PB-PB ZIRCON AGES OF THE PORTO NACIONAL HIGH-GRADE METAMORPHIC TERRAIN, NORTHERN PORTION OF THE GOIÁS MASSIF, CENTRAL BRAZIL

PAULO SERGIO DE SOUSA GORAYEB1, CANDIDO AUGUSTO VELOSO MOURA1 AND GISELE RIBEIRO DE BARROS2

ABSTRACT Single zircon Pb-evaporation ages were determined for a mafic granulite, two enderbites and a kinzigite of the Porto Nacio-
nal High-Grade Metamorphic Terrain (PNHGT) in the Goiás Massif. Zircons from mafic granulites and one of the enderbites yielded average
207Pb/206Pb ages of 2125 ± 3 Ma and 2153 ± 1 Ma, respectively, being interpreted as minimum ages of the igneous protoliths. The other
endebite, whose zircons present round terminations, yielded an average 207Pb/206Pb age of 2097 ± 2 Ma. Zircons from the kinzigite, displaying
cores and rims overgrowth, presented 207Pb/206Pb ages ranging between 2072 and 2115 Ma. However, a very homogeneous zircon crystal
without overgrowth yielded an age of 2100 ± 2 Ma, with a distinctive low Th/U value (0.02). This zircon is interpreted as a metamorphic crystal
and its age probably sets the age of the granulite facies metamorphism, indicating that the PNHGT is a result of the Tranzamazonian thermo-
tectonic event.

Keywords: Geochronology, Pb-Pb zircon, Granulite, Porto Nacional High-Grade Metamorphic Terrain

INTRODUCTION AND GEOLOGIC SETTING The Porto
Nacional region, central-south portion of the state of Tocantins, Brazil, is located in the Goiás Massif, which is an old crustal block
surrounded by Neoproterozoic belts: the Araguaia Belt to the west and the Brasília Belt eastward. These major tectonic units are included in
the Tocantins Province (Almeida et al. 1981). An extensive crustal
segment, with pervasive NNE-SSW trending structures, occurs in the
northern portion of the Goiás Massif. These structures are defined by
a regional thrusting system that mixed rocks of different crustal levels,
and extends southwardly to the Gurupi and Porangatu regions (Costa
1985, Costa et al. 1988a, Gorayeb 1996a). The geometry of the major
litho-structural units defines anastomosed surfaces dipping at low-
angle to SE with NW-SE stretch lineation. This crustal segment was
named Tocantins Shear Belt (TSB) by Gorayeb (1996b) (Fig. 1). The
gravimetric data in the Porto Nacional region are interpreted to
represent crustal thickening where high-grade metamorphic rocks
overthrusted gneissic terrains toward west, establishing an important
N30E discontinuity (Hasui and Haralyi 1985, Costa et al. 1988b).
Along a traverse between the cities of Paraíso do Tocantins and
Dianópolis, gneissic terrains (Rio dos Mangues, Manoel Alves
complexes), metavolcano-sedimentary sequences (Rio do Coco Group,
Morro do Aquiles Formation) granulitic terrains (Porto Nacional
Complex) and granitoids are exposed for over 300 km (Hasui et al.
1984, Costa 1985, Gorayeb et al. 1988, Gorayeb 1996b, Moura and
Souza 1996). All these units, which are cut by important NNE-SSW
shear zones, were dismembered from the Goiano Complex (Cunha

In spite of the reasonable geologic knowledge of this region, the
geochronological information is very limited, and does not allow a
reliable interpretation for the age of this crustal segment. An Archean
evolution has been usually assigned to the gneissic terrains, the
metavolcano-sedimentary sequences, the granulitic rocks and
granitoids (Cunha et al. 1981, Danni et al. 1982, Hasui et al. 1984,
Costa 1985, Gorayeb et al. 1988). However, more recent
geochronological data have pointed to Upper Paleoproterozoic age for
the gneisses of the Rio dos Mangues Complex (Moura and Souza
1996).

This study presents the results of the single zircon lead (Pb)
evaporation dating in granulitic rocks of the Porto Nacional High-Gra-
de Metamorphic Terrain (PNHGT), which is one of the most important
geostructural unit of the TSB. The aim of this work is not only contribute
for the geochronological knowledge of this region, but also to offer a
preliminary discussion on the meaning of the new ages in the context of
the TSB evolution.

GEOLOGY OF THE PORTO NACIONAL HIGH-GRADE
METAMORPHIC TERRAIN The PNHGT is exposed in 100 km
long NNE-SSW trending structure. Its maximum width is 35 km,
narrowing to the south until it disappears under the gneissic terrains. In

1 Centro de Geociências, Universidade Federal do Pará. Caixa Postal 1611, 66017-970, Belém, Pará, Brazil. Phone/Fax: 0_ _ 2111478.
e-mail: gorayeb@ufpa.br, c_moura@ufpa.br.
2 Bolsista CNPq/PIBIC-UFPa. e-mail: agbarros@amazon.com.br
the northeastern it is covered by the Paleozoic Parnaíba Basin (Fig. 2). In the southeast, normal faults put the PNHGT in contact with the low-grade metasedimentary rocks of the Natividade Group, and generated grabens that were filled with conglomerates, arkoses and rhyolites of the Monte do Carmo Formation (2.0 Ga – Barradas et al. 1992, Gorayeb et al. 1992). The Matança Granite is a 555–560 Ma old batholith (Gorayeb et al. submitted) with tectonic emplacement between the PNHGT and the gneisses of the Rio dos Mangues Complex. The Palmas Granite, a 548 ± 5 Ma old pluton (Gorayeb et al. submitted), cuts the PNHGT in the north area (Fig. 2).

Two main, tectonically juxtaposed lithological-metamorphic units are present in the PNHGT. One of them (Porto Nacional Complex) was stabilized at medium to high pressure granulite facies and consists of mafic granulites, enderbites, kyanite and/or sillimanite-bearing garnet gneisses and anatectic granitic bodies (leucoenderbites, trondhjemites, S-type granites).

The other unit (Morro do Aquiles Formation) was subjected to high-amphibolite facies at low-middle pressure conditions. It main rock types are sillimanite and/or andalusite-bearing cordierite gneiss, tonalitic gneisses, graphite schists, gondites and amphibolites which are cross-cut by the Carreira Comprida Anorthosite (Fig. 2).

The PNHGT is composed of infra-crustal granulite facies rocks, which were imbricated and thrust over gneissic terrains towards west representing a mega-slice of a tectonically exhumed lower crust.

**PETROGRAPHY OF THE DATED ROCKS**

The rocks of the PNHGT selected for dating are mafic granulites and enderbites, which occur as concordant layers and irregular bodies associated with garnet gneisses (kinzigites). The mafic granulites are black, equigranular and fine to medium grained. Generally, they are massive or show a weak banding. They are composed of orthopyroxene, clinopyroxene, plagioclase and hornblende with minor garnet, opaque minerals, apatite, zircon and rare spinel. The granoblastic polygonal texture dominates and defines triple point junctions between orthopyroxene, clinozoisite, plagioclase and hornblende. This texture reflects equilibrium conditions during the peak of granulite facies metamorphism that affected the PNHGT. Simplectite textures displayed by garnet-clinopyroxene-quartz-opaque association were formed by reactions involving orthopyroxene and plagioclase after the peak of the metamorphism. They are probably related to the higher pressures that resulted from crustal thickening during the collision tectonic responsible for the structural framework of the TSB.

The enderbites are dark or greenish gray, middle to coarse-grained granoblastic rocks. They are made up mainly of quartz and plagioclase with little or no K-feldspar, minor orthopyroxene, hornblende ± clinopyroxene and biotite. A weak foliation is marked by biotite trails and banding is defined by quartz-feldspar layers.

The kinzigites are brown-colored, strongly banded quartz-feldspar gneisses. They are garnet-rich rocks with minor amounts of biotite, sillimanite/kyanite and graphite. Accessory minerals include zircon, rutile, apatite, ilmenite and magnetite. They present a dominant granoblastic texture with garnet porphyroblasts displaying intragranular trails of sillimanite, graphite, plagioclase and quartz. Feldspars are represented by antiperthitic plagioclase and perthitic microcline.

**GEOCHRONOLOGY Analytical Procedures**

The ages of representative rocks of the PNHGT were obtained by the single zircon Pb evaporation technique (Pb-Pb in zircon) established by Kober (1986, 1987). Four fresh rocks of the main lithotypes of the PNHGT were sampled for Pb-Pb zircon age determination: one mafic granulite (PN-02A), two enderbites (PN-08.2, PN-23A), and one kinzigite (PN-02B) (Fig. 2). The isotope analyses were carried out on a FINNIGAN MAT 262 mass spectrometer at the Laboratório de Geologia Isotópica da Universidade Federal do Pará (Pará-Iso). The data acquisition was dynamically using the ion counting system of the instrument. Pb signal
was collected by peak hopping in the order 206, 207, 208, 206, 207, 204 along 10 mass scans, defining one block of data with 18 207Pb/206Pb ratios. Outliers were eliminated using Dixon’s test. The average 207Pb/206Pb ratio of each step was determined based on five blocks, or till the intensity beam was sufficiently strong for a reliable analysis. The 207Pb/206Pb ratio was measured in three evaporation steps at temperatures of 1450°, 1500°, and 1550°C. Usually, the average 207Pb/206Pb ratio obtained in the highest evaporation temperature was considered for age calculation. The ages were calculated with 2σ error and common Pb correction, for those blocks in which the 204Pb/206Pb considered for age calculation. The ages were calculated with 2σ error using also Stacey and Kramers (1975). Th/U values for the zircons were estimated from time-integrated 232Th/238U values calculated from the present-day 207Pb/206Pb values for each heating steps, based on the respective age of the evaporation step (Bartlett et al. 1998). 207Pb/206Pb ratios were corrected for common Pb using also Stacey and Kramers (1975).

Results

The zircon crystals of the mafic granulite (sample PN-02A) are transparent, pale brown to yellowish, prismatic and dipyrامidal. The 207Pb/206Pb ages for these crystals ranged from 2112 to 2134 Ma along the three steps of evaporation (Table 1). Consistent 207Pb/206Pb ratios derived from successively higher temperatures of evaporation reflect the composition of radiogenic lead from regions slightly affected by lead loss (Kober 1986, 1987; Karabinos and Gromet 1993). Probably, each analyzed crystal is composed of a concordant homogeneous phase, without significant metatmorphic component. The very low 207Pb/206Pb ratios of these crystals support this assumption. Four zircon crystals yielded an average 207Pb/206Pb age of 2125 ± 3 Ma (Table 1). The Th/U values for the highest temperature of evaporation ranged roughly between 0.2 and 0.3, which are in the field of magmatic zircons (Bartlett et al. 1998).

The zircon crystals of the enderbite PN-08.2 are transparent, pale brown to yellowish, and dominantly prismatic with pyramidal ends. The 207Pb/206Pb ages of the crystals varied between 2130 and 2160 Ma along the three steps of evaporation (Table 1), showing very consistent 207Pb/206Pb ratios similarly to the zircons of the mafic granulite. This consistency, along with the small 204Pb/206Pb ratios, also suggests the presence of homogeneous phases and the absence of significant metamorphic portions in these crystals. An average 207Pb/206Pb age of 2153 ± 1 Ma was obtained based on four zircon crystals. The Th/U ratios varying roughly between 0.2 and 0.3 are also in the range of the magmatic zircons (Table 1).

The zircon crystals of the enderbite PN-23A have similar size, length and color of those zircons of the sample PN-08.2. However, the prism and the pyramidal ends of the crystals do not show well develop edges, but usually present round terminations, probably produced by metamorphic recrystallization. The 207Pb/206Pb ages of the crystals varied between 2088 and 2110 Ma along the three steps of evaporation (Table 1). These very consistent values are accompanied by very low 204Pb/206Pb ratios. Four zircon crystals yielded an average 207Pb/206Pb age of 2097 ± 2 Ma. This age is younger than that obtained for the enderbite PN-08.2 and may reflect a post-magmatic homogenization of the main phase of the zircon. This interpretation is suggested by the morphology (absence of edges and rounded terminations) of the zircon crystals of the enderbite PN-23A.

The kinzigite PN-02B was sampled in the same outcrop of the mafic granulite PN-02A. The zircon crystals are pale brown and stubby, with rounded termination. Observations under the polarized microscope show significant overgrowth in a number of crystals defining cores and rims. This morphology indicates that the zircons are not true metamorphic minerals but inherited crystals that underwent metamorphic overgrowth. The 207Pb/206Pb ages of the crystals varied between 2072 and 2115 Ma along the three steps of evaporation (Table 1), approximately, the same range of the enderbite PN-23A. Since the zircons display cores and rims any 207Pb/206Pb average age is geologically meaningless. The Th/U ratios range from very low value (0.02) to values higher than 0.3. The Th/U ratios higher than 0.2 suggest a magmatic inheritance while those values lower than 0.2 may be interpreted as mixing of two end members: the inherited core and metamorphic overgrowth (rim). Since the zircon crystals show two distinct growth phases (core + rim), the older age obtained in crystal 9 (2115 ± 3 Ma) may be interpreted as minimum age of the core phase (Table 1). The crystal 1 is the only exception to this mixing feature. This zircon is very homogeneous, free of inclusions and without overgrowths. The very low Th/U value is indicative that this zircon crystallized in a Th depleted environment, which is typical of the lower crust. Thus it is interpreted as a metamorphic zircon crystal.

Discussions and Conclusions

The interpretation of 207Pb/206Pb evaporation age in single zircons of high-grade metamorphic rocks is not a simple task, since the Pb-loss is variable within the single grains. Kröner et al. (1994) did not get concordant 207Pb/206Pb evaporation age in zircons from enderbites and charnockites of Sri-Lanka, and observed that the 207Pb/206Pb evaporation age may be lower than those in the original pre-metamorphic grains. Bartlett et al. (1998) interpreted progressively older 207Pb/206Pb evaporation zircon ages of polymetamorphic high-grade rocks as representing progressive amounts of mixing with an older core phase. They assumed the older age as the minimum age for the core phase. The average 207Pb/206Pb ages of 2125 ± 3 Ma and 2153 ± 1 Ma obtained for the mafic granulate and enderbite PN-08.2, respectively, could be interpreted as magmatic crystallization ages, since the igneous characteristics of the zircons grains is well preserved, in spite of the granulate facies overprinted. Additionally, the 207Pb/206Pb ratios of the zircons are very consistent along the successive steps of evaporation (Table 1). However, repeated evaporation analyses on zircons of the same sample yielding approximately the same 207Pb/206Pb ratios is not a guarantee that the same ratios measured approach those of the primary zircon formation, since such zircons may have lost their Pb in approximately equal proportions (Kröner et al. 1994). Thus, the average 207Pb/206Pb ages obtained for the mafic granulate and the enderbite PN-08.2 are interpreted as minimum ages for the zircon crystals of the igneous protolith.

Due to limitation of the single zircon Pb-evaporation systems in high-grade metamorphic rocks, the ages of the igneous protoliths of the PNHGT remain unknown. However, no indication of Archean age has been found in this work for these granulite terrain. Additionally, the available 207Pb/206Pb zircon ages for the nearby geologic units suggest a major period of rock formation around 2.1 Ma in the northwest portion of the Goiás Massif (Gorayeb 1996b, Moura and Souza 1996). Based on the present geological and geochronological information it is suggested that this region was formed mainly during the Paleoproterozoic as a result of the Transamazonian orogenic collage.
<table>
<thead>
<tr>
<th>ZIRCON</th>
<th>Temp. °C</th>
<th>#ratios</th>
<th>204/206</th>
<th>208/206</th>
<th>207/206</th>
<th>207/206*</th>
<th>(N=D*/ &lt;θ&gt; 1) and NonN + D*, using common Pb corrected present-day 206Pb/204Pb values for each heating step.</th>
</tr>
</thead>
<tbody>
<tr>
<td>CRYSTAL 1</td>
<td>1450</td>
<td>0/90</td>
<td>0.000064 (38)</td>
<td>0.08946 (47)</td>
<td>0.13269 (28)</td>
<td>0.13149 (30)</td>
<td>218 ± 4</td>
</tr>
<tr>
<td>CRYSTAL 2</td>
<td>1450</td>
<td>0/90</td>
<td>0.000149 (53)</td>
<td>0.09454 (23)</td>
<td>0.13432 (31)</td>
<td>0.13240 (65)</td>
<td>213 ± 9</td>
</tr>
<tr>
<td>CRYSTAL 3</td>
<td>1500</td>
<td>0/84/84</td>
<td>0.000096 (31)</td>
<td>0.08866 (33)</td>
<td>0.13425 (40)</td>
<td>0.13420 (40)</td>
<td>213 ± 7</td>
</tr>
<tr>
<td>CRYSTAL 4</td>
<td>1500</td>
<td>0/86</td>
<td>0.000015 (04)</td>
<td>0.07640 (19)</td>
<td>0.13126 (20)</td>
<td>0.13116 (23)</td>
<td>214 ± 3</td>
</tr>
<tr>
<td>CRYSTAL 5</td>
<td>1485</td>
<td>90/90</td>
<td>0.000010 (06)</td>
<td>0.11160 (185)</td>
<td>0.13202 (29)</td>
<td>0.13185 (38)</td>
<td>213 ± 5</td>
</tr>
<tr>
<td>CRYSTAL 6</td>
<td>1500</td>
<td>90/90</td>
<td>0.000056 (06)</td>
<td>0.12101 (45)</td>
<td>0.13257 (19)</td>
<td>0.13172 (25)</td>
<td>212 ± 3</td>
</tr>
<tr>
<td>CRYSTAL 7</td>
<td>1500</td>
<td>88/88</td>
<td>0.000000 (00)</td>
<td>0.11709 (41)</td>
<td>0.13206 (40)</td>
<td>0.13206 (40)</td>
<td>216 ± 5</td>
</tr>
<tr>
<td>CRYSTAL 8</td>
<td>1500</td>
<td>0/14</td>
<td>0.000082 (20)</td>
<td>0.04668 (51)</td>
<td>0.13207 (65)</td>
<td>0.13099 (70)</td>
<td>212 ± 9</td>
</tr>
<tr>
<td>CRYSTAL 9</td>
<td>1500</td>
<td>86/86</td>
<td>0.000030 (03)</td>
<td>0.05807 (17)</td>
<td>0.13248 (14)</td>
<td>0.13203 (19)</td>
<td>212 ± 2</td>
</tr>
<tr>
<td>CRYSTAL 10</td>
<td>1500</td>
<td>82/82</td>
<td>0.000099 (10)</td>
<td>0.09260 (42)</td>
<td>0.13390 (52)</td>
<td>0.13261 (58)</td>
<td>213 ± 8</td>
</tr>
<tr>
<td>AVERAGE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>2125 ± 3</strong></td>
</tr>
</tbody>
</table>

**Table 1** 206Pb/204Pb zircon ages of granulite facies rocks of the Porto Nacional High-Grade Metamorphic Terrain. Temp °C = temperatures of the evaporation steps; # ratios = number of 207/206 ratios used in the averaged age calculation over the total measured ratios; 207/206* = ratios corrected for common Pb; Th/U = estimated Th/U ratio of the zircon for each evaporation step based on 232Th/238U and calculated from the basic radioactive decay equations (N=D*/ <θ> 1) and NonN + D*, using common Pb corrected present-day 206Pb/204Pb values for each heating step.


Contribution IGC-189
Received March 10, 2000
Accepted for publication May 15, 2000.

References