GEOCHRONOLOGY OF CALC-ALKALINE AND THOLEIITIC DYKE SWARMS OF TANDILIA, RIO DE LA PLATA CRATON, AND THEIR ROLE IN THE PALEOPROTEROZOIC TECTONICS

[1]Teixeira, W., [2]Pinese, J.P.P., [3]Iacumin, M., [1]Girardi, V.A.V., [3]Piccirillo, E.M., [4]Echeveste, [4]H., Ribot, A., [4]Fernandez, R., [5]Renne, P.R., [6]Heaman, L.M.

[1]University of São Paulo – Institute of Geosciences. Rua do Lago, 562 (05422-900) São Paulo, SP, Brazil. wteixeir@usp.br and girardi@usp.br
[2]University of Londrina, Dept. of Geoscience. P.O. Box 6001 (86051-990) Londrina, Pr, Brazil. pinese@uel.br
[3]University of Trieste, Dept. Scienze della Terra. Via Weiss, 8 (34127) Trieste, Italy. jacumin@univ.trieste.it and picciril@univ.trieste.it
[4]University of La Plata, Calle 52, P.O. Box 128 (1900) La Plata, Argentina. rfernand@isis.unlp.edu.ar and aribot@isis.unlp.edu.ar
[5]Berkeley Geochronology Center, 2455 Ridge Road, Berkeley, CA 94709 – USA. prenne@bgc.org
[6]University of Alberta, Alberta – Canada. larry.heaman@ualberta.ca

Keywords: Paleoproterozoic dykes, Tandilia System, Rio de la Plata craton

INTRODUCTION AND GEOLOGICAL SETTING

Paleoproterozoic gneisses, schists and migmatites intruded by tonalitic-granitic plutons and later by leuco-monzogranites are collectively known as the Buenos Aires Complex. These rocks make up the Tandilia System (Dalla Salda et al., 1988, 1992) - a WNW-ESSE igneous-metamorphic belt in Southern Rio de la Plata craton (RLPC). The tonalitic-granitic suite yields Rb-Sr isochron ages between 2,150 and 1,970 Ma, and represent the syn-collisional phase of the Transamazonian orogeny. These plutons have major and trace elements and Sr-IRos (0.7023-0.7059) that resemble those patterns of rocks generated in modern arc environments. The late monzogranitic plutons emplaced at 1,770 ± 88 Ma (Rb-Sr isochron age) during the post-collision orogenic stage, and are crustal derived (e.g., Sr-IRo= 0.7181). Further transcurrent tectonics have led to the appearance of major W-E shear zones in Tandilia, producing variable cataclasis on both the country rocks and the intrusive plutons. Such a geologic framework coupled with the Sr isotopic and geochemical evidences of the intrusive suites support the interpretation that the Tandilia System was formed through a juvenile accretion event which was followed shortly by crust recycling.

Two distinct unmetamorphosed Paleoproterozoic dyke swarms intrude the Tandilia System, the isotopic data of which will be presented and discussed hereafter. The older dykes exhibit main EW trends, and emplaced during the transtensional stage of the Transamazonian orogeny. The youngest dykes show NW trends and crosscut the 1,770 Ma leuco-monzogranites as well as the regional EW shear zones (see above). Previous K-Ar ages for the Tandilia dykes vary from 1,750 Ma to 800 Ma, suggesting variable argon losses have affected the mineral systems.

PETROGRAPHY AND GEOCHEMISTRY

The Tandilia dykes can be classified into four types according to petrography and whole rock geochemistry (Jacumin et al., 2001):
1) intermediate dykes **(I)** with porphyritic to intergranular texture (10% of the dykes); 2) acid dykes **(A)** with porphyritic texture (15%). The **(I)** and **(A)** dykes may show cataclastic fabric; 3) basic dykes **(B_1)** with subophitic and sometimes intergranular textures (63% of the dykes) and 4) basic dykes **(B_2)** with ophitic texture (12%).

The **(I)** dykes are 0.5-10 m thick and exhibit medium-fine texture. They have phenocrysts of andesine-plagioclase and augite, both sometimes altered to clay minerals and amphibole, respectively.

The groundmass is made up of plagioclase, epidote, biotite, opaques, alkali-feldspar and quartz. Where the fabric is intergranular the plagioclase and augite are often altered to clay minerals and amphibole. Granophyric quartz-feldspar intergrowths are common. The **(A)** dykes are composed of phenocrysts of oligoclase-plagioclase, alkali-feldspar and augite which also constitute the groundmass. Secondary zeolites or quartz and K-feldspars may fill vesicles or fractures. They may be 30 m thick, are associated with and sometimes intruded by **(I)** dykes.

The **(B_1)** dykes vary in thickness from 10 to 50 m, and are fine-grained at the the border and coarse-grained in the center. They are characterized by labradoritic plagioclase, somewhat altered to clay minerals, and pyroxenes (augite and minor pigeonite) which may be partly replaced by hornblende, tremolite and chlorite. In general, olivine is scarce and exclusive to low-Ca pyroxene-free samples. The accessory minerals include magnetite, ilmenite, quartz, apatite and epidote. The relatively scarce **(B_2)** show contrasting medium- to fine-grained textures compared to the **(B_1)** dykes, and have thicknesses from 0.5 to 10 m. The mineralogy is also different, given by the presence of Ti-augite and absence of olivine. The labradoritic plagioclase in the **(B_2)** dykes is often altered to clay minerals and sericite and are sometimes albitized. The clinopyroxene may be replaced by hornblende, actinolite-tremolite and chlorite. The accessory minerals are ilmenite, magnetite and apatite.

Chemically, the **(I)** dykes correspond to andesitic basalts and subordinately to andesites, while the **(A)** dykes are rhyolites. The **(B_1)** dykes correspond to tholeiitic basalts and subordinately to tholeiitic andesitic basalts and latibasalts. The **(B_2)** dykes vary from tholeiitic andesitic basalts to latibasalts and trachybasalts.

In the AFM diagram the **(B_1)** and **(B_2)** dykes plot in the tholeiitic field whilst both **I** and **A** dykes plot in the calc-alkaline field. Published means of major, minor and trace elements, including REE, reveal also significant differences between the calc-alkaline and tholeiitic dykes. The **(I)** dykes show higher SiO_2, K_2O, Na_2O, Ba and Rb than the tholeiites that have otherwise higher mean contents of TiO_2, FeOt, CaO and Ni. In addition, the calc-alkaline dykes are characterized by REE patterns with $(La/Lu)_N$ much higher (I=12-10, A=14-40) than the tholeiitic dykes (**B_1**=1.3-2.8, **B_2**=6.63). The genetic differences among the calc-alkaline and tholeiitic dykes are also supported by the significant Eu negative anomaly of the **(A)** dykes, as well as the characteristic flat REE pattern of the **(B_1)** dykes. Moreover, the calc-alkaline dykes are also more enriched in LREE [$(La/Sm)_N$ ranging from 3.1 to 6.3] relative to the **(B_1)** types (0.9 to 1.9). The **(B_2)** dykes present also an enriched LREE pattern, but in conjunction with the **(B_1)** dykes are more enriched in HREE.

GEOCHRONOLOGY AND ISOTOPE GEOLOGY

Two calc-alkaline dykes have been dated by $^{40}Ar/^{39}Ar$ analyses on biotites from baked country rocks at the very contact with the A54 **(I)** and A48 **(A)** intrusion. The former biotite yielded a concordant spectrum with an integrated age of 1,974 ± 24 Ma and a plateau age of 2,007 ± 24 Ma. The biotite from the other sharp contact yielded a comparable age spectrum with an integrated age of 2,019 ± 24 Ma and a plateau age of 2,020 ± 24 Ma. Comparatively the small difference (13 Ma) between the plateau ages of the biotites suggests a moderate to rapid cooling after emplacement of the calc-alkaline **(I and A)** dykes, or implies preferential Ar loss from the biotite during a possible subsequent reheating. Following the first interpretation the crystallization age is taken as 2,020 ± 24 Ma.

A plagioclase concentrate from tholeiitic dyke A4 **(B_1)** dyke yielded a discordant $^{40}Ar/^{39}Ar$ spectrum with an integrated age of 1110 ± 120 Ma and a plateau age of 811 ± 36 Ma. The discordant age spectrum at high temperature degassing (> 1150 °C) is accompanied by elevated Ca/K, which could reflect the presence of cryptic secondary phases within the minerals. This interpretation is consistent with occurrence of hydrothermal alteration which has been reported for some basic dykes of Tandilia. Additionally, the plagioclase age spectrum shows a "saddle – shaped" pattern which is, in many cases, evidence for samples containing excess ^{40}Ar from older, K-rich host rocks. However, considering the typical low argon blocking temperature of plagioclase (~176 ^{0}C), the age spectrum may be also related to episodic ^{40}Ar loss at 810 Ma, thereby implying a secondary low thermal overprint affecting the Tandilia crust. This interpretation is consistent with two additional K-Ar whole rock ages of 803 ± 14 Ma and 1,193 ± 18 Ma already reported for the tholeiitic **(B_2)** dykes. Such a scenario is therefore coherent with the

Neoproterozoic orogenic episodes that are widely recognized along the eastern margin of RLPC.

A $^{207}Pb/^{206}Pb$ discordia upper intercept age on two baddeleyites from tholeiitic (**B$_1$**) dyke A17 constrains its eruption at 1,588 ± 11 Ma. This age is herein extrapolated for the (**B$_2$**) dykes of Tandilia, as they exhibit tholeiitic affinity, similar geologic relations with the country rocks and regional shear zones (see above). Therefore, the published K-Ar ages on the Tandilia dykes (1,750 – 1,540 Ma and 1,070 - 800 Ma) probably reflect variable argon losses of the mineral systems from the two distinct swarms that intrude the Tandilia System. In addition, the lower intercept U/Pb age of the discordia at 644 ± 170 Ma indicates a further episodic Pb loss, suggesting a low grade alteration overprinted this dyke. This is supported the petrography (augite partly replaced by hornblende, actinolite-tremolite and chlorite; plagioclase sometimes altered to clay minerals). This phenomenum is probably related again to the Neoproterozoic orogenic episodes, in agreement with the K-Ar and $^{40}Ar/^{39}Ar$ evidence of the tholeiitic dykes (see above).

Rb-Sr whole rock determinations were carried out on calc-alkaline dykes (four samples each of **I** and **A** types) and 14 tholeiitic dykes (eight **B$_1$** and six **B$_2$** types). The calc-alkaline dykes yielded an errorchron of 1,956 ± 110 Ma (1σ), Sr-IR$_0$ of 0.7038 ± 0.0025 and MSWD = 19. The calculated $^{87}Sr/^{86}Sr$ values for t_0=2.0 Ga ($^{40}Ar/^{39}Ar$ age) range from 0.70129 to 0.70497 (mean 0.70322 ± 0.00170). The (**I**) dykes have Sr-IRo$_s$ between 0.70327 and 0.70416 (mean 0.70375 ± 0.00037), slightly higher than the (**A**) dykes (0.70129 - 0.70497), but not significantly distinct within the errors (**A** dykes have mean Sr-IRos = 0.70268 ± 0.00241). In any case the Sr-IRo$_s$ mean ratios are comparable within the errors with the with Sr-IRos of the tonalitic-granitic plutons of Tandilia (as low as 0.7020), thereby suggesting that crustal contamination, if present, was negligible for the calc-alkaline dykes.

The (**B$_1$**) and (**B$_2$**) dykes did not yield a Rb/Sr array due to isotopic disturbance. This may be related to the polyphase tectonic framework of Tandilia which may have included reactivation of the shear zones (see above). This situation may have favoured post-crystallization mobility of Rb and Sr resulted from low grade hydrothermal fluids overprinting the tholeiitic dykes, as suggested by their secondary mineralogy (clay minerals, uralite, hornblende, tremolite, actinolite and chlorite).

The (**B$_1$**) dykes have calculated Sr-IRo$_{(1.6\ Ga)}$ values from 0.70292 to 0.71006 (mean 0.70604 ± 0.00220) whilst the (**B$_2$**) dykes between 0.70295 and 0.71091 (mean 0.70727 ± 0.00338). The wide range of the Sr-IRos values observed for both **B$_1$** and **B$_2$** types suggest that crustal contamination by radiogenic ^{87}Sr (AFC model) was important for the samples with Sr-IRo >0.7050, although this is not show by the chemical data (Jacumin et al., 2001).

Ten Sm-Nd whole rock determinations were carried out on 5 calc-alkaline (**I**, **A**) and 5 tholeiitic (**B$_1$** and **B$_2$**) dykes. The calc-alkaline dykes have T_{DM} model ages from 2.53 to 2.63 Ga that provide a restricted time period for the mantle remobilization. The ε_{Nd} and ε_{Sr} parameters, recalculated for t_0 = 2.0 Ga ($^{40}Ar/^{39}Ar$ age for the emplacement; see above), vary from –4.8 to –3.2 and +24 to +29, respectively. These data plot in the enriched quadrant with respect to the Bulk Earth, and indicate that the calc-alkaline dykes derived from partial melting of a mantle source with low Sm/Nd, probably subjected to metasomatism.

Three tholeiitic (**B$_1$**) dykes do not allow calculation of Sm-Nd model T_{DM} ages (single stage), as indicated by the $f_{Sm/Nd}$ values of –0.23, -0.18 and +0.01, respectively. However, two of these samples yield $\varepsilon_{Nd(1.6\ Ga)}$ and $\varepsilon_{Sr(1.6\ Ga)}$ values -- A5 (+4.5; +62) and A16 (-0.4; +24) – which coupled with the geochemical characteristics - may reflect a depleted mantle source relative to the Bulk Earth. On the other hand, two (**B$_2$**) dykes yielded contrasting $\varepsilon_{Nd(1.6\ Ga)}$ values of -1.2 and –7.2, respectively, suggesting derivation from a distinct enriched mantle source. From the above (**B$_1$**) and (**B$_2$**) tholeiites probably originated from distinct parental magmas, as suggested by their particular geochemistry (see above).

TECTONIC IMPLICATIONS

The geologic information supported by the radiometric data indicate that the oldest calc-alkaline dykes post-date the regional metamorphism and deformation of the Transamazonian orogeny during which the Tandilia arc-plutonism was formed. This interpretation is consistent with geochemical characteristics of both the tonalitic-granitic suite and calc-alkaline dykes (**I** and **A** types), as well as by the mean Sr-IRo = 0.7038, EM$_1$, and Nd source signatures, interpreted to be influenced by subduction-related metasomatism. The calc-alkaline dykes are therefore interpreted as transtensional representatives of the evolution of the Tandilia System. The scenario is analogue with that of several contemporary crustal domains within the Brazilian shield where the Transamazonian orogeny played important role in mantle- differentiation and crustal shortening events.

The emplacement of the tholeiitic dykes (**B$_1$** and **B$_2$**) at 1588 ±11 Ma indicates a significant change of the regional field stress post-dating the Transamazonian orogeny, as these dykes crosscut the E-W shear zones and the 1.77 Ga leuco-monzogranites of the Tandilia System. This reinforces the idea that extension tectonics predominated within the RLPC after stabilization of the Transamazonian orogeny, since the origin of the relatively older Florida tholeiitic dyke swarm (1.73 Ga) and coeval anorogenic plutonism (located in the Uruguay; RLPC) are genetically related to a continental aborted rift setting (Teixeira et al., 1999).

The 1.59 Ga (**B$_1$** and **B$_2$**) dykes of Tandilia show internal isotopic and geochemical differences which may be also explained by such rift dynamics, since this regime could favour interaction of the ascending asthenosphere with the thinned subcontinental lithosphere composed of crust materials of distinct temporal residence. However, the 1.59 Ga dykes show constrasting isotopic signatures (ε_{Ndt} values between +4.5 to –0.4 and –1.2 to –7.2) compared to those reported for the 1.73 Ga Florida dykes [$\varepsilon_{Nd(1.60Ga)}$ between –5.0 and –9.7), and also to the sources from which the 2.0 Ga calc-alkaline dykes of Tandilia originated [$\varepsilon_{Nd(1.60Ga)}$ between -9.5 to –7.5]). Moreover, the latter dykes yield $\varepsilon_{Sr(1.60\ Ga)}$ values significantly more positive (up to +266) compared to those of the 1.59 Ga tholeiitic dykes. The above isotopic evidences suggest that some variation in the magma sources underlying the RLPC may have occurred during the Paleo-Mesoproterozoic time-boundary.

Finally, considering South America and South Africa subcontinent prior to break up the Tandilia System show many geologic similarities with contemporary units in the Richtersveld and Bushmanland subprovinces (e.g., Dalla Salda et al., 1988), exemplified by the Vioolsdrif plutonic suite and co-magmatic calc-alkaline volcanics (2,100 – 1,730 Ma), the Koeris tholeiitic metabasalts (1,649 ± 90 Ma) and associated episodes of basin-accumulation. The broad tectonic scenario is consistent with the predominant intraplate regime that characterises the Staterian period (1.8 – 1.6 Ga) during which diachronous mafic dykes, anorogenic granites and fault block-basins developed across many Paleoproterozoic provinces worldwide.

REFERENCES

Dalla Salda, L. H., Bossi, J. and Cingolani, C., 1988. The Rio de la Plata Cratonic Region of Southwestern Gondwanaland. Episodes, 11: 263-268.

Dalla Salda, L. H., Franzese, J. R. and Posadas V. G., 1992. The 1800 Ma Mylonite-Anatectic Granitoid Association in Tandilia, Argentina. Basement Tectonics, 7: 161-174.

Iacumin, M., Piccirillo, E. M., Girardi, V. A. V., Teixeira, W., Bellieni, G., Echeveste, H., Fernandez, R., Pinese, J. P. P. and Ribot, A., 2001. Early Proterozoic calc-alkaline and middle Proterozoic tholleiitic unmetamorphosed dyke swarms from Central – Eastern Argentina: petrology, geochemistry, Sr-Nd isotopes and their bearing on source mantle. Journal Petrolology, in press.

Teixeira, W., Renne, P. R., Bossi, J., Campal, N. and D'Agrella Filho, M.S., 1999. ^{40}Ar-^{39}Ar and Rb-Sr geochronology of the Uruguayan dike swarm, Rio de la Plata Craton and implications for Proterozoic intraplate activity in western Gondwana. Precambrian Research, 93: 153-180.