IN-SITU ELECTRON MICROPROBE MONAZITE DATING OF THE COMPLEX RETROGRADE EVOLUTION OF UHT GRANULITES FROM ANDRIAMENA (MADAGASCAR) : APPARENT PETROGRAPHICAL PATH VS REAL PTt PATH.

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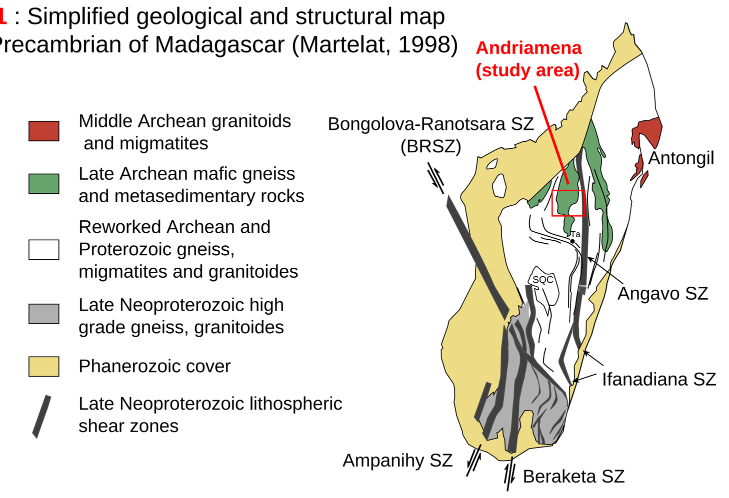
REGIONAL FRAMEWORK

Madagascar forms a part of the Mozambique belt, resulting of the continental collision between East and West Gondwana. Structures related to this event, like vertical lithospheric shear zones, are in agreement with an East-West horizontal shortening (Martelat et al., 2000) (figure 1).

The basement is generally divided in two parts. South of the BRSZ consists of Proterozoic rocks strongly reworked during Pan-African times (600-530 Ma). In contrast the North, consists mainly of late Archean rocks (granitoids, migmatite gneiss...) strongly reworked during a widespread igneous and metamorphic activity of middle Neoproterozoic age (~800-770 Ma) and later Neoproterozoic (~580-520 Ma). Our study area is located in this North part and more precisely in the **Andriamena mafic gneiss complex** (figure1).

figure 1 : Simplified geological and structural map of the Precambrian of Madagascar (Martelat, 1998)



The Andriamena complex is part of four North-South Archean mafic gneiss belt interpreted to form part of the same lithological unit. It corresponds to a synformal belt, structuraly overlying the granitic and migmatitic basement. The lithologies consist of amphibolite gneiss, migmatite, metasedimentary rocks intruded by mafic-ultramafic bodies at 787 ± 16 Ma (Guerrot et al., 1993).

The structural pattern (figure 2) results of the superposition of two distinctive phases of deformation.
- D1 deformation can be observed outside the high strain zone D2. Structures related to this event (figure 3) are compatible with **vertical shortening in a coaxial strain**.
- D2 event is characterized by the refolding of the S1 foliation into kilometric to centimetric folds (F2) with sub-horizontal axes. These folds with North-South axial plane are coherent with an **horizontal East-West shortening**. The shortening is associated with a strain partitioning between high strain zones (figure 2), characterized by upright F2 folds, and open folds areas. F2 folding affects also the stratoid granites dated at 630 Ma (Paquette et Nédélec, 1998) (figure 2).

This tectonic evolution is the same as the one proposed by Martelat et al. (2000) for the southern Madagascar during the late Neoproterozoic.

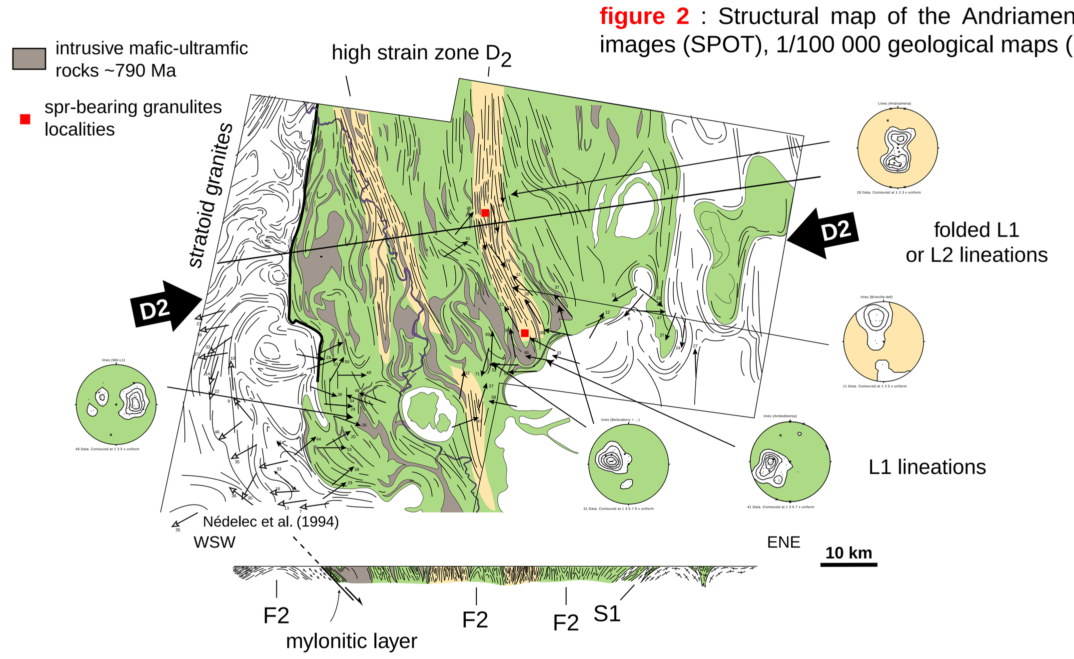


figure 2 : Structural map of the Andriamena area derived from the study of satellite images (SPOT), 1/100 000 geological maps (Besairie, 1969) and our field investigations.

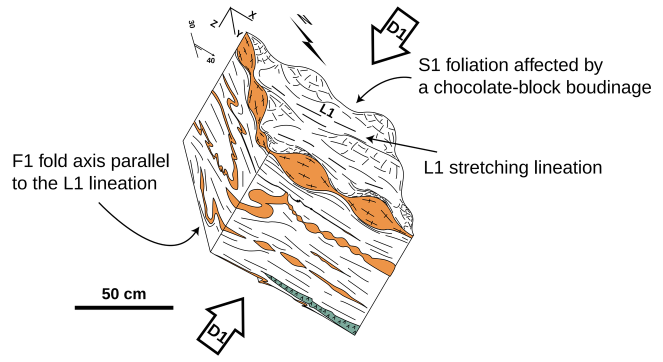
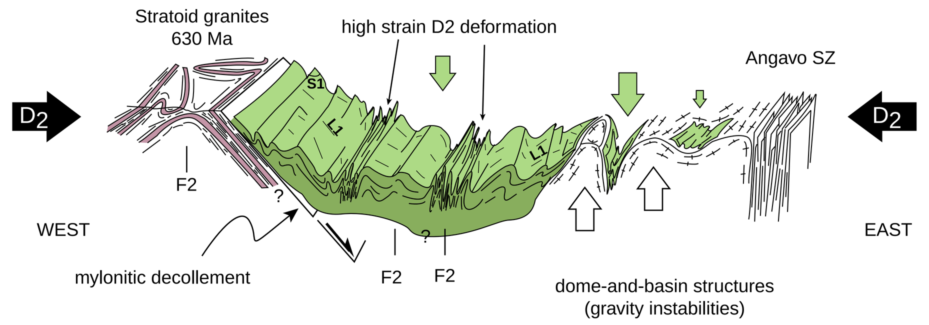


figure 3 : Example of D1 structures observed in preserved area of the D2 deformation

figure 4 : 3D schematic diagram showing the interference between boundary forces (horizontal regional shortening D2) and body forces (diapiric tectonic).



The Eastern part is characterized by dome-and-basin structures. It is probably the result of gravity instabilities between the dense mafic complex (forming the basin) and the overlyied low-density granitoid crust (domes) (figure 2). In the western part, the extensional mylonitic detachment between the two lithological units is not interpreted as a consequence of regional extension but as a decollement linked with the relative downward and upward moving of the two units.

CONCLUSION

We suggest that the Pan-African geometry and strain pattern reflect the interference between E-W regional horizontal shortening (boundary forces) and diapiric structuctures (body forces) (figure 4).

UHT METAMORPHISM

UHT metamorphism (>900°C, 7-13kbar) have been recognized in several terranes of the futur East Gondwana (India, Sri Lanka, Antartica). In Madagascar, it have been firstly identified by Nicollet et al. (1991). **High Mg-Al granulites** preserve numerous complex coronitic and symplectite textures providing plenty information to reconstruct an almost continuous **petrographical PT path**, near the peak temperature. PT evolution can be deduced from a FMAS petrogenetic grid (figure 5).

Sapphirine-bearing granulites occur in two localities (figure 2) and compose an infinitesimal volume with respect to the Andriamena complex. Due to the tropical weathering, they form several boulders, wich certainly come from a very near locality.

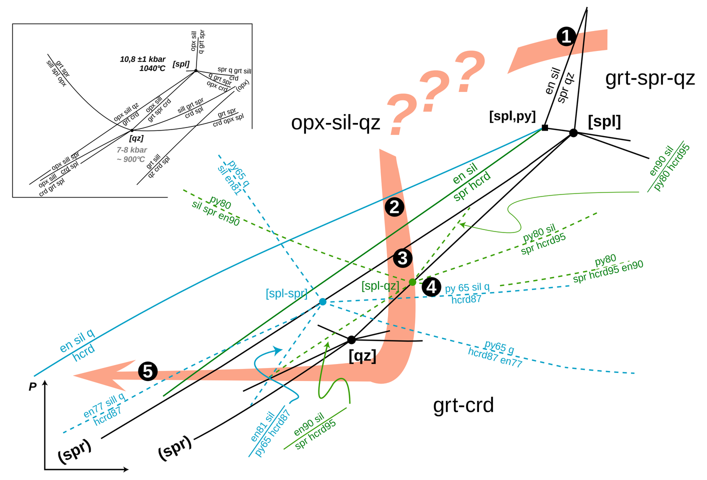
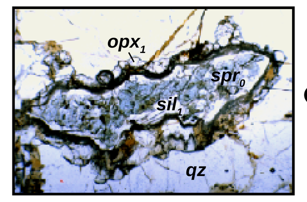


figure 5 : petrographical PT path deduced from the Al-Mg granulites in a FMAS system (black lines = univariante reactions and dashed lines = isopleths for divariante reactions)

- UHT metamorphism

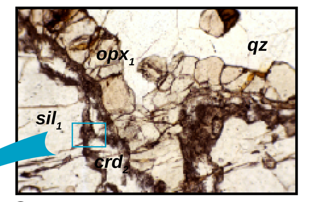


Earliest assemblage (spr_0-grt_0-qz) implies peak PT conditions of ~11kbar, >1050°C

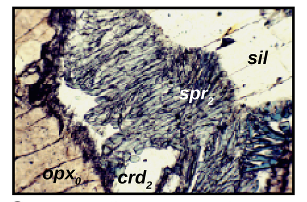
❶ spr_0 + qz = opx_1 + sil_1

→ cooling above the P [spl]

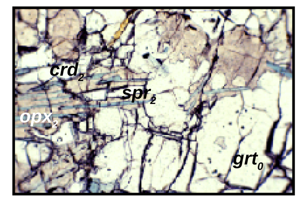
- near Isothermal Decompression (ITD)



❷ opx_1 + sil_1 + qz = crd_2



❸ opx_1 + sil_1 = spr_2 + crd_2

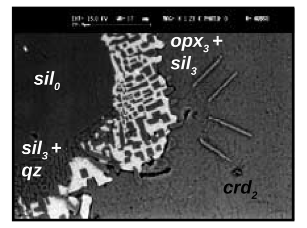


❹ grt_0 = opx_2 + spr_2 + crd_2

A sequence of symplectite assemblages developed at the expense of grt, opx and sil indicate a near-ITD of the order of 3-4 kbar, at about 900-1000°C : [spl]>T>[qz]

others ITD observed reactions :
- opx + sil = grt + spr + crd
- grt + sil = spr + crd
- grt + qz = opx + crd
- grt = opx + spl + crd

- Isobaric Cooling (IBC)



❺ crd_2 = opx_3 + sil_3 + qz

backscattered electron image

late development of opx_3-sil_3-qz at the expense of crd_2 suggesting a cooling into the opx-sil-qz stability field probably through an IBC at ~7 kbar.

This very fine symplectite is visible on the photo 1-2-3.

Near, the Al-Mg granulites outcrop, occur **Metapelitic Migmatites** in wich quartzo-feldspathic layers alternate with restitic layers characterized by various assemblages (grt bearing and qz-absent grt-spl bearing metapelites).

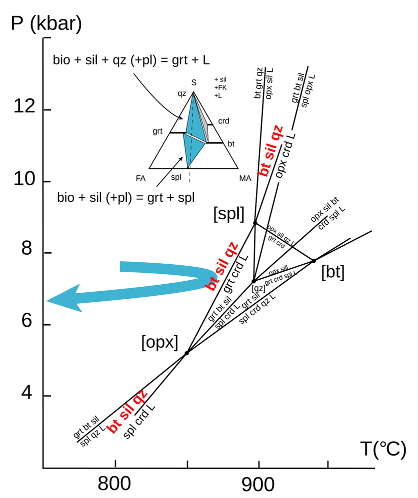


figure 6 : Partial grid for univariant KFMASH reactions for fluid-absent metapelites, and the deduced PT path from the metapelitic migmatite.

PT path deduced from the metapelitic migmatites records a heating-cooling path at about 7 kbar without any significant change in pressure (figure 6).

Initial prograde melting was achieved by **biotite dehydration-melting** reactions at temperature below 850 °C.

The cooling part of this PT evolution is characterized by the late development of sil (±grt) coronas around spl and bio-sil patches interpreted as the result of **back melting reactions** between the spl and the silica-undersatured melt.

CONCLUSION

Petrographical investigation of both samples clearly shows two different PT evolutions. The UHT and near isothermal decompression characteristic of the Al-Mg granulite are not recognized in the migmatite, whereas the isobaric cooling at about 7 kbar is recognized in the both. Nevertheless, without geochronological constraints, it is very difficult to interpret these PT paths.

ELECTRON MICROPROBE DATING OF MONAZITE

U-Th-Pb electron microprobe dating have been use to constrain the metamorphic evolution from the Al-Mg granulites and migmatites. This in-situ technique have the advantage to combine textural observations and chemical composition to **distinguish several episodes of monazite growth or reset during thermal events**.

This method is useful in polymetamorphic cases, like the North-Central Madagascar, where at least 3 magmatic and/or metamorphic events have been recognized (Guerrot et al., 1993; Nicollet et al., 1997; Tucker et al., 1999 and Kröner et al., 2000).

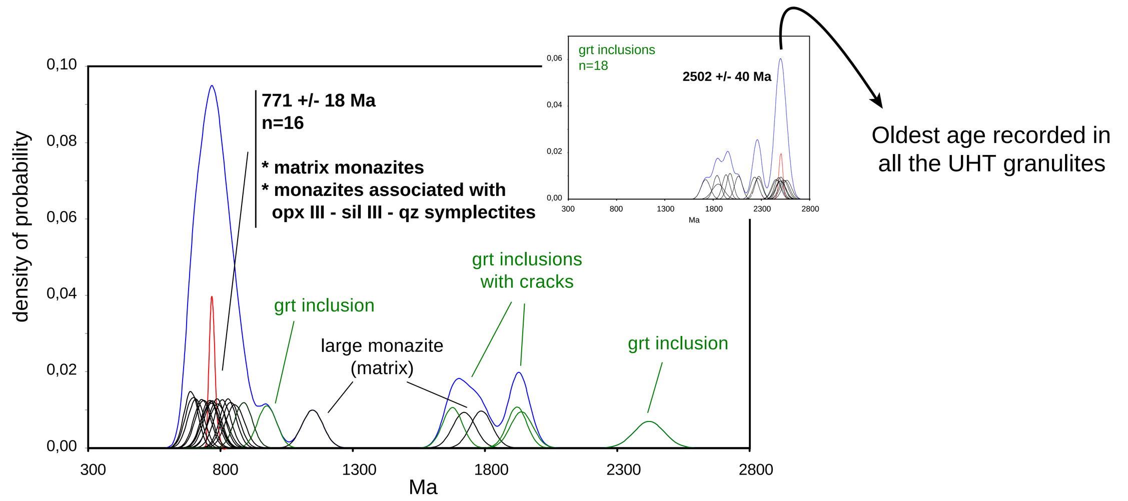


figure 7 : Weighted-histogram representation of all the electron-microprobe monazite ages derived from one Al-Mg granulite. Inset: data from monazites include in garnets from another granulite.

Three populations were identified in thin-sections :

- monazites included in garnet yield the oldest age with systematically a maximum at 2.5 Ga (figure 7). We consider this late Archean age, as proposed by Nicollet et al. (1997), to reflect the **timing of the UHT metamorphism**. The conservation of this old event is related to the shielding effect of garnet for the U-Th-Pb system (Montel et al., 1996).

- matrix grains, 20-70 mm in size, with irregular morphologies, yield ages from about 1.8 Ga to 710 Ma with a main age population at 770 Ma (figure 7). We suggest that these monazites grew during the 2.5 Ga UHT event and they were subsquently totally (or no) **reset at 770 Ma**.

- monazites <20 mm in size, in close association with the opx_3-sil_3-qz symplectites (figure 9) are characterized by a single age population at about 770 Ma. Textural relationships and chemical composition (figure 8) suggest a **new episode of monazite growth at 770 Ma**, contemporaneous with the late development of the opx_3-sil_3-qz assemblage (ie the IBC at ~7kbar).

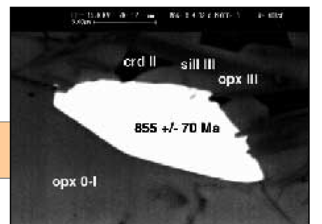
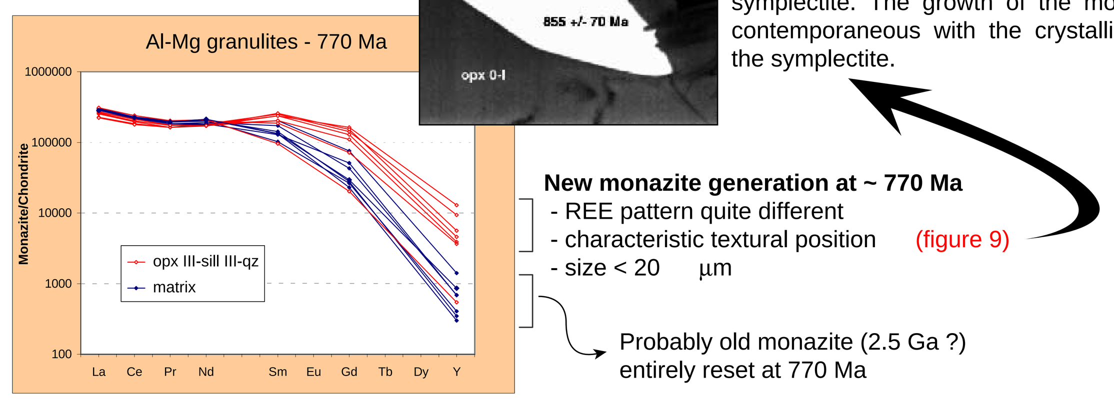


figure 9 : backscattered electron image showing the textural relationships between this monazite population and the opx_3-sil_3-qz symplectite. The growth of the monazite is contemporaneous with the crystallisation of the symplectite.



New monazite generation at ~ 770 Ma
- REE pattern quite different
- characteristic textural position (figure 9)
- size < 20 µm

Probably old monazite (2.5 Ga ?) entirely reset at 770 Ma

figure 8 : Chondrite-normalised REE distribution of monazite at 770 Ma located in two clearly different textural position : in the matrix and associated with the late opx_3-sil_3-qz.

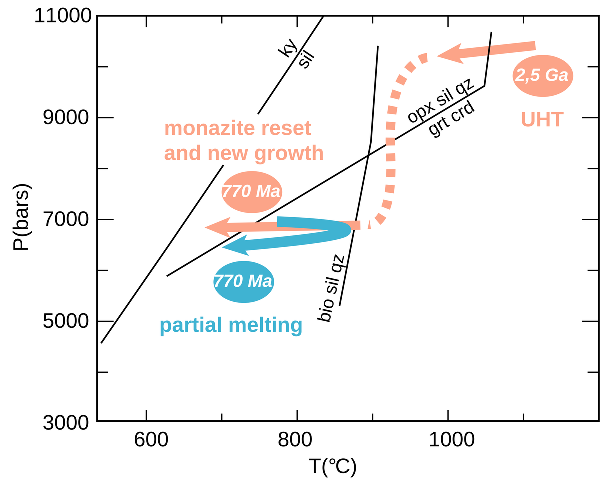


figure 10 : Semi-quantitative partial grid of KFMASH and FMASH univariante reactions, with the PTt path of Al-Mg granulites (blue) and migmatites (orange). Continuous section of the P-T path are those chronologically constraint and the dashed ones are not.

CONCLUSION

It is obvious that the petrographical PT path deduced from the Al-Mg granulites cannot be considered as a continuous path in a single metamorphic event. At least two distinct geochronological events occured (figure 10):

- UHT metamorphism preserved in Al-Mg granulites at 2.5 Ga

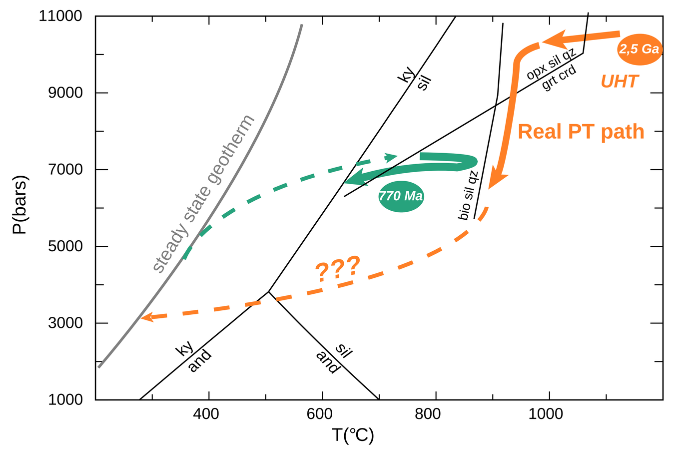
- Partial melting and the IBC at ~7 kbar at 770 Ma

CONCLUSION

APPARENT PETROGRAPHICAL PATH VS REAL PT PATH

What is the signification and the age of the petrographical ITD recorded by the Al-Mg granulites ?

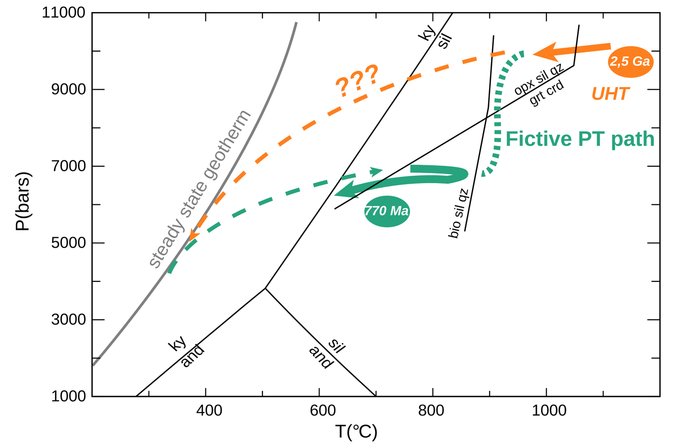
1) Decompression occured during the UHT event at 2.5 Ga.



Isothermal decompression textures define a **real PT path** at 2.5 Ga.
After UHT-ITD stages, granulites cooled to normal thermal conditions (near the steady state geotherm) at 2.5 Ga. The conservation of the UHT assemblages is related to the refractory behaviour of Al-Mg granulites.

In a second time, at 770 Ma, a thermal event generate partial melting, destabilisation of the crd_2 into opx_3-sil_3-qz symplectite, and an isotopic resetting associated with a new monazite growth episode.

2) Development of decompression textures at 770 Ma.



The UHT metamorphism and the cooling (near isobaric?) to the steady state geotherm were achieved in a single event at 2.5 Ga.

The thermal perturbation at 770 Ma brought back the sample to high temperature (~850°C, 7kbar). The primary UHT assemblages were reequilibrated in this new conditions by a **fictive PT path** (isothermal decompression of about 3-4 kbar) joining the 2.5 Ga "high pressure" stability field and the lower pressure stability field associated with the 770 Ma event.
In the same time, partial melting, isotopic resetting and new monazite growth occured.

A POLYMETAMORPHIC HISTORY FOR THE ANDRIAMENA COMPLEX: IMPLICATIONS FOR THE PRE-GONDWANA EVOLUTION.

The earlier stage at 2.5 Ga is characterized by UHT metamorphism (> 1050°C , ~11 kbar), associated with a late Archean granitoid magmatism. The Southern part of India (Nilgiri, Palni Hill Ranges) is composed of granulite terranes subjected to UHT metamorphism at 2.5 Ga. It suggests that the already proposed connection between South India and North-Central Madagascar is a strong probability.

The 770 Ma metamorphic event (partial melting at 850°C, ~7 kbar) could be the consequence of a thermal perturbation caused by the emplacement of basic intrusions at this time. Handke et al. (1999) proposed a continental arc setting for the Neoproterozoic magmatism, in relation with the subduction of the Mozambique ocean under the North-central part of Madagascar (breakup of Rodinia).

Archean basement was structurally reworked during the late Neoproterozoic. The finite geometry reflects an E-W shortening related with the cratonic convergence between East and West Gondwana and contemporaneous with a granulitic metamorphism widely recognized in the South of Madagascar (Martelat et al, 1997).

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