

## THE AGES OF CRYSTALLIZATION AND METAMORPHISM OF THE PASSIRA ANORTHOSITE COMPLEX-BORBOREMA PROVINCE-NORTHEASTERN BRAZIL

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### THE PASSIRA ANORTHOSITE COMPLEX

The Passira Anorthositic Complex (PAC) is located in Pernambuco State, Northeastern Brazil and crops out around the neighborhood of Passira City. It is situated in the Borborema Province, north of the Pernambuco Lineament and it is nested in Rio Capibaribe terrain. The Paudalho and Limoeiro shear zones are the tectonic limits of this Complex and they are both part of the Pernambuco Lineament (Fig.1).

The local lithostratigraphy is divided into the following units, from top to base: Undifferentiated Granitoids represented by diorites related to the Pernambuco Lineament, Peralkaline Orthogneiss, the metavolcano-sedimentary rocks of the Vertentes Complex, Anorogenic Granitic Orthogneiss associated to the Passira Complex; and high grade metamorphic rocks of the Transamazonian Gneissic-Migmatitic Complex.

The Passira Complex is a batholithic body, which consists of metanorthosites, subordinate metagabbros, metagabbro-norites, and lenses of Fe-Ti oxides-bearing ultramafic rocks, considered as a massif-type anorthosite complex. A dyke complex, made up of apatite-rich metaferrodiorite, encloses the Passira Anorthositic Complex. The PAC is deformed and recrystallized by at least two tectonic-metamorphic events, which have produced two distinct structural elements. The first is a penetrative sub-horizontal foliation denoted by amphibole-rich bands and the second is a sub-vertical to sub-horizontal foliation, which corresponds to the steeply dipping foliation on rocks, mainly near the shear zones. Symplectitic garnet was produced by the tectonic metamorphic event.

This paper presents K-Ar, Sm-Nd and U-Pb geochronology data that together with the mineral chemistry of the metamorphic paragenesis will be used to assess the crystallization and metamorphic age of the complex.

### PETROGRAPHIC ASPECTS OF THE PASSIRA ANORTHOSITE COMPLEX

Qualitative studies of mineral relationships were performed in order to determine the peak of the metamorphism. The mineral assemblage in meta-diorites, metagabbros and metanorthosites (metabasites) were

compared with some other examples described in literature (Winkler, 1977; Yardley, 1989; Ashwal, 1993, Cotkin, 1997, Emslie, 1985).

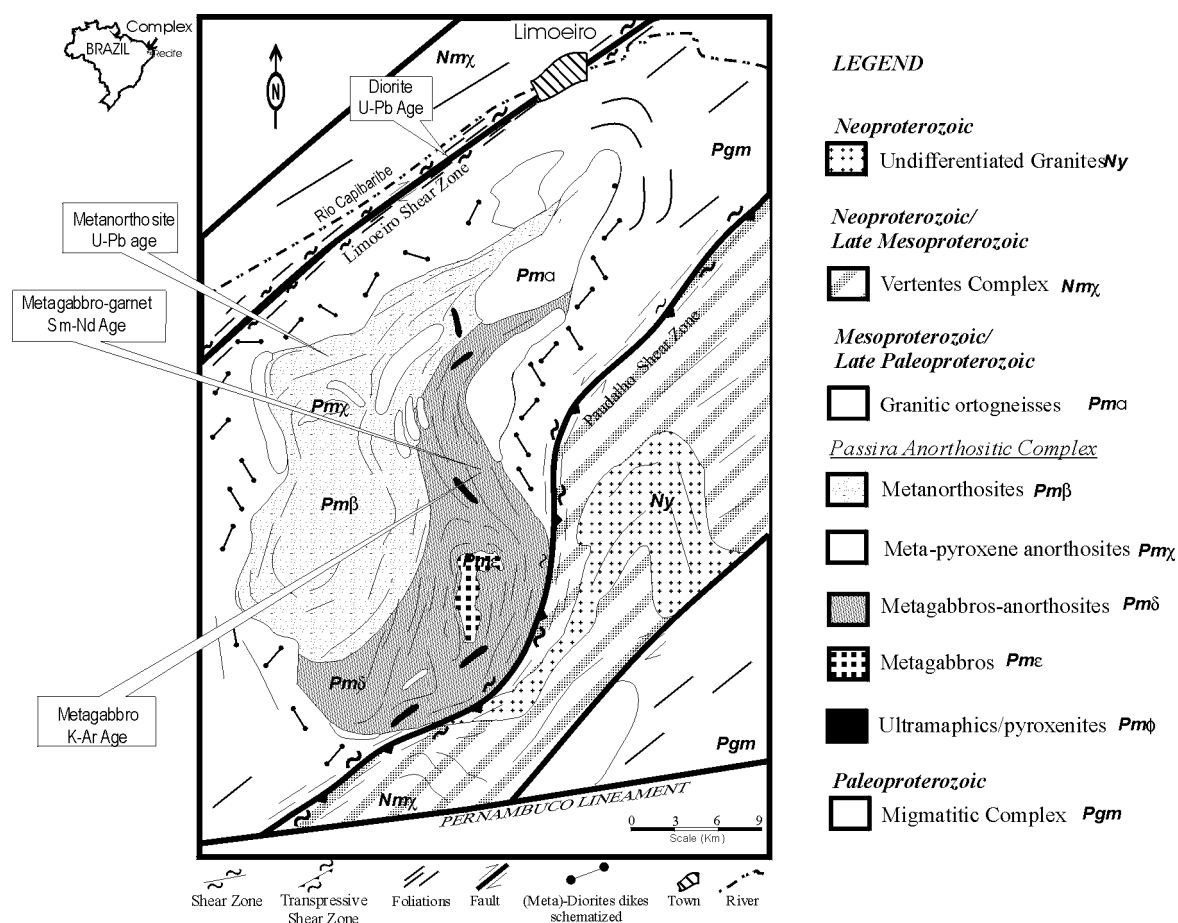
The metabasitic rocks of the PAC have the following parageneses:

- (1) Primary Association: Plagioclase (andesine, labradorite) + pyroxene (Fe-enstatite metanorthosites; augite metagabbros) ± amphibolites (Metadiorites) + ilmenite. This association may represent the original mineral assemblage that could be represented by plagioclase, pyroxene megacrystals. This paragenesis shares many features with undeformed anorthosites/gabbros/ diorites described in literature (Ashwal, 1993).
- (2) Main metamorphic assemblages: Pyroxene megacrystals (augite recrystallized) + brown greenish amphibole (Mg-hornblende/tschermakite) ± garnet ± plagioclase ± rutile. This assemblage is ascribed the main metamorphism in area and it is mostly observed in garnet-bearing metagabbros, which also contain recrystallized augite, amphibole (tremolite) that replace Fe-enstatite in metanorthosites (Photo 1).
- (3) Retrometamorphic-related assemblage: Amphibole (reoriented) + biotite (annite-flogopite) + epidote + chlorite ± garnet (meta-stable). This mineral assemblage was formed during principal metamorphism (Photo 2).

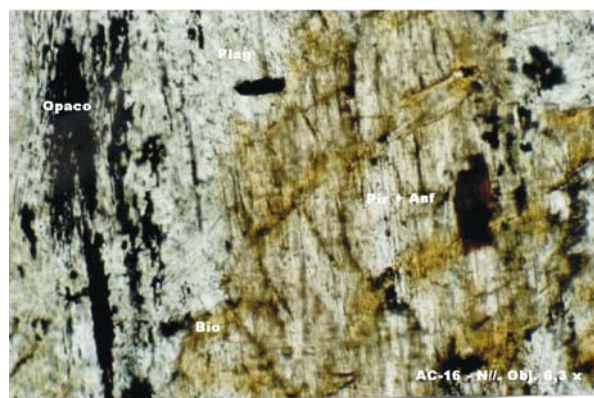
Pyroxene, amphibole and garnet were formed during the peak of metamorphism and they represent a transitional stage between the amphibolite and granulite facies in the garnet zone sequence. Garnet formation in metabasitic rocks in Passira Anorthosite Complex is here explained via two metamorphic reactions:



Evidence for reaction (I) was found in the rare examples of high pressure (>6Kb) granulite facies metagabbros. Reaction (II) was observed in the majority of the metagabbros, and in the metanorthosites of the PAC. Temperatures would have been around 700° C (Yardley, 1989).



**Figure 1.** Schematic geological map of the PAC showing the location of the main shear zones, and the location of the analyzed samples.



**Photo 1.** Amphibole (tremolite) replacing pyroxene in metanorthosite. Opaco-opaque minerals. Plag-plagioclase. Pir-pyroxene. Anf-Amphibole. Bio-Biotite.



**Photo 2.** Coronitic-textured meta gabbros exhibiting amphibole, opaque and plagioclase around garnet.

The retrometamorphic effects are represented by: hydrous secondary phases (biotite, epidote, chlorite), garnet and quartz, which might be ascribed to metamorphic destabilization and replacing processes of original paragenesis. These processes are observed in sheared metadiorites, in garnet bearing metagabbros and metanorthosites mostly present in the Paudalho and Limoeiro shear zones.

Reaction coronas around garnet (Photo 2) are diagnostic for the retro metamorphic episodes.

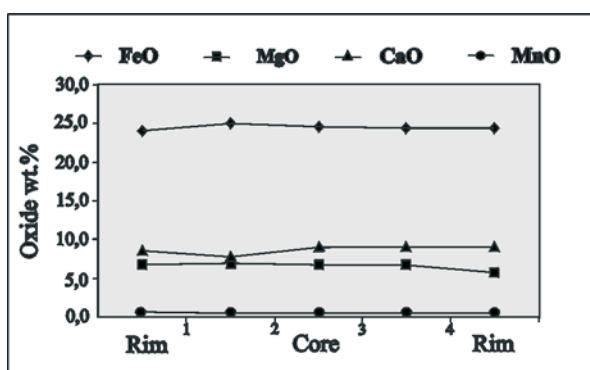
These coronas are formed in greenschist facies (Messiga et al., 1995) and represent symplectitic intergrowth between amphibole and plagioclase around garnet. This association is conformable to stretching lineation and it is mainly observed near the shear zones.

## GEO THERMOMETRY

The application of quantitative geobarometry to the metabasites is difficult since specific calibrations for anorthosites are very scarce. We therefore focus on geothermometry to understand the metamorphic evolution of the PAC, using geobarometers only for the minor components of the intrusion.

P-T conditions were estimated by the semi-quantitative calibrations of TiO<sub>2</sub> and Al<sub>2</sub>O<sub>3</sub> contents in amphibole presented by Ernst & Liu (1998). These temperatures around 675°C and pressures of about 13.5 Kb were obtained for metagabbros.

The amphibole-plagioclase geothermometry (Holland & Blundy, 1990) yielded temperatures of about 750°-770°C for metagabbros, 693°-735°C for metanorthosites and 638°-699°C for metadiorites, for an estimate interval pressure of 10-15Kb. A temperature range of 634°-700°C for metagabbros of the PAC has been obtained by the garnet-clinopyroxene geothermometer (Ellis & Green, 1979). A major oxides profile as performed in a single grain garnet by electron microprobe (Fig. 2), which depicts uniform outlines ascribed to temperature higher than 700°C.



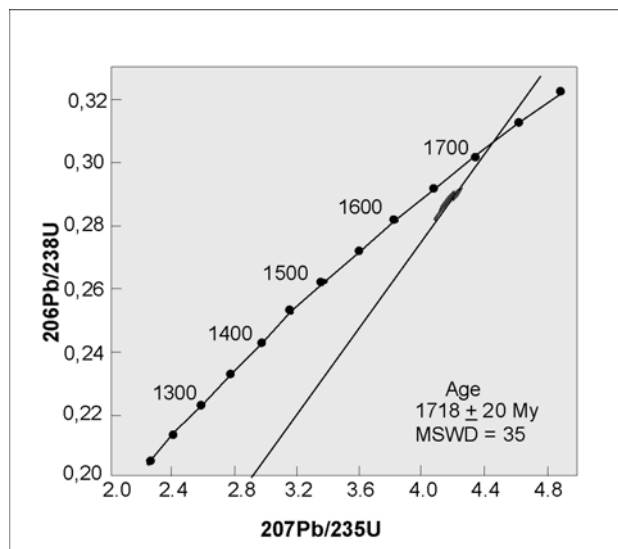
**Figure 2.** Electron microprobe major oxides profile in a single grain garnet from metagabbro.

Estimates of the crystallization temperatures of anorthosite complexes are in the range from 1140° to 1185°C (Markl et al., 1998). The calculated temperatures presented here are interpreted to represent the conditions of granulite facies metamorphism.

## GEOCHRONOLOGY

U-Pb dating of four hand-picked least magnetic multi-crystal zircon fractions separated from pegmatitic anorthosite yielded nearly-concordant points defining an age of  $1,718 \pm 20$  Ma, which is interpreted as the crystallization age of the anorthosite complex (Fig. 3).

The age of metamorphism was investigated via K-Ar system and by preliminary Sm-Nd mineral/whole rock isochron. The results obtained for garnet-amphibole metagabbros has yielded ages that vary from 1,100 to 1,000 Ma, which are correspondent to the Cariris Velhos event (Table 1).



**Figure 3.** Age of anorthosite using U-Pb method on zircon.

These data are well in accordance with a 1,100 Ma  $T_{DM}$  model age obtained by Accioly (2001) for a Neoproterozoic peralkaline orthogneiss body located 8km eastward of the anorthositic complex. This apparently confirms the effects of the Cariris Velhos event in the area, despite that it should be expected amphibole production via metamorphic recrystallization would provoke possible losses of radiogenic Ar. This would eventually reset the isotopic system, which might have produced younger ages for those amphiboles. In metaigneous rocks, K-Ar ages normally reflect that isotopic resetting which commonly obliterate the crystallization ages during medium to high metamorphism (Faure, 1986).

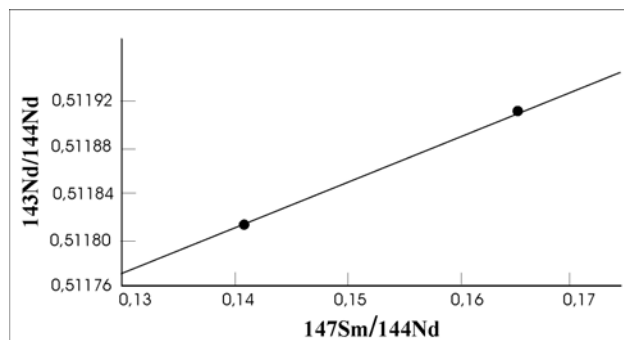
**Table 1.** Representative mineral analyses from amphibole from metagabbros.

	K (%)	Error	Ar <sup>40</sup> (rad)	Ar <sup>40</sup> (atmos)	T <sub>MAX</sub> (Ma)	Error (Ma)
AC-23	0.38	0.017	19.7	15.50	1,000	56.7
AC-28	0.33	0.039	21.6	16.78	1,100	78.9

A Sm-Nd internal isochron using garnet and whole rock for metagabbros indicates a Brasiliano age ( $612 \pm 50$  Ma), interpreted as correspondent to the age of the metamorphic peak in area (Fig. 4).

Sm-Nd and K-Ar results are conflicting and present no firm conclusions on the age(s) of the metamorphic event(s) can be made.

It should be expected that the metamorphic peak would be registered by the amphibole K-Ar method, but nevertheless the age are rather related to the Brasiliano event. The calculated metamorphic temperatures show that some resetting of the K-Ar system in amphibole must be expected, and the K-Ar ages obtained are probable mixed.



**Figure 4.** Garnet whole-rock isochron for garnet-metagabbros. Age =  $612 \pm 150$  Ma,  $Nd^{143}/Nd^{144} = 0.51125 + 0.000014$ .

## CONCLUSIONS

The geochronological data presented here point to the possible effect of the main metamorphic event and its peak in the mineral and whole-rock Sm-Nd systems. This metamorphism could be associated to the Brasiliano Cycle. Accioly (2001) has produced 597 Ma U-Pb age by the multicrystal zircon method of sheared diorites which she assumes that is due to later tectonic thermal retro-metamorphism that produced these shear zones such as the Paudalho and Limoeiro shear zones.

The amphibole + clinopyroxene + garnet + labradorite assemblage generated by the metamorphic peak, with a later re-equilibrium given by the amphibole + biotite + epidote + carbonate association could be related to the following episodes:

- Crystallization of the original gabbroic assemblage: (plagioclase  $\pm$  clino or orto pyroxene) – U-Pb zircon:  $1,718 \pm 20$  Ma.
- Paragenesis related to the metamorphic peak: garnet + clino-pyroxene whole-rock (opx + plg  $\rightarrow$  cpx + gar + qtz) Sm-Nd - garnet isochron -  $612 \pm 150$  Ma.
- Destabilization of the high or P/T mineral phases and formation of stable plagioclase and amphibole (pirox  $\rightarrow$  anf + plag) possibly around 597 Ma.

Thus, the Passira Anorthositic Complex has crystallized in Upper Paleoproterozoic to Mesoproterozoic and it resembles some analogous features with Proterozoic anorthosites massif-type complexes described in literature. It is also suggested here the possible existence of a post-tectonic thermal event that latter affected the complex. This event is interpreted through the isotopic date of peralkaline orthogneiss ( $T_{DM}$  1,100Ma). The Sm-Nd age of  $612 \pm 150$  Ma suggest that the main metamorphic event was occurred during the Brasiliano event and the retro-metamorphic assemblage is associated to the Paudalho and Limoeiro Shear zones, which represent a later Brasiliano related thermal event.

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