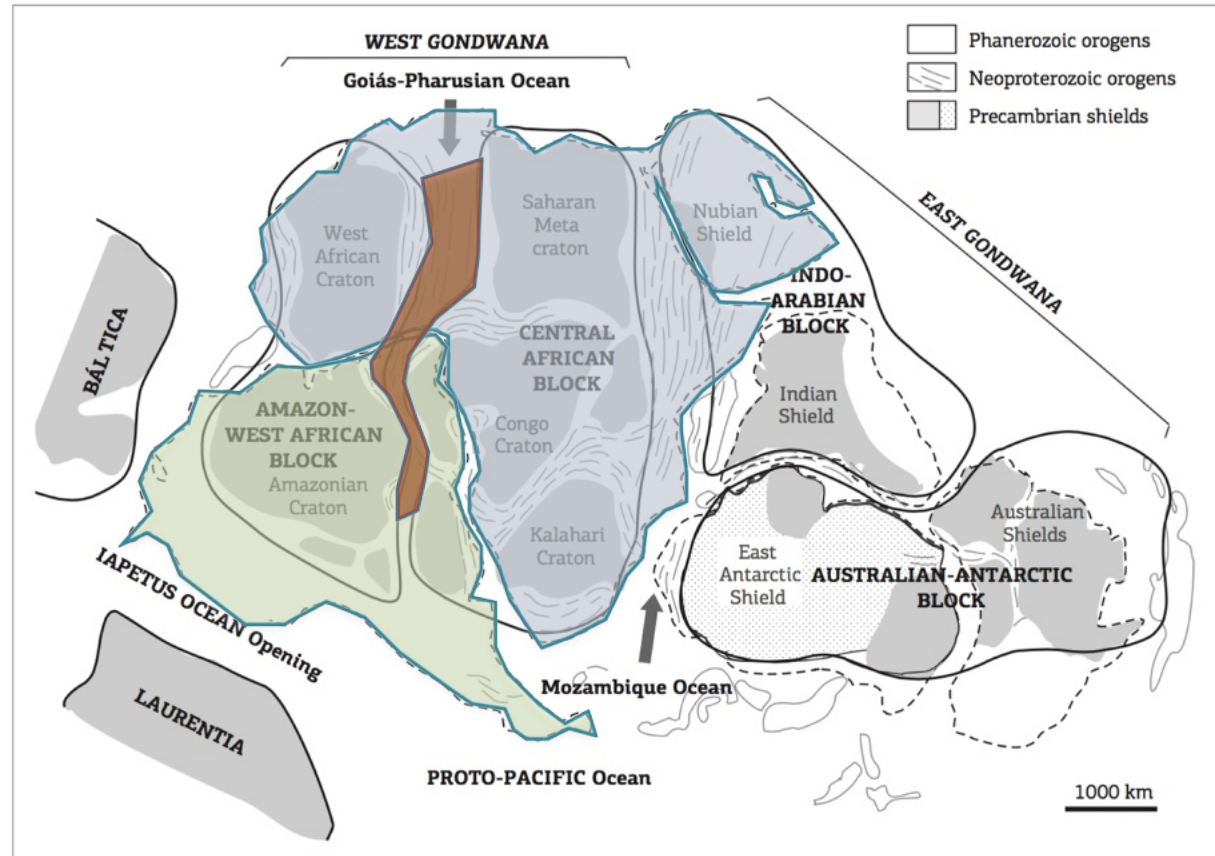
The Pan-African orogen: World's largest orogeny through geologic time



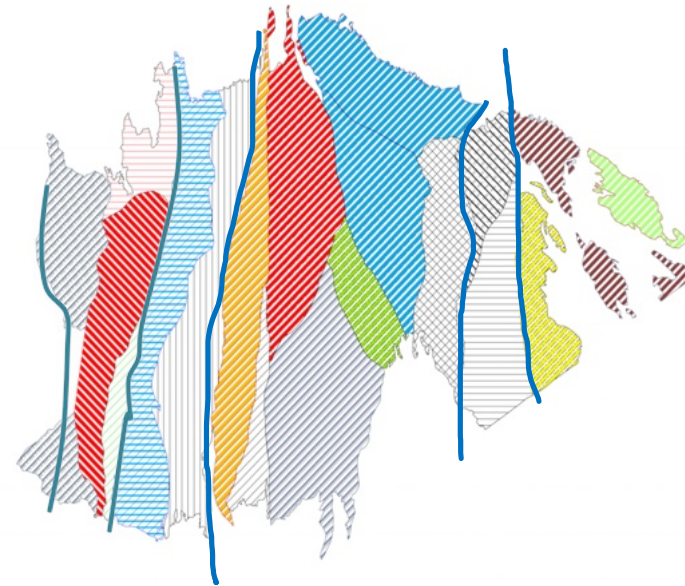
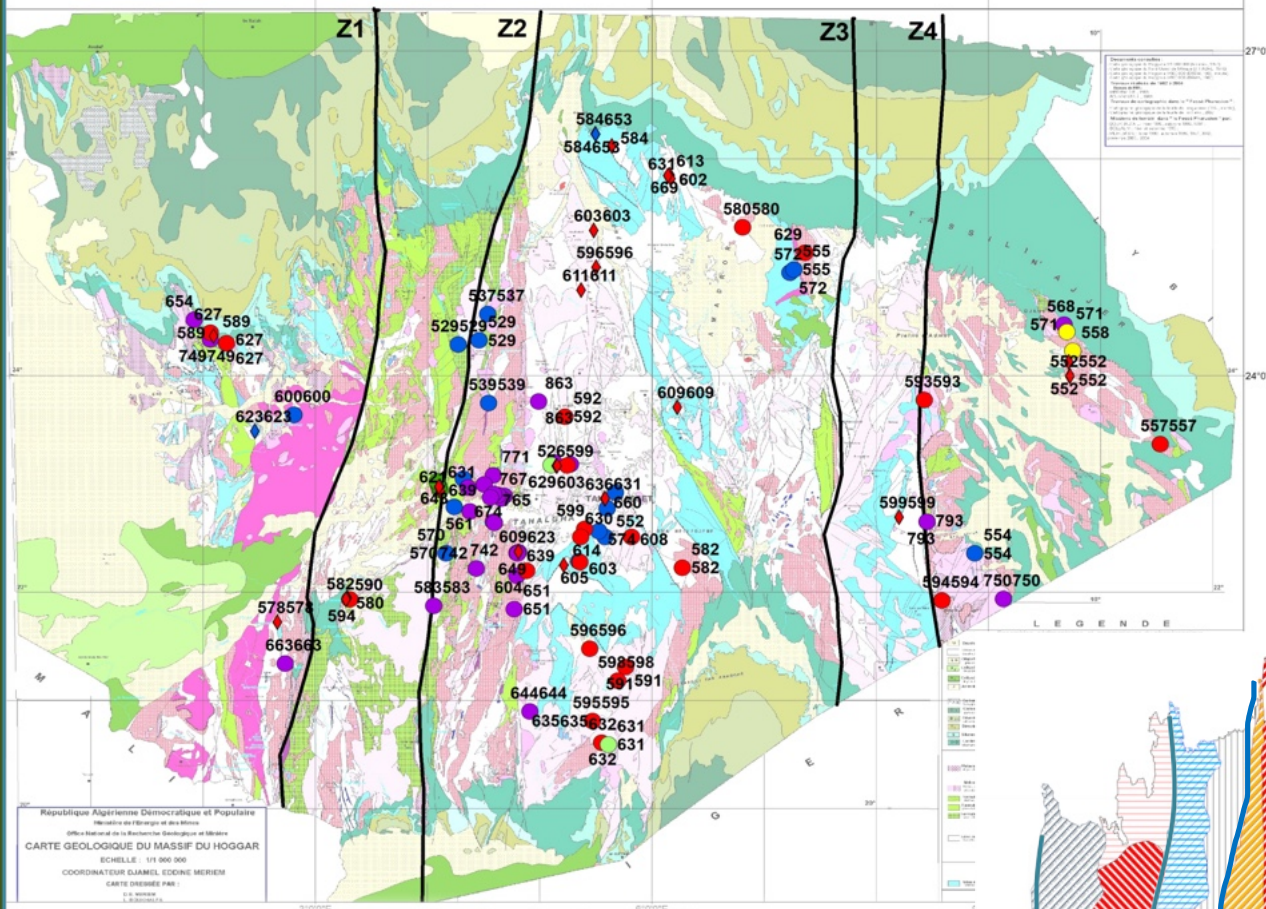
Neoproterozoic



As for the Trans-Saharan belt, it extends from the Hoggar to the Gulf of Guinea and continues as the Brazilian mobile belt in northeastern Brazil. It corresponds to the amalgamation of the western and central parts of Gondwana.



Neoproterozoic



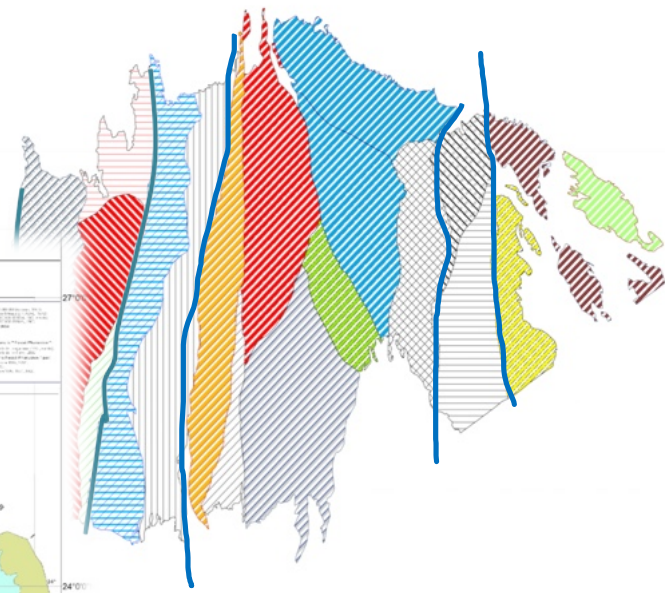
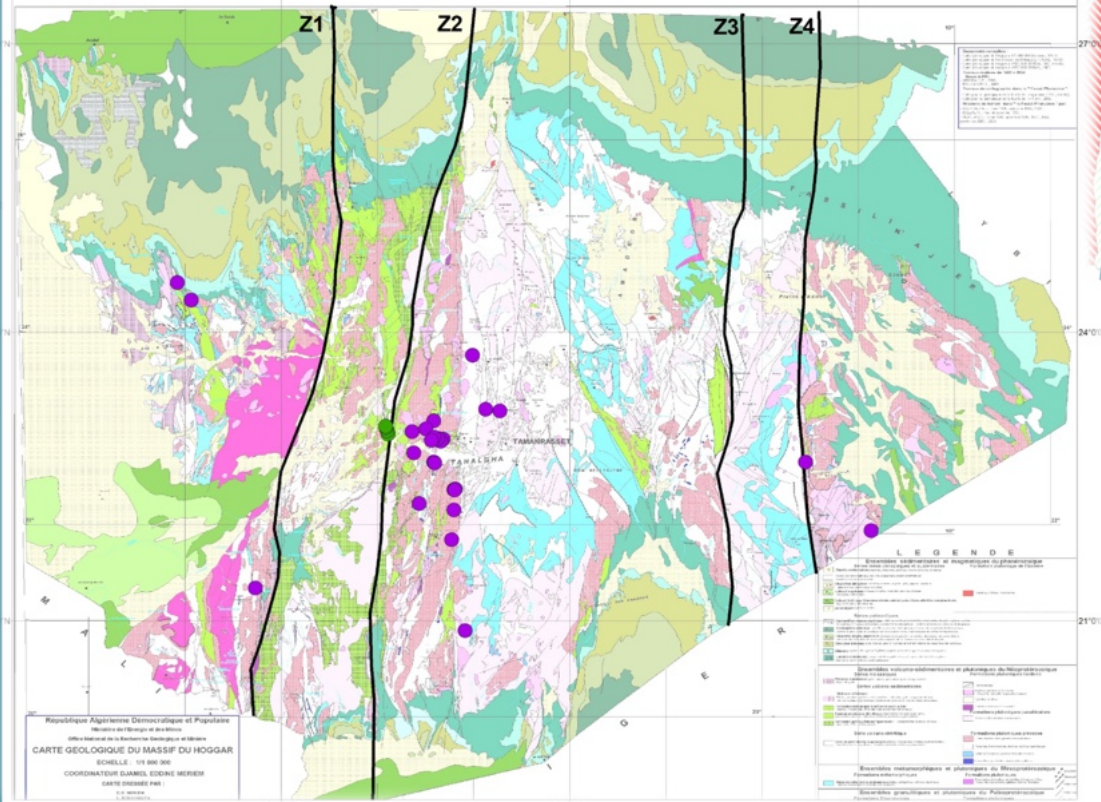
The points you see on this map correspond to dating results obtained from igneous and metamorphic rocks associated with the Pan-African orogeny, covering a period ranging from the subduction phase to the end of the orogeny and the post-orogenic period.

In total, we have 104 dates. More than a third has not yet been published.

Two crustal blocks, block 2 and block 4, remain unexplored in geochronological terms.

Most of the data are concentrated in the central part, in the LATEA continental block.

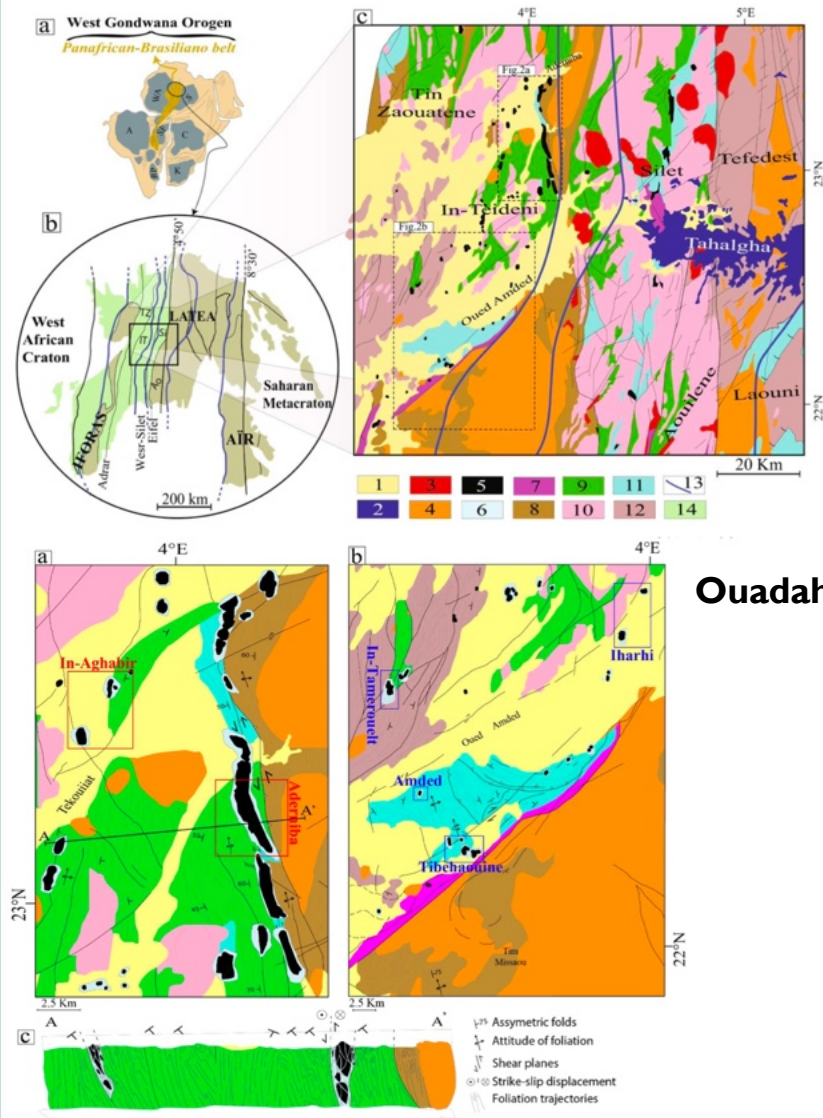
Neoproterozoic



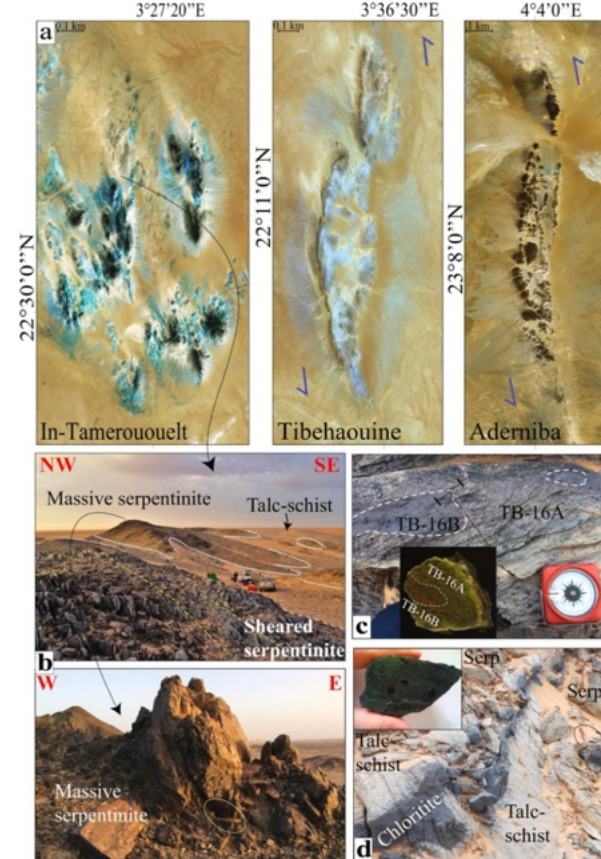
And as we can see here, the most thoroughly studied suture zone is the one that borders the Latea microcontinent to the west, in the central part of Hoggar.

Neoproterozoic

The suture zone at the west of LATEA

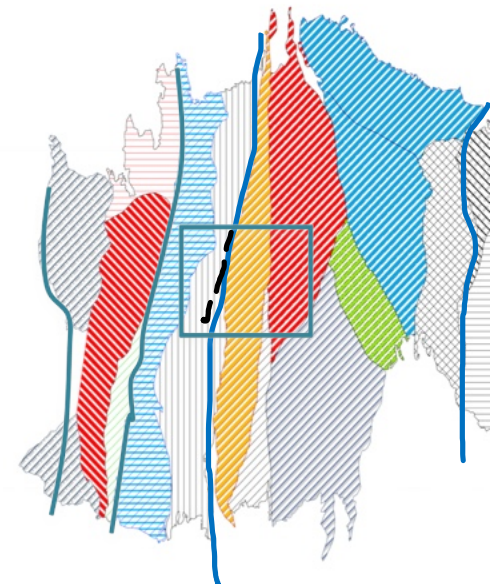
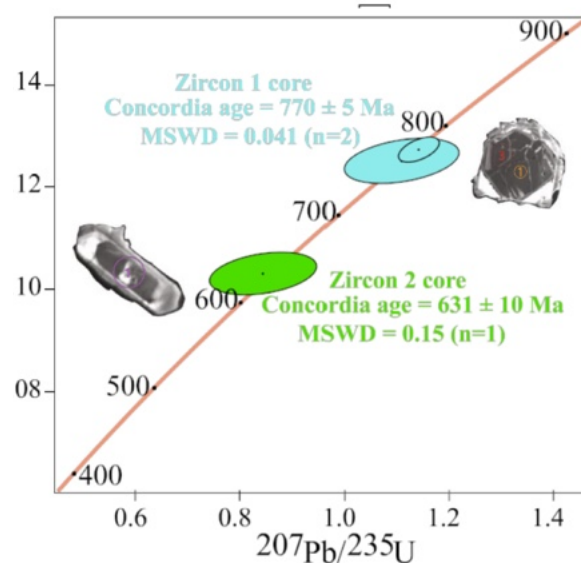
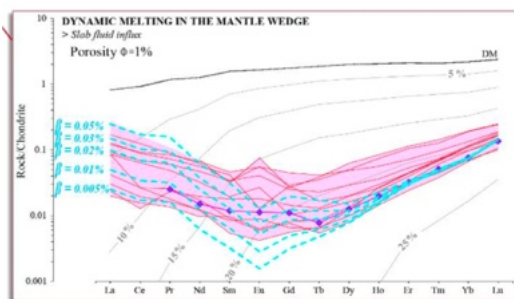
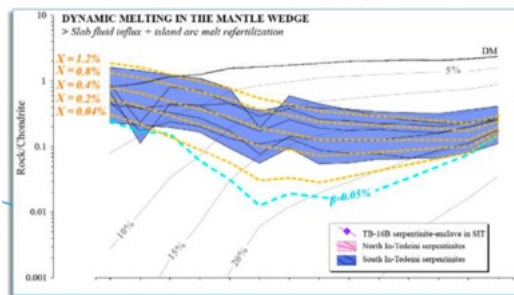
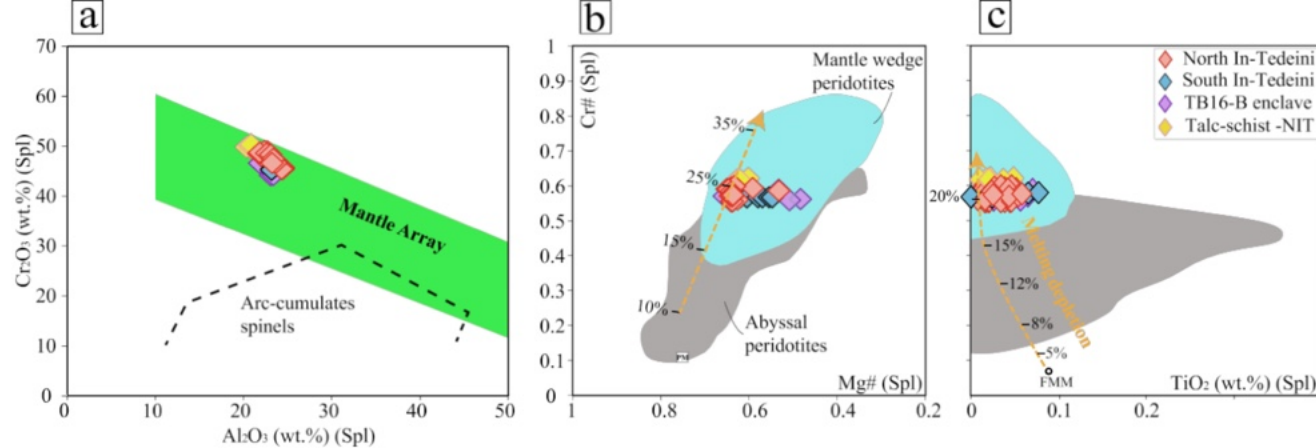


Ouadahi et al., 2022



This suture is marked by exhumed mantle serpentinite lenses. It connects the western Hoggar to the central Hoggar, resulting from an east-dipping Pan-African subduction. This tectonic system is thought to have contributed to the closure of the Goias-Pharusian Ocean.

Neoproterozoic

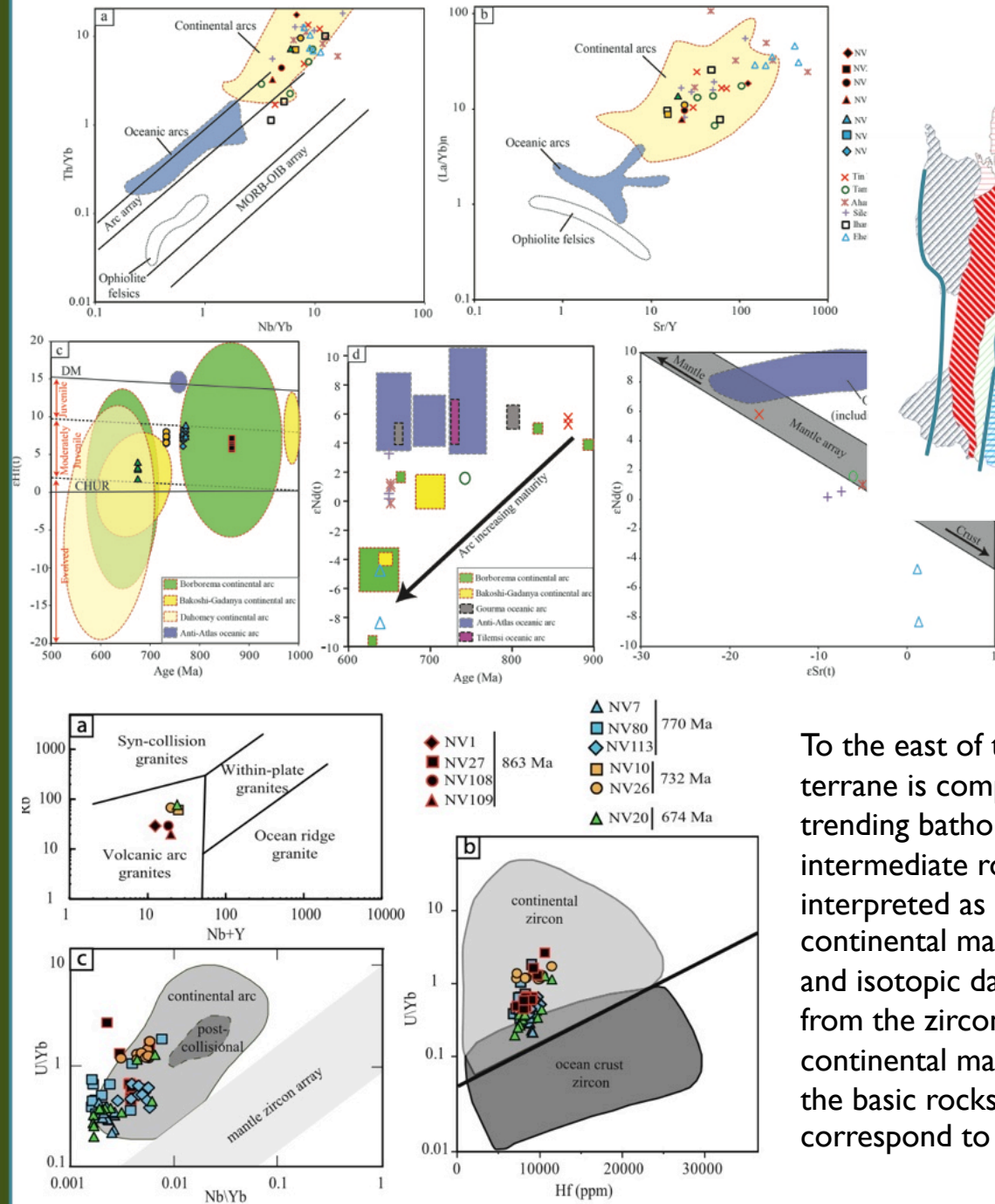


Quadahi et al., 2022

Thus, the composition of spinel and the geochemistry of the In-Tedeini serpentinites shows that they correspond to mantle wedge harzburgites, associated with a subduction setting, and that they exhibit a high degree of melt depletion.

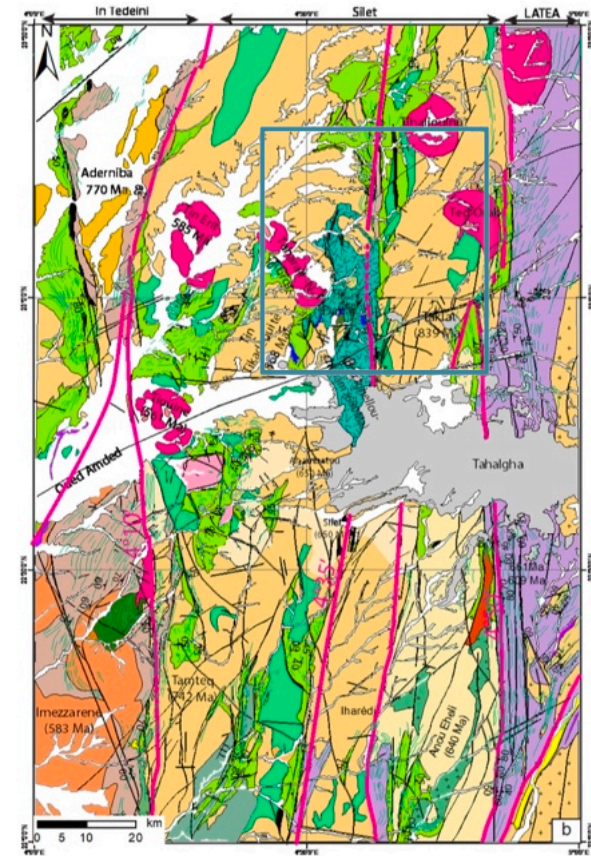
Ages of the rare zircons recovered from a metasomatic chloritic dike crossing the serpentinites have recorded the subduction related arc melts at 770 Ma and the exhumation at 631 Ma of mantle wedge serpentinites within the crust, or a hydrothermal events endured by serpentinites during their geodynamic evolution.

Neoproterozoic



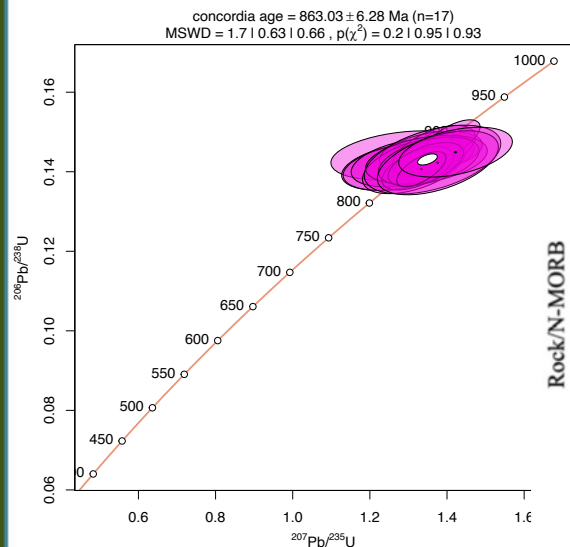
Berrahmane et al., 2025

To the east of these serpentinites, the Silet terrane is composed by large north-south-trending batholiths, associated with basic to intermediate rocks. This region has been interpreted as either a set of island arcs or a continental margin. The combined geochemical and isotopic data from these batholiths, as well as from the zircons they contain, suggest a continental margin context. The composition of the basic rocks, meanwhile, indicates that they correspond to a back-arc basin environment.



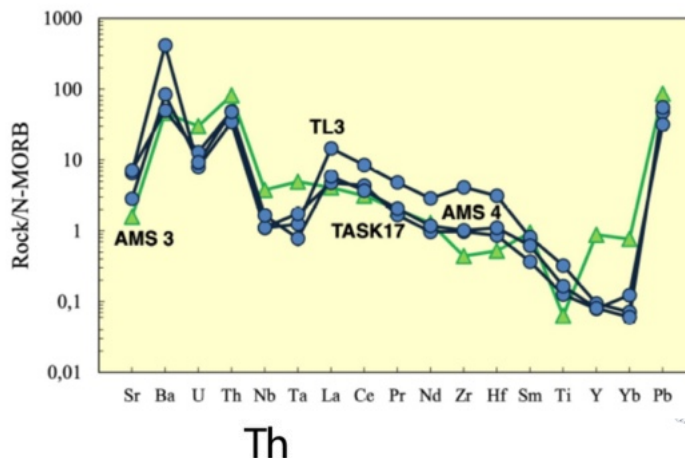
The batholiths in the northern part of this margin are dated at between 865 and 730 Ma. The back-arc basin, meanwhile, is dated at between around 770 Ma.

Neoproterozoic

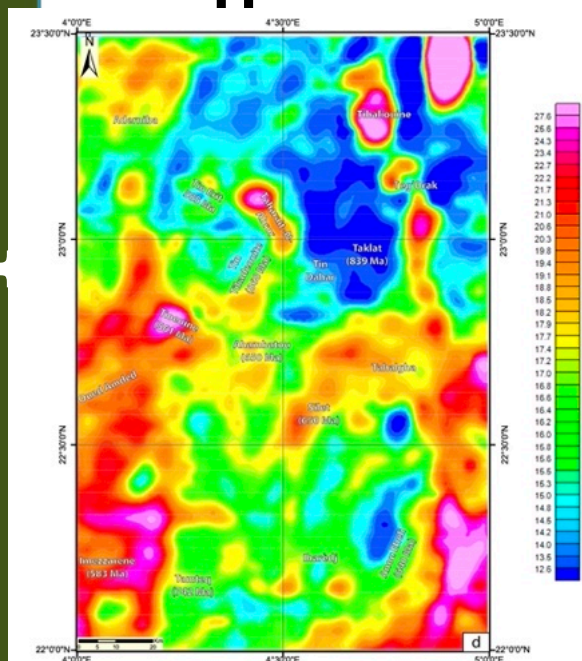


Tefedest (LATEA) : a continental arc

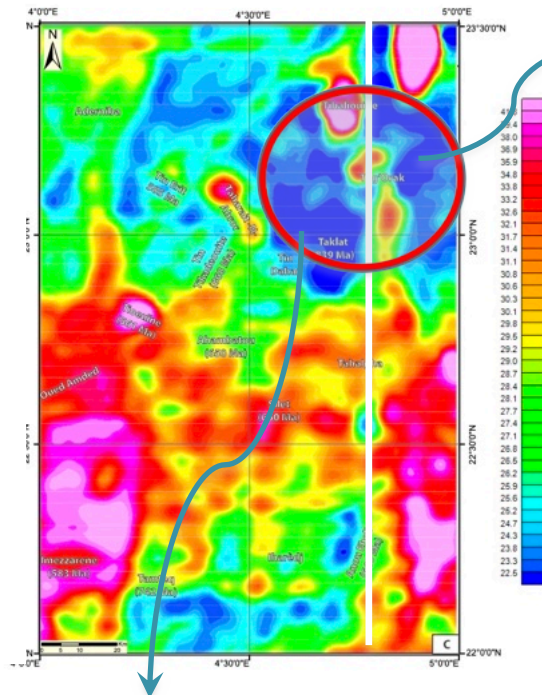
Amara et al., 2024



Tefedest orthogneiss
= 863 Ma

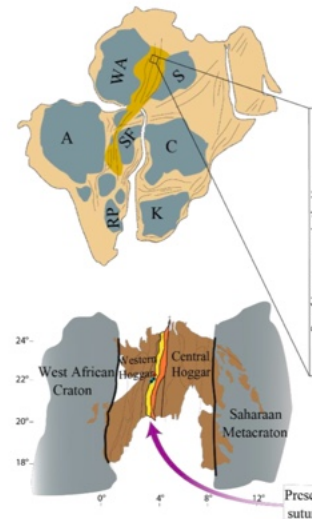
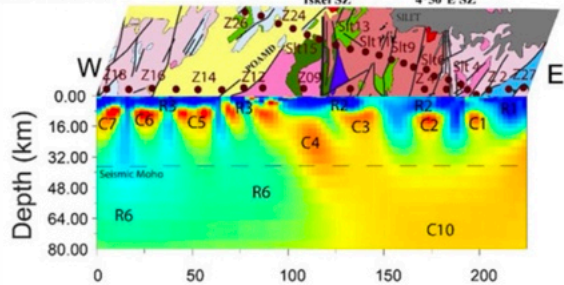


North Silet Batholith = 863 Ma



Further east, in the Tefedest terrane, which is part of the Latea microcontinent, orthogneisses have been dated to 863 million years (Ma), which is the same age as the northern Silet batholith. Aeroradiometric data show that these two areas exhibit similar signatures.

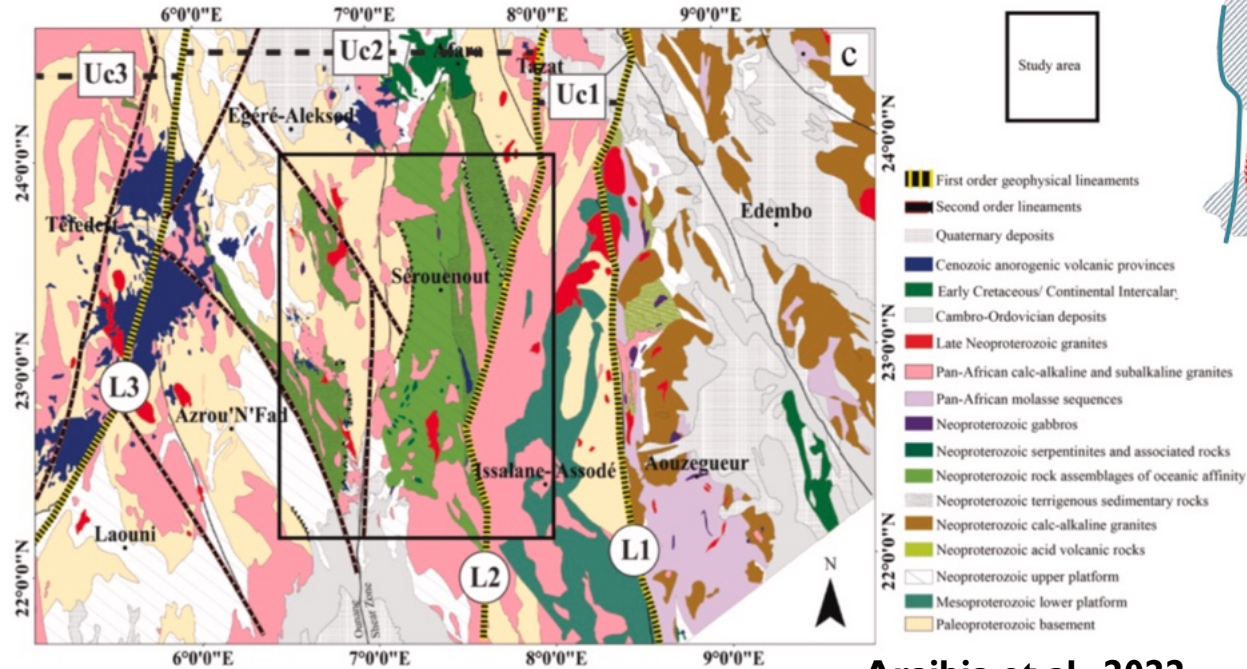
Profile C



By combining these results with magneto-telluric and gravimetric data, we infer that the occurrence of remnants of a continental arc domain to the east and continental platform deposits to the west constitute key markers of a Neoproterozoic suture zone between the central and western Hoggar domains, resulting from east-dipping subduction.

Neoproterozoic

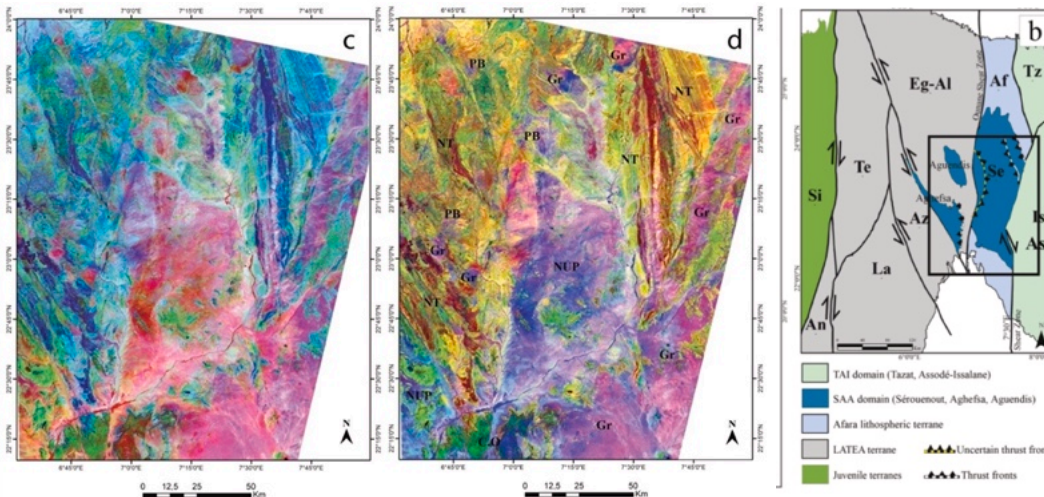
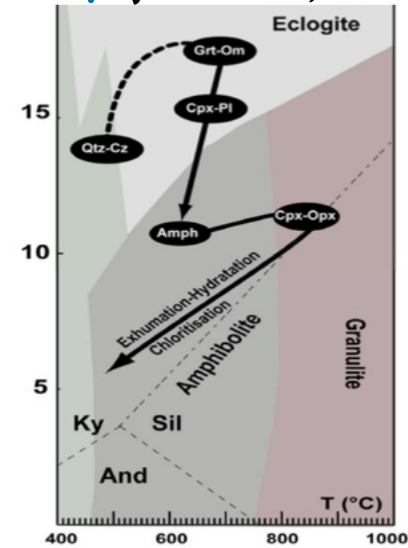
Eastern margin of the LATEA



Araibia et al., 2022

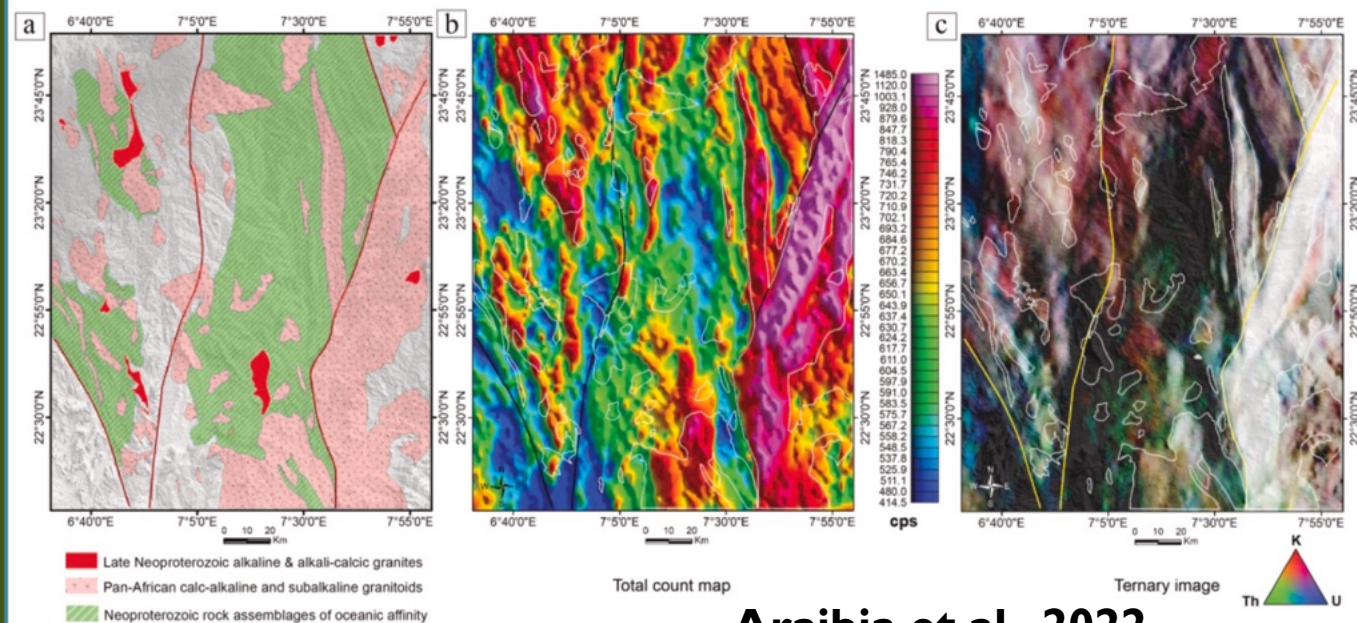
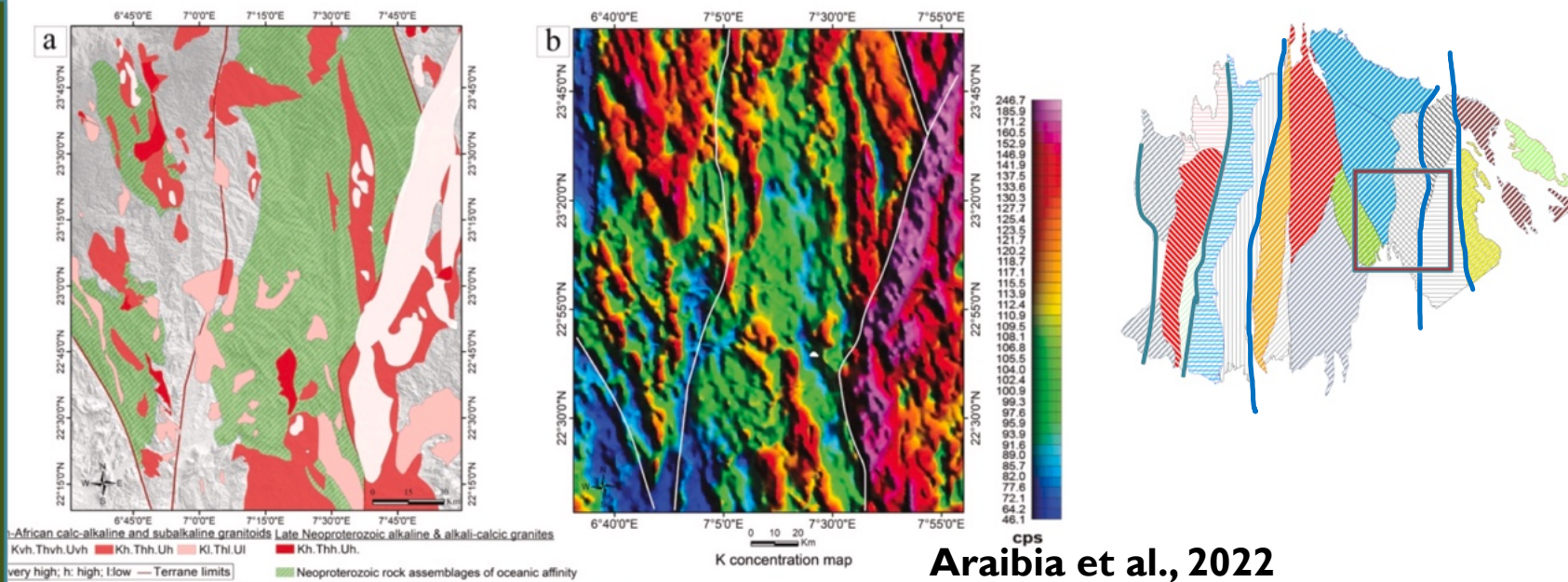


Adjerid et al., 2015



As regards the eastern margin of the Latea, no geochronological data are available. Previous studies have focused mainly on the high-pressure rocks of Serouanout, shown here in green. We have therefore made use of other tools: old geological maps from the Algerian Geological Survey, satellite imagery and, above all, geophysical data.

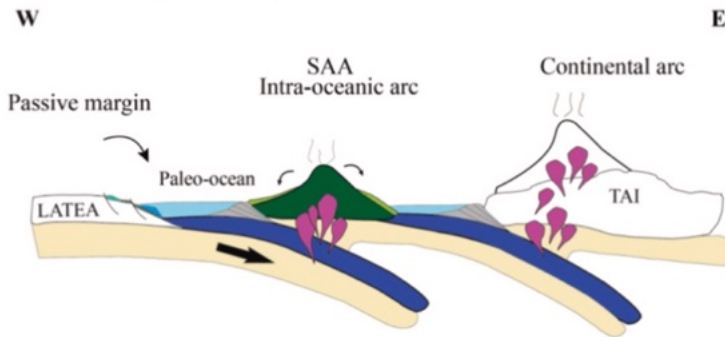
Neoproterozoic



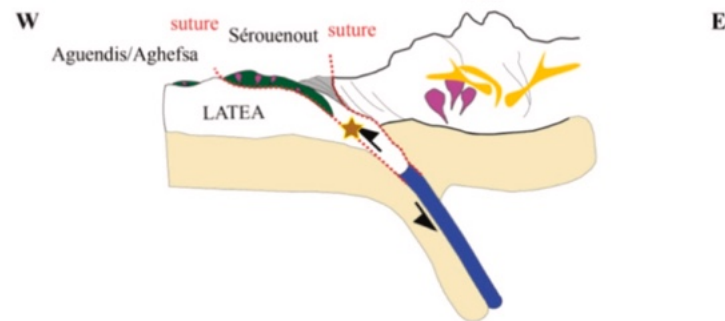
This does indeed make it possible to distinguish between the different types of granitoids. Alkaline granites and anatectic granites have high concentrations of U, Th and K, whereas TTG-type syn-subduction granites have low concentrations of these elements, as do basic and ultrabasic rocks.

Neoproterozoic

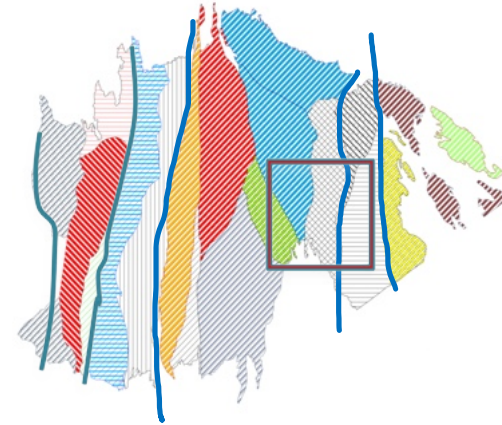
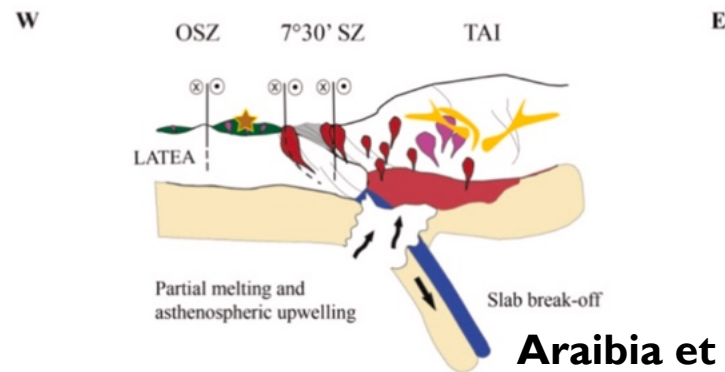
A) Subduction (? - 650 Ma)



B) Collision (650-630 Ma)

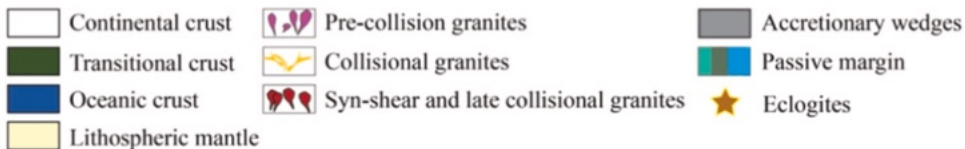


C) Transpression + lithospheric delamination (630-575 Ma)

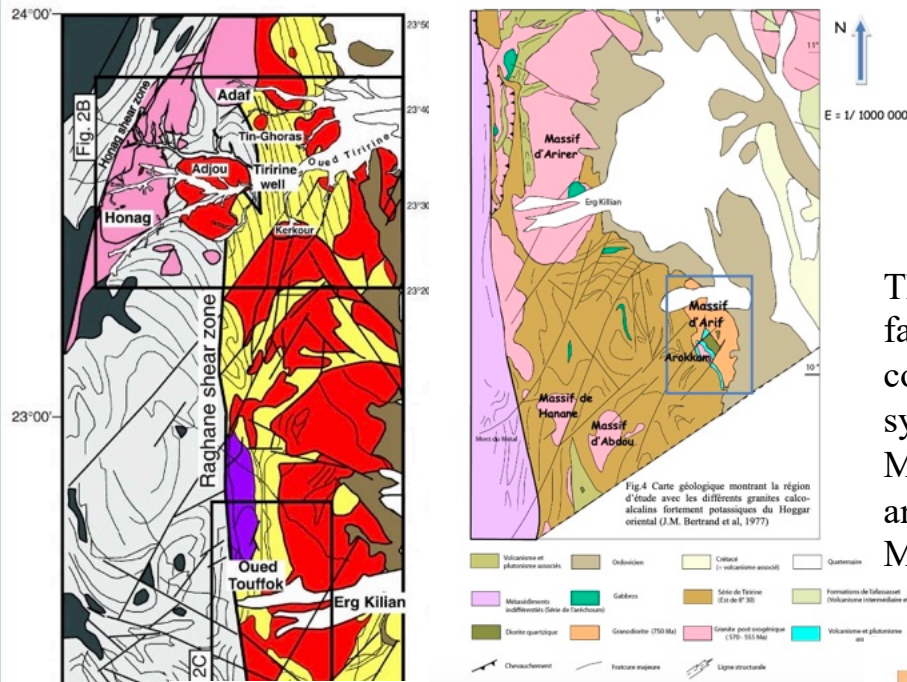


These results, the relative positions of the various types of granitoids and eclogites—have enabled us to locate the suture zone and propose a model of geodynamic evolution during the Pan-African orogeny, in which both the oceanic crust and the continental crust are subducted and then exhumed.

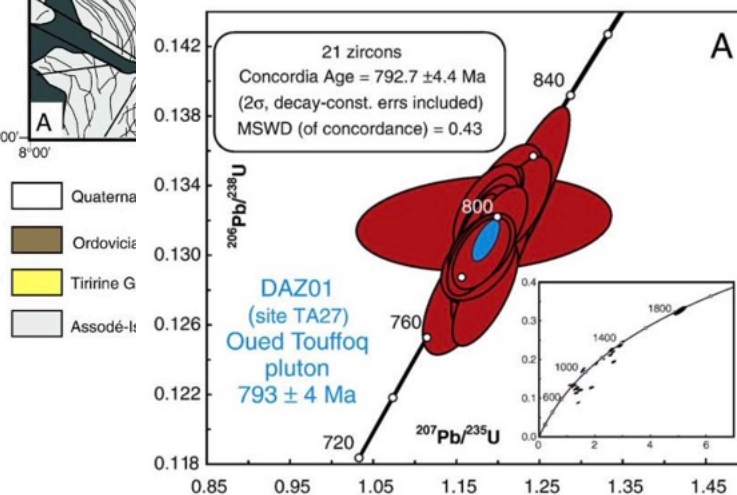
Araibia et al., 2022



Oriental Hoggar (Saharan Metacraton)



The easternmost suture zone corresponds to the $8^{\circ}30'$ fault. The eastern Hoggar, to the east of this fault, corresponds to the Eastern Saharan Metacraton. The syn-subduction granitoids, dated between 793 and 750 Ma, as well as the other oceanic-affinity formations, are considered to have been obducted onto this Metacraton.



Henry et al., 2009

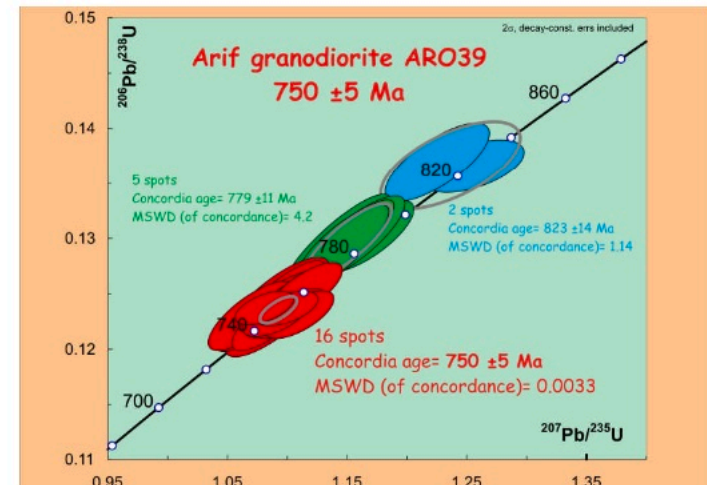


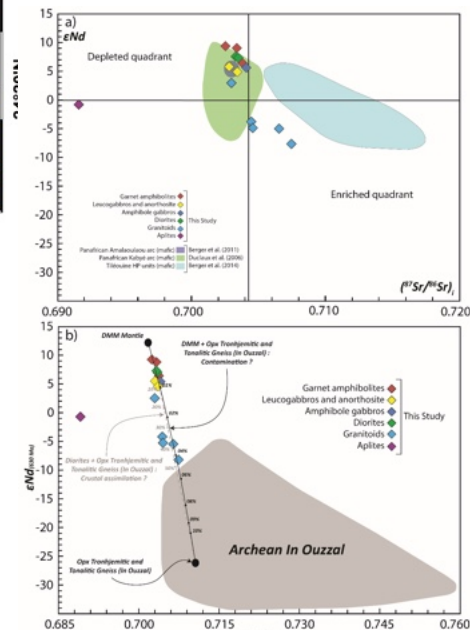
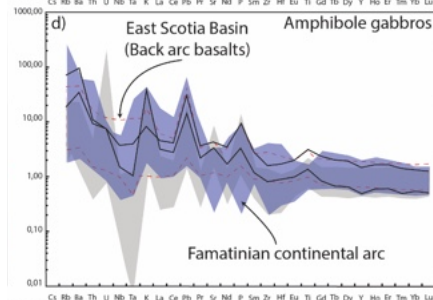
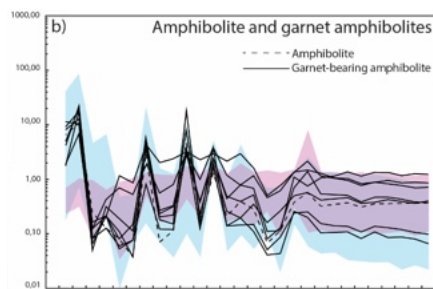
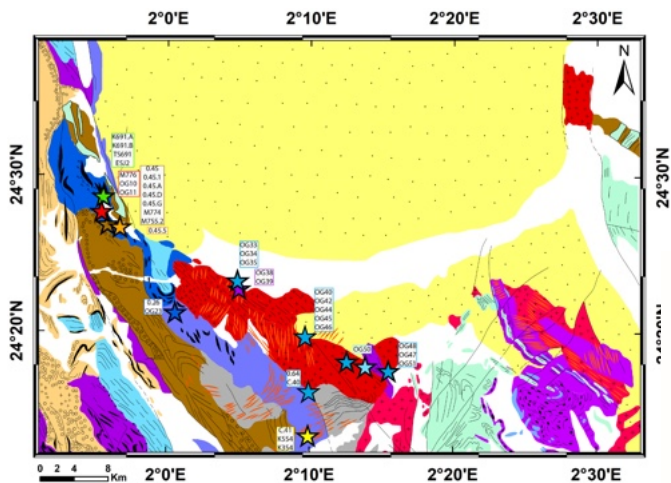
Fig.24 : Datation U/Pb sur une granodiorite du pluton

Abbassene, 2010

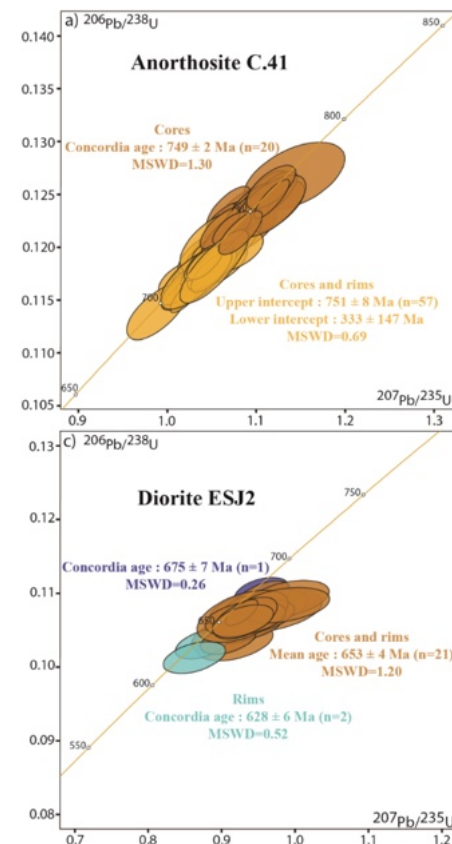
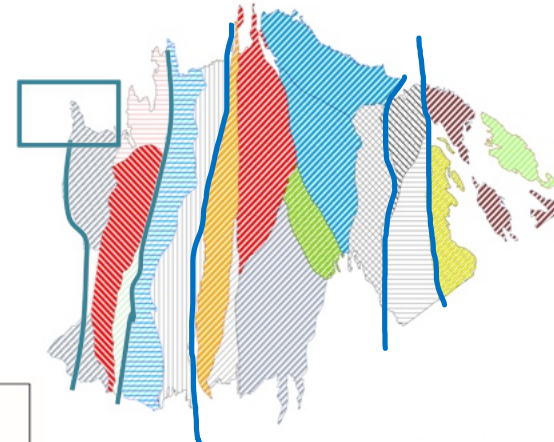
Neoproterozoic

Ougda arc

Bendimerad et al., (2025)

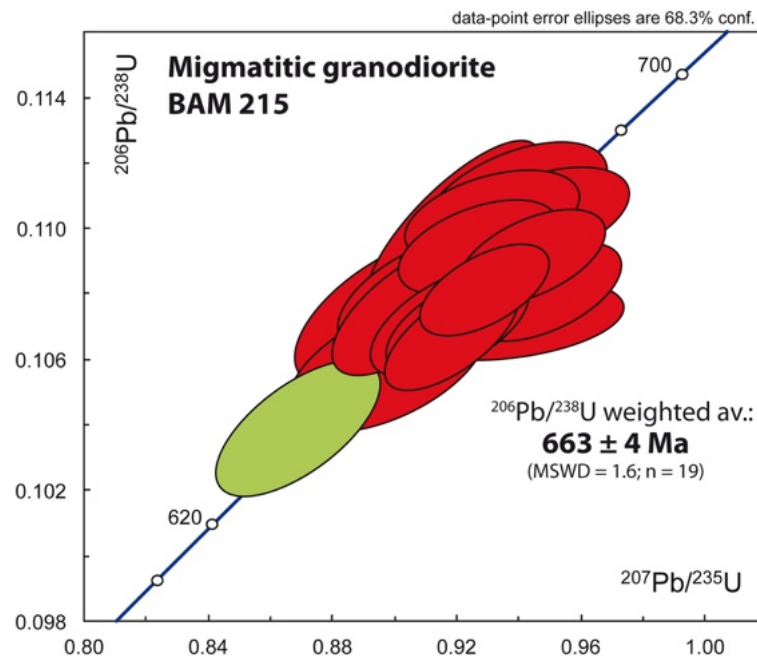
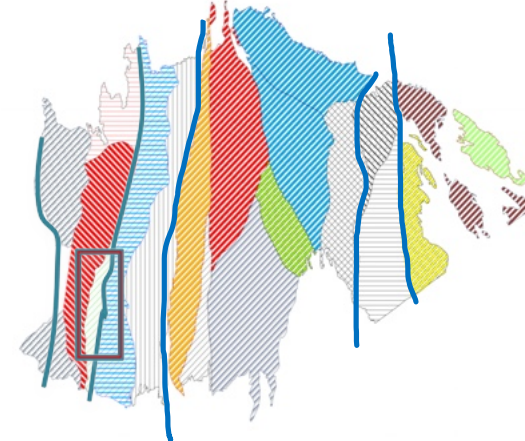
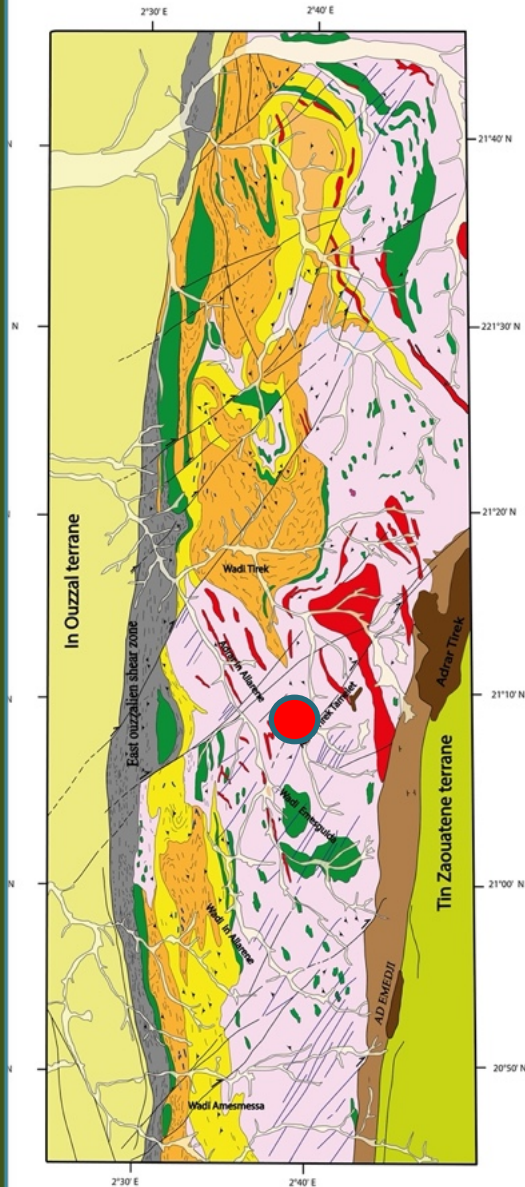


On the other hand, studies along the suture zone separating the Tuareg Shield from the West African craton show that syn-subduction magmatism – involving both island arcs and an active continental margin on the Touareg shield side – occurred between 750 Ma and 628 Ma.



Neoproterozoic

Tirek

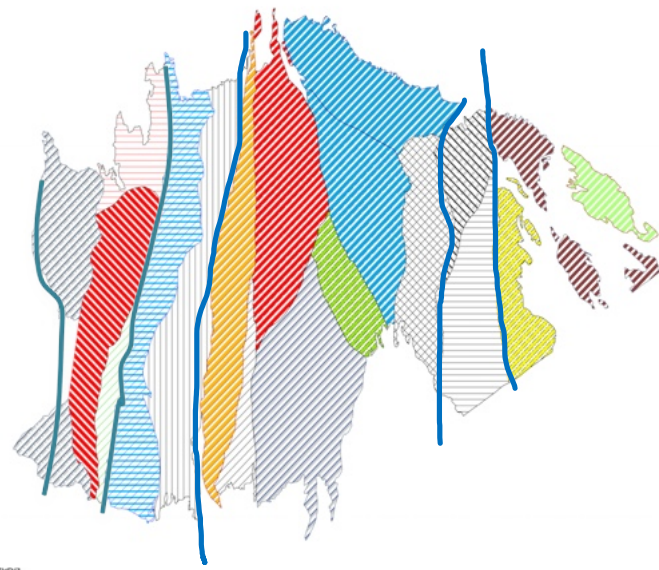
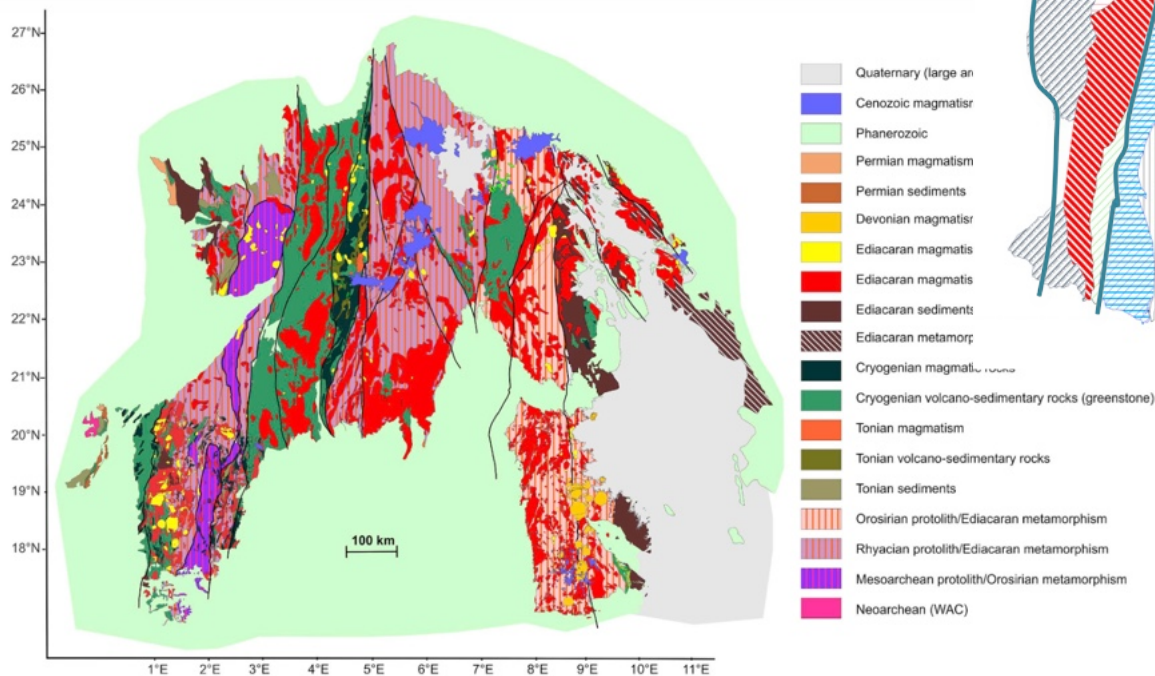


Bendaoud et al., 2025

The ages obtained for the syn-subduction magmatism in the subduction zone bordering the eastern parts of the In Ouzal and Tirek ranges range from 665 to 625 Ma.

We can therefore see that subduction, as well as continental collisions and arc accretion, occurred much earlier in the east than in the west.

Neoproterozoic



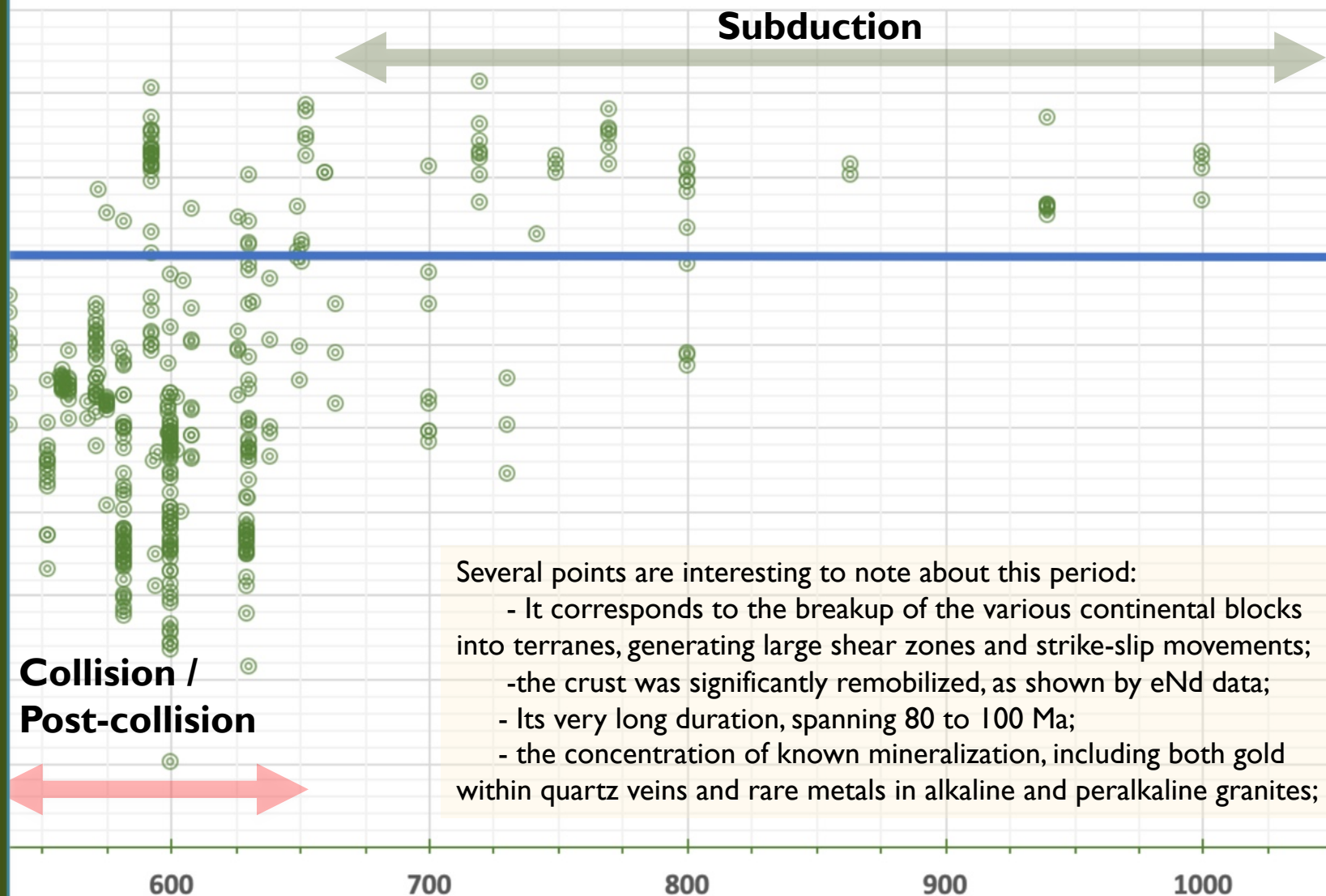
Pan-African syn-collisional and, most notably, post-collisional magmatism is the most widespread. It is shown here in red. These are primarily high-potassium calc-alkaline granitoids of hybrid mantle-old crust origin. The crustal contribution varies from 20 to 80 per cent. Less commonly, peraluminous granitoids are of entirely crustal origin. As with subduction-related magmatism, it occurs diachronously among the different crustal blocks. The collision at the western edge of Latea occurred approximately 650 Ma, while the collision at the suture zone with the West African craton took place 628 Ma.

This post-collisional magmatism peaked at 600 Ma and continued until 580 Ma in the central and western Hoggar, and between 600 and 550 Ma in the eastern Hoggar.

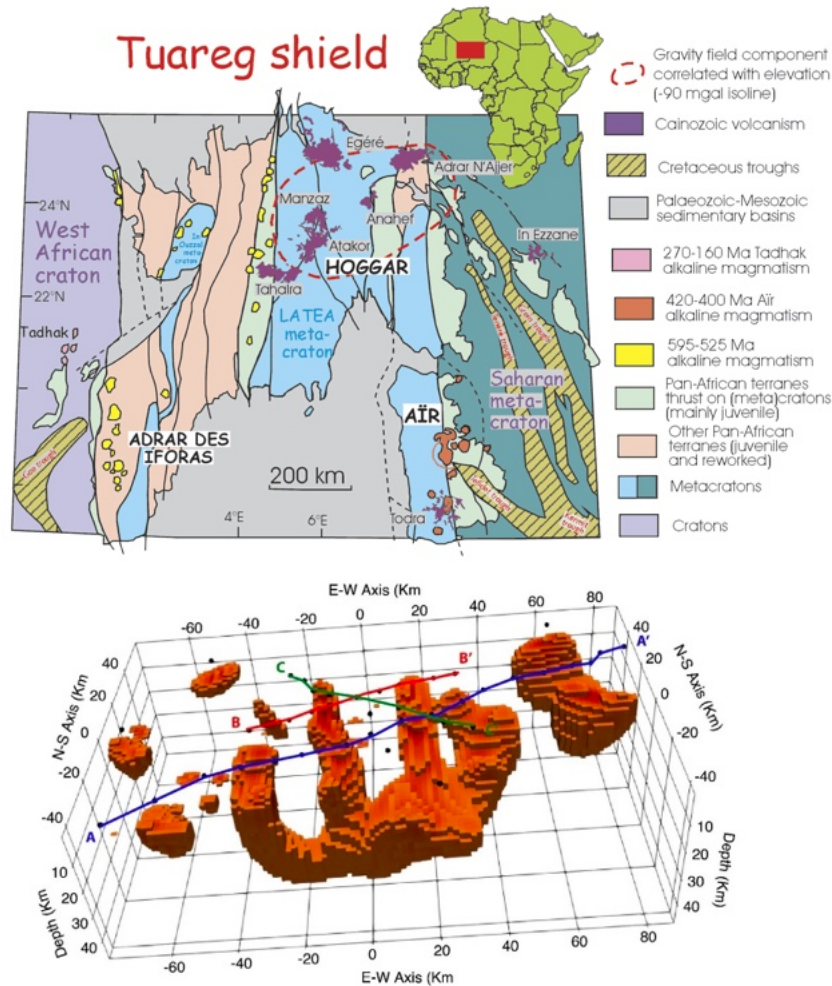
The shallow alkaline to peralkaline granites, shown here in yellow and many of which are rare-metals-rich, are dated to between 600 and 525 million years in the Hoggar.

Neoproterozoic

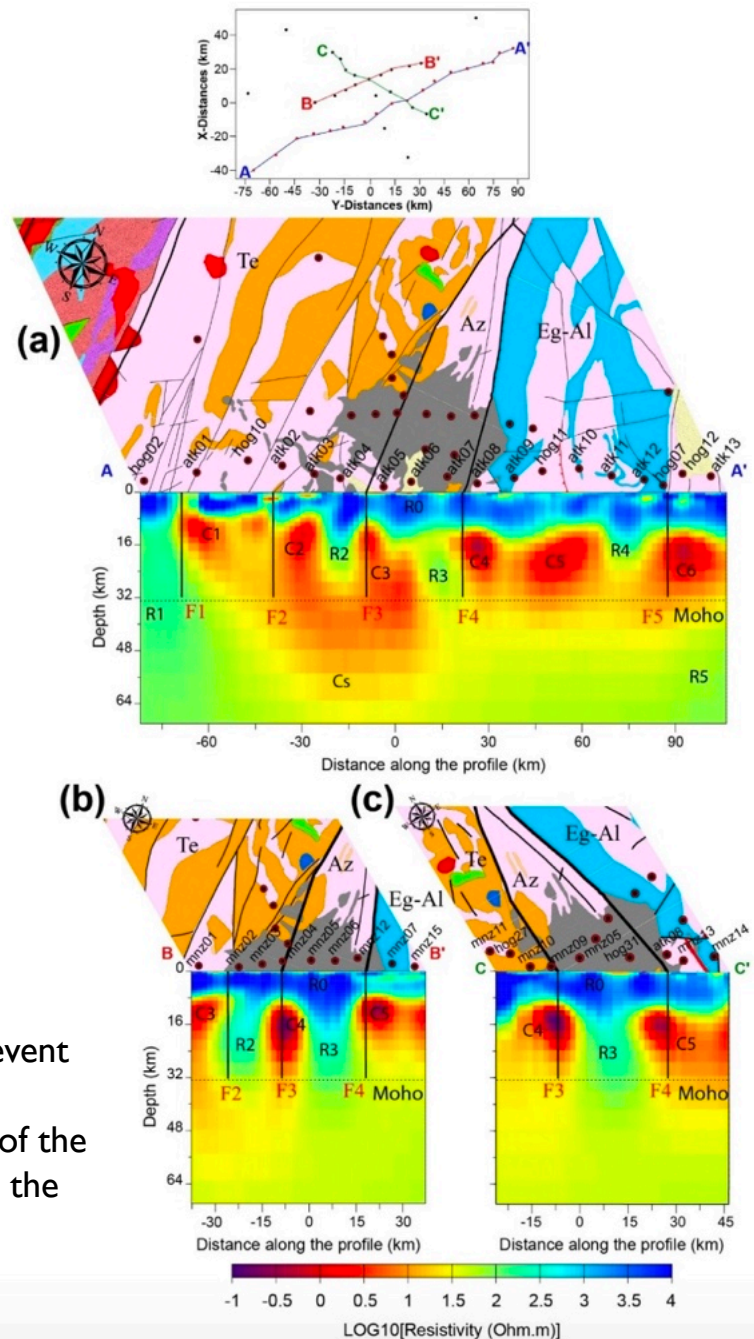
ϵNd vs Age Touareg Shield

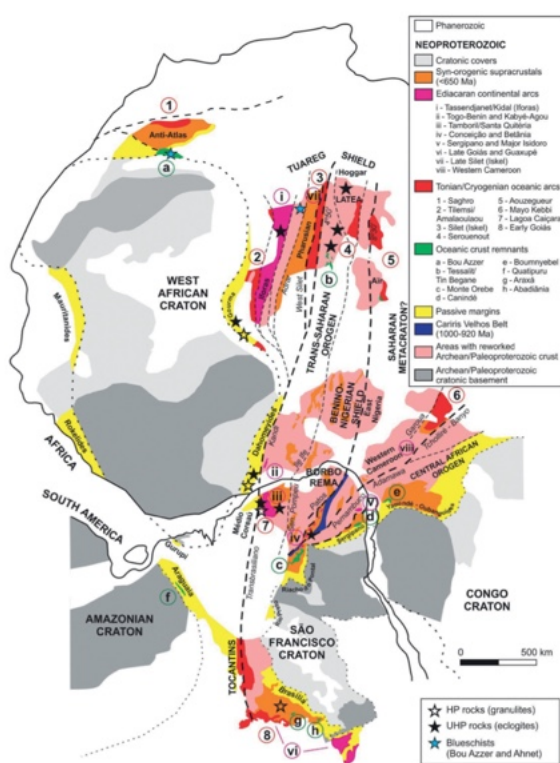


Cenozoic



Finally, a few words on Cenozoic intraplate volcanism. This event is responsible for the exhumation of the Hoggar, while its northern extension remained beneath the Paleozoic basins of the Saharan platform. We used magnetotelluric surveys to show the link between this event and the reactivation of ancient precambrian shear zones.



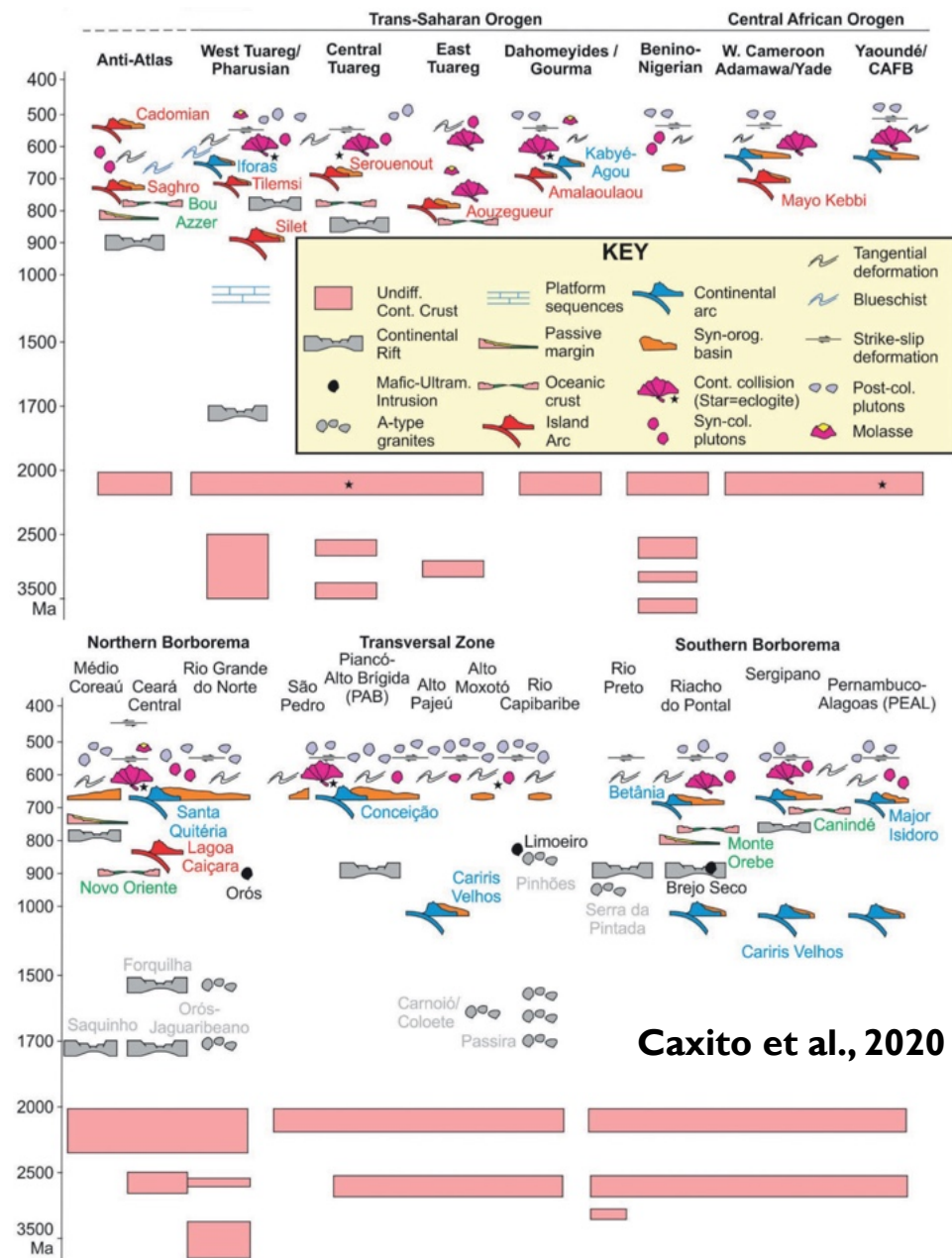


Thus, the Tuareg Shield is a complex geological region characterized by the superposition of distinct geological events.

In recent years, various studies have led to the discovery and characterization of key tectonic units such as ophiolites, eclogites, granitoids, as well as oceanic and continental magmatic arcs. This research has provided a better understanding of the structure of this massif and has led to the development of models for its geodynamic evolution.

It has also allowed us to establish initial correlations with other components of the Trans-Saharan and Central African belts, as well as with the Borborema Province in Brazil.

Current efforts are focused on exploring the mineral resources it contains. The potential is immense.



Caxito et al., 2020



Merci pour votre attention