40Ar/39Ar geochronology of Mesozoic and Cenozoic magmatism in NE Brazil

$^{40}Ar/^{39}Ar$ GEOCHRONOLOGY OF MESOZOIC AND CENOZOIC MAGMATISM IN NE BRAZIL

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INTRODUCTION

Mesozoic and Cenozoic magmatism and volcanism in the Borborema Province, Northeastern Brazil, reflect mantle thermal anomalies associated with the break-up of Gondwanaland and, possibly, the migration of the South American Platform over the Santa Helena plume (Cordani, 1970; Chang et al., 1992). To understand the fundamental mechanisms leading to the Borborema Province Mesozoic and Cenozoic magmatism, it is necessary to determine exact ages of magma emplacement, the chemical and isotopic characteristics of the magma sources, and the extent of crustal contamination in these magmas. To achieve these goals, we have comprehensively sampled the magmatic bodies in this region and are in the process of obtaining detailed isotopic and trace element data for these samples. We will present here some preliminary $^{40}Ar/^{39}Ar$ results for the magmatic events, discuss the possible reasons for the discrepancy between these results and previous dates, and discuss the advantages of the $^{40}Ar/^{39}Ar$ method as a geochronological tool in the study of these magmatic events.

ADVANTAGES OF $^{40}Ar/^{39}Ar$ GEOCHRONOLOGY

One of the major difficulties in providing accurate and precise age constraints for the Mesozoic and Cenozoic magmatic rocks from the Borborema Province is their advanced stages of weathering, the low K contents of some units, the presence of wall-rock contamination, and the possible presence of excess Ar. Previous K-Ar dating provides useful age constraints; however, the absolute ages of the magmatic events are not precisely determined by this method given the limitations of the method in addressing the complicating factors listed above.

Contrary to the K-Ar technique, where K and Ar are determined in different aliquots of the sample, in the $^{40}Ar/^{39}Ar$ method K and Ar contents are determined from the same aliquot, mineral grain, or crystallographic site in a sample. The main advantages of the application of the $^{40}Ar/^{39}Ar$ method are: i) the fine-scale resolution of the method, which allows the age determination of very fine-grained phases (0.5-1 mm grains of Cenozoic rocks can be dated); ii) the multiple-step analysis of single grains, which enables the determination of the Ar retention history for a mineral, the presence of excess/inherited Ar, and the possibility of K and/or Ar loss; iii) the crystallochemical information obtained by the analyses of ^{40}Ar, ^{39}Ar, ^{38}Ar, ^{37}Ar, and ^{36}Ar from the same gas aliquot.

METHODOLOGY

All samples were irradiated (for 14 hours) together with Fish Canyon sanidine neutron flux standards in the Triga Reactor at the Oregon State University. After a two-month cooling period, each sample was step-heated under a continuous Ar-ion laser with a 2mm-diameter beam. The fraction of gas released was cleaned through a cryocooled cold-trap (T=-140 °C) and two C-50 SAES™ Zr-V-Fe getters and analyzed for Ar isotopes in a MAP-215-50 mass spectrometer at the UQ-AGES (University of Queensland Argon Geochronology in Earth Sciences) laboratory. Automation and analytical procedures are described in Vasconcelos (1999) and Vasconcelos et al. (2002). Data corrected for mass discrimination, nucleogenic interferences, and atmospheric contamination were used to calculate apparent ages for each degassing step. Although single crystals are preferred to analyze, we also analyzed total rock samples if the grain sizes were sufficiently small (phenocrysts smaller than 50-100 µm).

In this study, we define an age plateau as a sequence of two or more steps corresponding to at least 50% of the total ^{39}Ar released, and whose age values are within two sigma from the mean value. If a sample reaches a well-defined plateau, it implies that the sample hosts its radiogenic and nucleogenic gas fractions in a tight crystallographic reservoir, that the reservoir has been closed during the history of the sample, and that contaminating hypogene phases are unlikely to be present.

OCCURRENCE OF MAGMATIC ROCKS IN NE BRAZIL

Northeastern Brazil comprises a widespread geotectonic unit of the South American platform, the Borborema Province. In this province, there are a great number of volcanic and hypabyssal rocks, with ages ranging from Cretaceous to Tertiary. They occur as dykes, sills, small flows, volcanic conduits and plugs (Sial, 1976; Almeida et al., 1988). These rocks preceded or succeeded the implantation of the Cretaceous rifts in this province (e.g., the Rio do Peixe interior basin and the Potiguar-Ceará and Pernambuco-Paraíba coastal basins) and they probably contributed to the processes of regional uplifting and re-heating. A recent compilation of

geochronological data by Mizusaki et al. (2002) identifies three distinct magmatic events.

The oldest one, the so-called Rio Ceará Mirim Magmatism, yields a K-Ar age peak around 130 Ma. It is represented by several tholeiitic diabase dykes, oriented predominantly in an E-W direction, that outcrop mainly in the southeast portion of the Potiguar basin, with minor occurrences in the oriental part of the Parnaíba basin. Recent $^{40}Ar/^{39}Ar$ dates (Araújo et al., 2001) of plagioclase crystals from diabase dykes from João Câmara, Açu and Lajes (RN) yield plateau ages of 136 ± 4 Ma, 127 ± 1.3 Ma e 110.7 ± 1.3 Ma, respectively.

For the second event, Almeida et al. (1988) report K-Ar ages between 105 e 95 Ma for alkalic and calc-alkalic rocks from the Pernambuco Basin and, possibly, the Itapororoca region (eastern Paraíba state). They occur as dykes, plugs, small flows, sills and laccoliths, crosscutting cretaceous clastic sequences of the Cabo Formation in the Pernambuco Basin (Amaral & Menor, 1979; Sial, 1976). Recent whole rock $^{40}Ar/^{39}Ar$ analyses of basalts, trachytes, rhyolites and ignimbrites from this basin yield ages between 111 and 100 Ma (Lima Filho & Szatmari, 2002). Slightly younger K-Ar dates (80.4 ± 2 Ma) are cited for the Cuó basaltic flows from Açu (RN) (Sial et al., 1981). Based on compilation of available K-Ar data, Mizusaki et al. (2002) places the peak of the Cuó magmatism at ca. 90 Ma. However, Araújo et al. (2001) interpret an $^{40}Ar/^{39}Ar$ integrated age of 98.3 ± 0.8 Ma and a compatible weighted mean average age of 99 ± 2 Ma as the best estimate for this magmatic event, placing this magmatism temporally very close to the one found in the Pernambuco Basin.

The youngest magmatic event in the Borborema province is related to Tertiary volcanic rocks of the Macau-Queimadas and Mecejana-Fernando de Noronha alignment (Almeida et al., 1988). The K-Ar whole-rock data compiled by Mizusaki et al. (2002) is consistent with two groups, one with ages ranging between 12.3 ± 1 and 1.81 ± 0.13 Ma (peak around 7 Ma in Fernando de Noronha), and the other one with ages ranging between 45 ± 1 and 12.5 ± 1.0 Ma (peak around 30 Ma). For Mecejana phonolites, Vandoros & Oliveira (1968) furnished K-Ar ages of 28.6 ± 0.6 Ma and 26.6 ± 0.8 Ma, whereas Cordani (1970) obtained 27.8 ± 0.8 Ma. A Rb-Sr isochron of phonolites from Mecejana gave an age of 36 ± 2 Ma (Nascimento et al., 1981, in Almeida et al., 1988). A recent $^{40}Ar/^{39}Ar$ date for whole rock basalt sample from Serrote Preto (Cerro Corá/RN) yield a plateau age of 24.2 ± 0.3 Ma (Moraes Neto et al., 2002), estimated by these authors as the best age for this sample. Araújo et al. (2001), however, interpret an integrated age of 29.7 ± 0.6 Ma as the best estimate for the Cerro Corá magmatism. Basalts from the Cabugi neck (Lajes/RN) yield a plateau age of 23.7 ± 1.2 Ma (Araújo et al., 2001).

In this report we present new $^{40}Ar/^{39}Ar$ data of basalts from Cabugi neck (130 km western of Natal) and Cuó flow (4 km eastern of Açu and 190 km western of Natal), as well as one diabase dyke from Pedro Avelino (15 km north of Cabugi neck). We will provide detailed interpretation of the $^{40}Ar/^{39}Ar$ results, and discuss the pitfalls of $^{40}Ar/^{39}Ar$ geochronology interpretation. Appropriate interpretation of the $^{40}Ar/^{39}Ar$ results may contribute to a better understanding of the processes of regional uplifting and brittle tectonics associated to the magmatic events in the Borborema Province and may aid in directing future studies.

SAMPLE LOCATION AND TEXTURAL DESCRIPTION

One of the sampling sites was the central gabbroic zone a thick (40 m) diabase dyke (100° Az). This dyke crosscuts high grade gneisses of the Precambrian crystalline basement and shows a net variation to a fine grained border in the contact with the basement.

The other sampled site, the basaltic rocks from the Cuó magmatism, constitute small flows of olivine basalts outcropping in the interface between the crystalline basement and the sedimentary rocks of the Potiguar Basin, in this case the sandstone of the Açu Formation. The top of the flow is 52 m high, is slightly inclined toward north and probably constitutes a sill into this formation.

The third sampled site, the Cabugi body, is topographically very expressive in the region, forming a hill that reaches a 650 m height, surrounded by the 150 Lajes plain. It corresponds to a volcanic neck intrusive into the Precambrian gneissic rocks. In the Cabugi neck, Souza et al. (2002) distinguish three textural/stratigraphic facies. The oldest one is a medium to coarse-grained basalt ($basalt_1$), which forms the major part of the body and predominates in the NW, W and SW borders of the neck. The youngest one outcrops in the NE border, presenting fine grained texture and abundant xenoliths of peridotite, crystalline basement rocks (gneiss, granite, pegmatite) and $basalt_1$, and frequent xenocrysts of olivine, clinopyroxene, brown spinel, quartz and oligoclase. There are also several dykes of microgabbros (20-30° Az) crosscutting $basalt_1$ or, otherwise, found as inclusions in $basalt_2$. In this study, we analyzed one sample of $basalt_2$.

$^{40}Ar/^{39}Ar$ GEOCHRONOLOGY RESULTS

DIABASE DYKE

Two amphibole grains analyzed yield well-defined spectra with plateau ages of 133 ± 3 and 132.2 ± 1 Ma, and compatible integrated ages of 134.8 ± 1.3 and 132.8 ± 1.1 Ma (Fig. 1). An ideogram plotted for this sample yields a most probable peak of 132.1 Ma and a weighted mean average age of 133 ± 3 Ma for all the steps obtained for the two grains (Fig. 1). The best estimate age for this sample is the plateau age of 132.2 ± 1 Ma, given the size of the grain analyzed, the volume of ^{39}Ar contained, and the reproducibility of the steps defining the plateau. As the amphibole grains are derived from some process of uralitization of augite grains, this date is considered as a cooling age for the diabase dyke.

CUÓ BASALTIC FLOW

The Cuó basalts are fine to medium grained and show abundant, frequently serpentinized, olivine phenocrysts,

sometimes in glomeroporphyritic aggregates. They have intergranular short augite grains, plagioclase laths and magnetite. Six total rock fragments (grains 2442-01/02/03 and 2512-01/02/03) analyzed by the incremental heating method yield the spectra illustrated in Figures 2a and b. An ideogram representing all the steps analyzed yield two high probability peaks, one at 99.2 Ma and another at 93.1 Ma and a weighted mean average age of 96.4 ± 0.9 Ma (Fig. 2c). This weighted mean average also corresponds, within 2 sigma, to the integrated age for each of the grains analyzed (96.4 ± 0.3, 96.3 ± 0.3, and 96.8 ± 0.3 Ma for grains 2442-01/02/03 and 95.0 ± 0.3, 95.5 ± 0.3 and 96.0 ± 0.3 Ma for grains 2512-01/02/03). Careful inspection of the incremental-heating spectra reveals a very similar pattern for the six grains, where the low temperature steps suggest a high K/Ca phase which yields higher apparent ages, while the high temperature steps are derived from a low K/Ca phase recording lower apparent ages. Because the older results are associated with the low temperature, K-rich, steps, and the younger ones are associated with the Ca-rich plagioclase phenocrysts, it is unlikely that the two peaks correspond to ages associated with the crystallization of the phenocrysts (which should be older, and recorded in the plagioclase crystals) and the extrusion of the basalt (which should be younger, and recorded in the glass). Because the feldspar ages are younger, it is also unlikely that the two-age pattern is related to excess Ar in the phenocrysts, either. A possible explanation for the pattern obtained is some degree of alteration and K loss from the glass matrix in this sample, leading to older results for the low temperature steps. If this interpretation is correct, the higher temperature steps, yielding a most probable peak at 93.1 ± 0.8 Ma, and related to the gas reservoirs represented by the unaltered feldspar phenocrysts, would be the best estimate for the age of this sample.

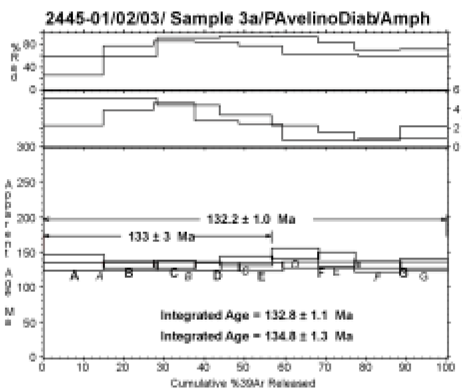

Figure 1. $^{40}Ar/^{39}Ar$ plateau ages for amphibole of a diabase dyke south of Pedro Avelino/RN (NE Brazil).

BASALT FROM CABUGI NECK

Two of the three total rock grains analyzed for this sample yield plateau ages of 24.8 ± 0.4 and 24.6 ± 0.6 Ma (Fig. 3). The integrated ages obtained for the two grains yielding plateaus are also indistinguishable at the 2-sigma confidence level (24.2 ± 0.3 and 24.1 ± 0.3 Ma). The third grain does not yield a plateau age, but the spectrum yielded by this grain is compatible with that obtained for the other two grains. However, this grain yields some steps recording slightly older results, possibly associated with recoil or excess Ar; and its integrated age, 25.0 ± 0.2 Ma, is also slightly older than that obtained for the other two grains. An ideogram plotted for this sample yields a wide peak, with most probable age at 24.14 Ma and a weighted mean average age of 24.6 ± 0.8 Ma (Fig. 3). The three incremental heating spectra show that the earlier steps, associated with plateau ages of 24.8 ± 0.4 and 24.6 ± 0.6 Ma are associated with fractions of gas released from K-rich reservoirs in the sample, while the higher temperature steps, which yield dates slightly different from the lower temperature steps, are associated with Ca-rich reservoirs, probably plagioclase crystals. The best age estimate for this sample is 24.6 ± 0.8 Ma.

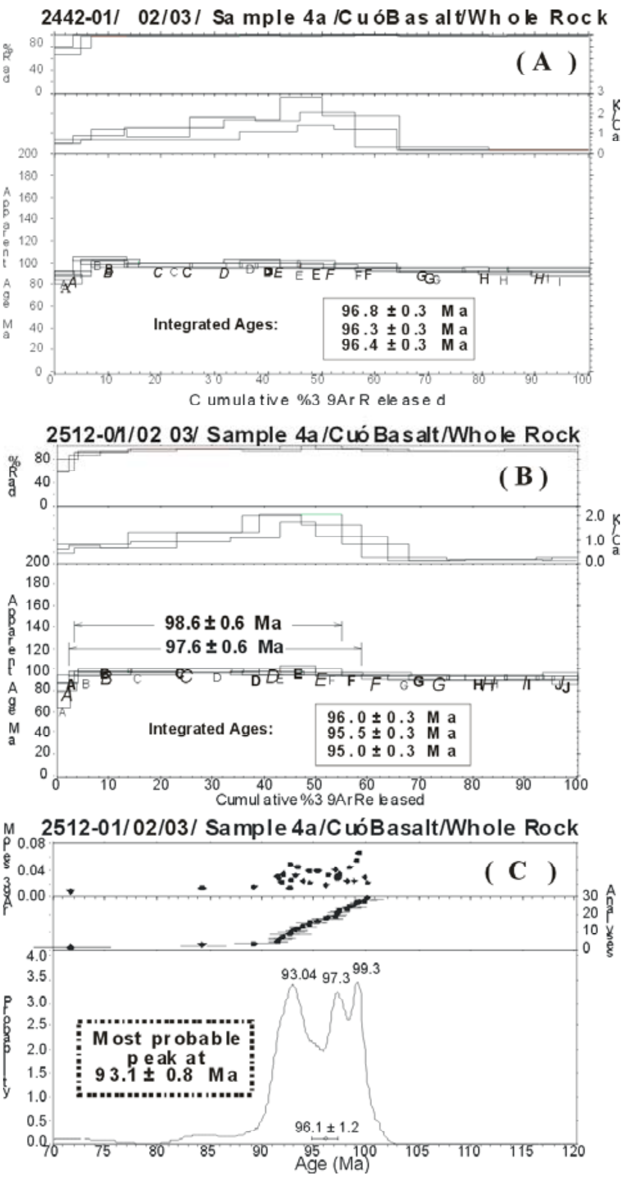

Figure 2. $^{40}Ar/^{39}Ar$ plateau (A, B) and ideogram ages for olivine basalt of the Cuó magmatism (Açu/RN, NE Brazil).

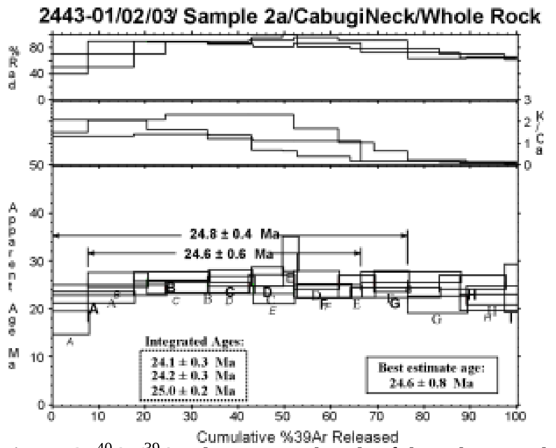

Figure 3. $^{40}Ar/^{39}Ar$ plateau ages basalt of the cabugi neck (Lajes/RN, NE Brazil).

GEOLOGICAL IMPLICATIONS

The $^{40}Ar/^{39}Ar$ geochronological data reported here confirm some previous results (i.e., our plateau age for the Cabugi basalt is compatible with the 23.7 ± 1.2 Ma plateau age obtained by Araújo et al., 2001), and also very close to the 25 ± 1 Ma age estimate for basalt of the Serrote Preto hill (Cerro Corá/RN) reported by Morais Neto et al. (2002). However, the age of 98.3 ± 0.8 or 99 ± 2 Ma determined for the Cuó magmatism by Araújo et al. (2001) is significantly different from our estimate of 93.1 ± 0.8 Ma for this magmatic event.

Based on the results presented here, results from the literature, and also the results presented by Nascimento et al. (this symposium), we identify four distinct Meso-Cenozoic magmatic events in the Borborema Province:

(1) The Rio Ceará Mirim dyke swarm magmatism, ranging from ca. 145 to 110 Ma (Araújo et al., 2001). Our plateau age of 132.2 ± 1 Ma represents one of the phases, possibly the main phase (Misuzaki et al., 2002), of this magmatic event.

(2) The Cabo Magmatic Province, with $^{40}Ar/^{39}Ar$ plateau ages ranging from 104.4 ± 0.8 to 98.3 ± 3 Ma, with a major peak at ca. 102 ± 1 Ma (Nascimento et al., 2003, this symposium).

(3) The Cuó Magmatism, with a most probable age of 93.1 ± 0.8 Ma.

(4) The alkaline basalt (Macau Magmatism), represented in this study by the Cabugi neck, with a best age estimate of 24.6 ± 0.8 Ma. These dates corroborate previous results (Araújo et al., 2001; Moraes Neto et al., 2002).

These magmatic events preceded or succeeded the implantation of Cretaceous rifts in this province. They likely contributed to the uplift and regional denudation related to the generation of sediments that filled continental and marginal basins; they probably enhanced the maturation and (re)mobilization of organic materials in sedimentary basins, being directly related to the generation of oil reservoirs in these basins; and they are possibly associated with tectonic reactivations that may have generated structural traps in these sedimentary basins.

Further $^{40}Ar/^{39}Ar$ geochronology is necessary to completely determine the spatial and temporal distribution of the magmatic centers in the Borborema Province and to answer an important question related to the genesis of the Meso-Cenozoic magmatic provinces in northeastern Brazil: are the magmatic centers indeed aligned in a north-south direction and related to a hot spot, as previously proposed by Almeida et al. (1988), Chang et al. (1992), and Mizusaki et al. (2002) based on K-Ar ages?

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