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U-Pb (Zircon) Ages of Metavolcanic Rocks From the Itaiacoca Group: Tectonic Implications

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Keywords: U-Pb zircon, metavolcano-sedimentary sequence, tectonic evolution.

ABSTRACT

The main aim of this work is to present and discuss the U-Pb ages obtained for zircon grains from metavolcanic rocks of the Itaiacoca Group. The Itaiacoca Group is a metavolcano-sedimentary sequence, which occurs as a narrow belt between the Cunhaporanga granitic batholith to the northwest and the Itapirapuã shear zone to the south and southwest, which separates the sequence from the Três Córregos granite batholith and metasedimentary rocks of the Açungui Group. Geological studies of the southern part of the Itaiacoca belt led to the recognition of three units, represented (from base to top) by metawackes with an important volcanic component, metacarbonate, and metapelitic and metapsammitic rocks. The U-Pb geochronological analyses of zircon grains from two outcrops of metavolcanic rocks yield ages of 628 ± 18 Ma (SHRIMP) and 636 ± 30 Ma (conventional multi-grain analyses). These ages are quite close to the metamorphic event recorded in the Itaiacoca Group (628 – 610 Ma), suggesting a short interval between the formation of these rocks and closure of the basin. Furthermore, this volcanism is very close to the age of formation of the Três Córregos (630 Ma) and Cunhaporanga (590 Ma) granitic batholiths, admitted as associated with a probable magmatic arc. Such an isotopic pattern characterizes a Neoproterozoic tectonic scenario involving volcanism, metamorphism and granitic plutonism, interpreted here as the final stages in the evolution of the Itaiacoca Basin.

Palavras-chave: U-Pb (zircões), seqüências metavulcano-sedimentares, evolução tectônica.

RESUMO

O objetivo principal deste trabalho é apresentar e discutir as idades geocronológicas U-Pb, em zircões de rochas metavulcânicas pertencentes ao Grupo Itaiacoca. Este é representado por uma seqüência metavulcano-sedimentar, que ocorre como uma faixa relativamente estreita, limitada a norte pelo Batólito Granítico Cunhaporanga, sendo balizada a sul, através da Zona de Cisalhamento Itapirapuã, pelo Batólito Granítico Três Córregos e pelos metassedimentos do Grupo Açungui. Os estudos geológicos efetuados na porção sul da Faixa Itaiacoca permitiram reconhecer três unidades geológicas maiores, representadas, da base para o topo, por metarcóseos (com importante contribuição vulcânica-vulcanoclástica), rochas metacarbonáticas e rochas metapelíticas-metapsamíticas. Análises geocronológicas U-Pb realizadas em zircões de dois afloramentos de rochas metavulcânicas, forneceram idades de 628 ± 18 Ma (SHRIMP) e 636 ± 30 Ma (convencional). O metamorfismo dessas rochas parece ter ocorrido em épocas bastante próximas (628 – 610 Ma) à cristalização dos zircões, sugerindo curto intervalo de tempo entre o vulcanismo estudado e os episódios de fechamento da bacia. Não obstante, as idades obtidas também se aproximam da época de formação dos batólitos graníticos Três Córregos (630 Ma) e Cunhaporanga (590 Ma), admitidos como prováveis arcos magmáticos. Tal padrão isotópico caracteriza um cenário tectônico Neoproterozóico envolvendo vulcanismo, metamorfismo e plutonismo granítico, interpretados como relativos aos estágios finais da evolução da Bacia Itaiacoca.

INTRODUCTION

The Itaiacoca Group is a metavolcanoclastic sequence occupying a narrow, NE-SW oriented belt between the Cunhaporanga (NW) and Três Córregos (SE) granitic batholiths in eastern Paraná State, Southeast Brazil. Here we discuss the age pattern revealed by SHRIMP and conventional U-Pb dating of zircon from metavolcanic rocks of this Group. We use current views on tectonic positioning, lithostratigraphic characteristics, and previously obtained ages to discuss the possible geological scenarios, which were associated with the deposition and subsequent evolution of the belt (Figure 1).

The interpretation of the tectonic position of Precambrian basins – rifted continental margin, continental rift back arc, fore arc, intra-arc, interarc - is often not an easy task since the some of the essential features may not always be evident. Furthermore, it is usually necessary to allow for the profound transformations which occur during the evolution from the original depositional environment through subduction and collision processes with accompanying deformation, development of shear zone systems, and intrusion by granitic plutons. Finally, some of the essential geological records may be missing.

GEOLOGICAL FEATURES

The bibliography on the Precambrian units of eastern Paraná and southeastern São Paulo is quite extensive, including more than a hundred publications and reports. The earlier works were dedicated to geological reconnaissance, and separated the Crystalline Basement Complex from the metasedimentary and metavolcanosedimentary sequences of the Açungui Group.

Almeida (1956) studied the region around Itaiacoca and the Serra das Antas, the area of the present study. He proposed that a packet of dolomitic marble, quartzite, phyllite and metabasic rocks be separated as the Itaiacoca Formation. On the basis of the similarity of rock types and fossil content (*collenia itapevensis sp.)*, he correlated this formation with the Capirú Formation found south of the Lancinha shear zone (Figure 1). His proposal was supported by Bigarella and Salamuni (1956).

In attempts to define and interpret the Açungui Group in Paraná and the Apiaí fold belt in Paraná and São Paulo, many authors considered that the different metavolcanosedimentary sequences were deposited synchronically in separate basins. There was, however, disagreement about the ages of these basins, whether they were formed in both the Meso- and the Neo-proterozoic, or whether they were restricted to the Neoproterozoic. The difficulties in establishing stratigraphic columns and tectonic relationships for the metavolcanosedimentary terrains are shown by the numerous, different proposals. Fassbinder (1996) found about forty suggestions, some of which are totally discrepant.

The many specialized studies of topics such as sedimentary environments, magmatism, metamorphism and structural characteristics, tectonic compartments and geochronology (Marini *et al.*, 1967; Fairchild, 1977; Hasui *et al.*, 1975; Soares, 1987; Campanha *et al.*, 1987; Biondi, 1989; Fiori, 1990, 1992; Basei *et al.*, 1992; Reis Neto, 1994; Soares & Rostirolla, 1997; Campanha & Sadowski, 1999; Campos Neto, 2000, Basei *et al*., 2002; Weber *et al*.; 2002; Cury *et al*., 2002) contributed to define and interpret the Apiaí Fold Belt in Paraná and São Paulo states.

The subdivision of the Itaiacoca Formation or Group into different rock units on the basis of lithological, stratigraphical and sedimentological criteria was undertakern by Chiodi Filho (1984), IPT (1985), Trein *et al.* (1985), Theodorovicz & Câmara (1988) Souza (1990) and Reis Neto (1994). Souza (1990) adopted the denomination Itaiacoca Group, following the previous suggestions of Hasui *et al*. (1984) and IPT (1985). He defined four lithostratigraphic units or formations which were later adapted, with slight modifications, by Reis Neto (1994).

In the present study which has an essentially geochronological approach, we prefer to treat this region (Apiaí Fold Belt) as a series of five large geographical compartments separated by important lineaments. These compartments were informally named Bocaiúva do Sul, Rio Ribeira, Guapiara, Ribeirão Branco and Campina dos Veados, and have as their infrastructure the Atuba Complex, composed of granite-gneisses and migmatites, which is located to the Southeast (Siga Jr. *et al.*, 1995). The Campina dos Veados Compartment includes the metavolcanosedimentary sequences of the Itaiacoca Group and the Cunhaporanga granite batholith (Fuck *et al.*, 1967, 1971; Prazeres Filho, 2000, Prazeres Filho *et al*., 2001).

The geological information used here was obtained during geological mapping of the southern part of the Itaiacoca belt between Abapã and Socavão, PR undertaken by members of the IGc-USP in 1997 (Prazeres Filho *et al.*, 1998; Siga Jr *et al.*, 2001; Figures 3 and 4). In this area, three main units are recognized, from base to top: metawackes with an important volcanic contribution; metacarbonate and metapelitic - metapsammitic rocks. Regional metamorphism is in the chlorite to biotite zones of the greenschist facies (Table 1). This succession is similar to that described by Souza (1990) and Reis Neto (1994) who also considered that the Água Clara Formation (SE of Itapirapuã Shear Zone), usually con-

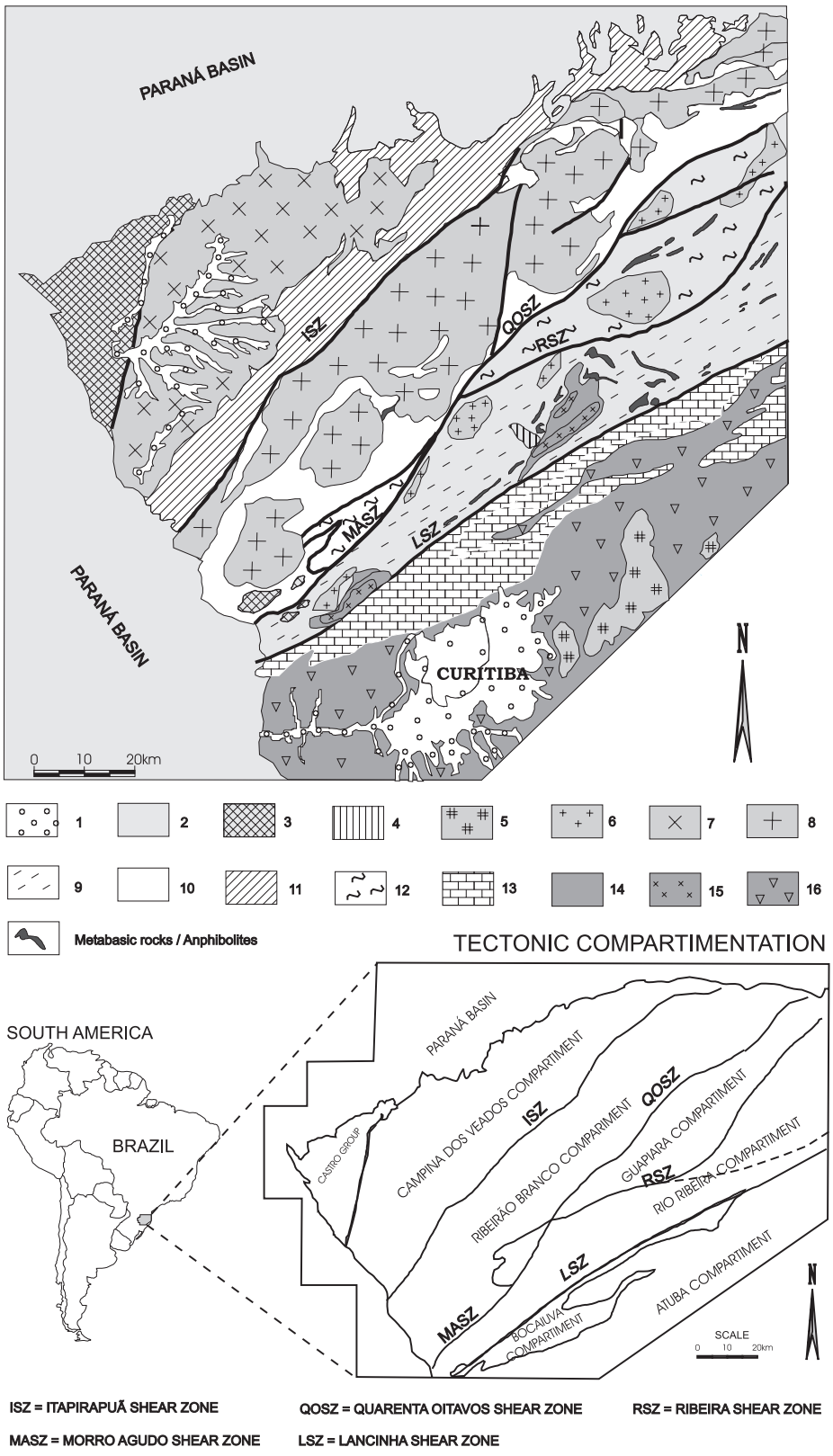

Figure 1. Geological sketch map showing the main geological units and tectonic subdivisions in eastern Paraná and southern São Paulo.

1 – Quaternary cover; **2 -** Paraná Basin; **3 -** foreland basins {Castro (NW) and Camarinha (SW) Groups}; *Campina dos Veados Compartment:* **7 –** Cunhaporanga batholith [600 - 590 Ma], **11 –** Itaiacoca Group; *Ribeirão Branco Compartment:* **8 –** Três Córregos batholith and granitic massifs associated [630-600 Ma], **10 –** Água Clara sequence [c.1450 Ma];*Guapiara Compartment:* **12 –** Lajeado and Antinha sequences [Neoprot.?]; *Rio Ribeira Compartment:* **9 –** Votuverava sequence [c.1450 Ma], **14 –** Perau and Betara sequences [1450 Ma], **15 –** deformed alkaline [1750 Ma] and calc-alkaline granitoids [2100 Ma], **6 –** syn to post-colisional granitoids [590-570Ma], **4 –** Tunas syenite [85 Ma]; *Bocaiuva Compartment:* **13 –** Capirú sequence; *Atuba Compartment:* **16 –** Atuba gneiss-migmatite complex, **5 –** alkaline to peralkaline granitoids of Serra do Mar suite (after Campanha, 1991; Basei *et al.*, 1992; Siga Jr, 1995; Campos Neto, 2000).

Table 1. Metamorphic features and mineralogic association of Itaiacoca group rocks.

Unit	Regional Metamorphism Conditions	Regional Metamorphism Paragenesis	Contact Metamorphism	Dynamic Metamorphism
Itaiacoca Group	Green-Schist Facies (CloriteZone)	Qz+Fk+Se Qz+Se Bio(?)+Qz+Cl Qz+Cl±Opa Cl+Se+Qz Cc+Dol±Qz Dol+Cc Se+Qz±Grf	• silicification associated with Cunhaporanga Granitic Complex; • Adz, Mo ± Gar in metapelites; • Tlc ± Tr in metadolomites.	cataclasites, mylonites, silicification. (Uirapuru Shear Zone and Campina do Estepe Shear Zone)

Act – actinolite; **Adz –** andaluzite; **Bio –** biotite; **Cc –** calcite; **Cl –** chlorite; **Dol –** dolomite; **FK –** potassic feldspar; **Gar –** garnet; Grf – graphite; **Mu –** muscovite; **Opa –** opaques; **Qz –** quartz; **Se –** sericite; **Tlc –** talc; **Tr -** tremolite.

sidered to be part of the Açungui Group, forms part of the Itaiacoca Group.

In the basal unit, metamorphosed feldspathic sandstones predominate, and contain interbedded metavolcanic and metavolcanoclastic rocks. Graded and cross beddings are preserved in the metasandstones, which are immature, rich in quartz and microcline clasts, suggesting that the source area was granitic. The clasts are set in a fine-grained matrix composed of clay minerals, sericite and chlorite. The metavolcanic rocks form flows of variable thickness interbedded with metapsammites. Thin levels of pale green phyllites (volcanic ash beds?), and other possible metapyroclastic rocks (?) are also observed. The rocks are usually highly vesicular or rich in amygdales (Trein *et al.*, 1985; Reis Neto, 1994), which were stretched during deformation (Photos 1 and 2). The rocks are often sanidine-rich, and also contain devitrified material. We identify these rocks as trachytes, which according to Reis Neto (1994), are very rich in K_2O (6 - 12%) and other LILE.

Dolomitic marbles interbedded with impure marbles (calcic phyllites and carbonate-bearing phyllites) predominate in the middle unit. Wavy, lenticular, climbing and cross bedding structures are preserved, as are pisoliths and oolites. Banks of columnar stromatolites are associated with algal mats (Photo 3). The marbles host levels of pale green chlorite-sericite phyllites, which may be former volcanic ashes, and metatholeiites with geochemical characteristics of extensional environments (Reis Neto, 1994). In the proximity of the Cunhaporanga batholith, these rocks are transformed into contact metamorphic assemblages rich in talc and tremolite.

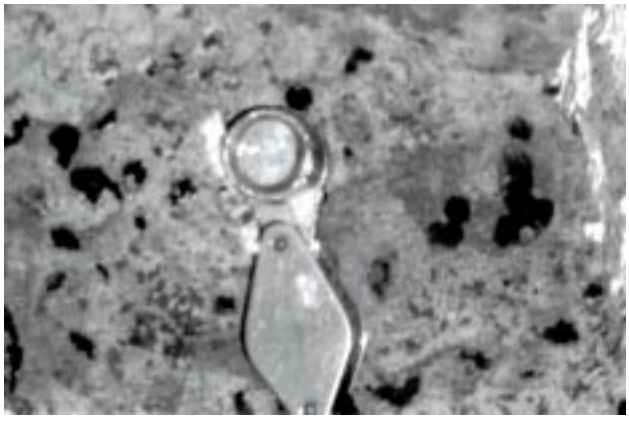

Photo 1. Vesicles in metavolcanic rocks.

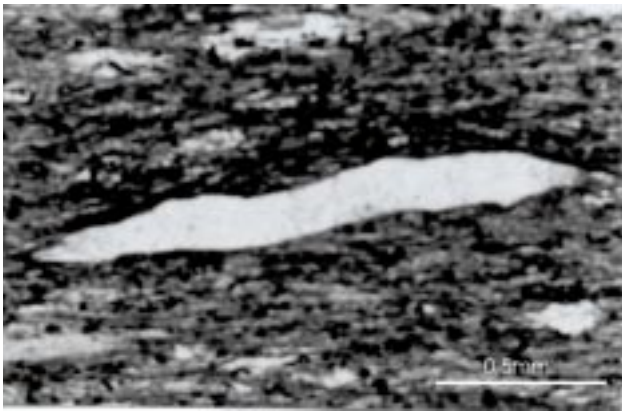

Photo 2. Microphotograph of stretched amygdales containing quartz parallel to the S_1 foliation; crossed polarizers.

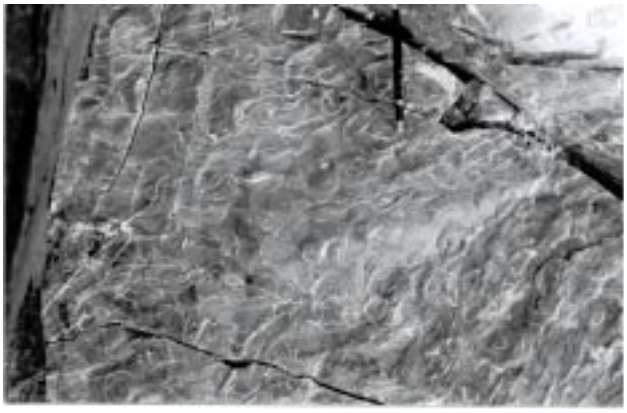

Photo 3. Stromatolites in dolomitic marbles.

The thin upper unit is formed by orthoquartzites and fine- to medium-grained sandstones, interbedded with sericite phyllites, graphite phyllites, psammitic-pelitic metarhythmites, metasiltites and meta-argillites. Horizontal lamination, normal micro-scale gradational bedding and low-angle cross lamination are preserved.

The S_1 foliation is almost parallel to the bedding S_o, and is defined by orientation of sericite, chlorite and, very rare biotite. S_1 is affected by heterogeneous crenulation (Table 2; Figure 2). This structural pattern is different from that seen in the Açungui basin (Ribeirão Branco, Guapiara, Rio Ribeira and Bocaiuva Compartiments, Figure 1), where deformation is controlled by low- and high-angle shear zones, and transport is southwards.

Table 2. Deformation phases related with structural features.

Observed Structures	Features
S_0	The primary structures, including geopetal structures, amygdales, stromatolites and algal layer, are well preserved in metarkoses/metavolcanic and metacarbonate units. The surface's top prevail in a normal position with N40E trend direction dipping to NW and SE.
D_1	A low metamorphic grade, thrust-related foliation is developed parallel to So, and is well defined by stretched amygdales (photo 2). Associated folds with N40E axial plane direction are present. S_1 is well defined in metapelitic and metavolcanic rocks interbedded in meta-arkose.
D_2	D_2 is defined by open folds, which develop a cleavage S_2 (axial plane) with NE-SW direction, parallel to the Itaiacoca Belt trend. The S_2 is expressive in metapelitic, metavolcanic and metarkose rocks, less so in metacarbonatic rocks. (figure 2 and photo 4)

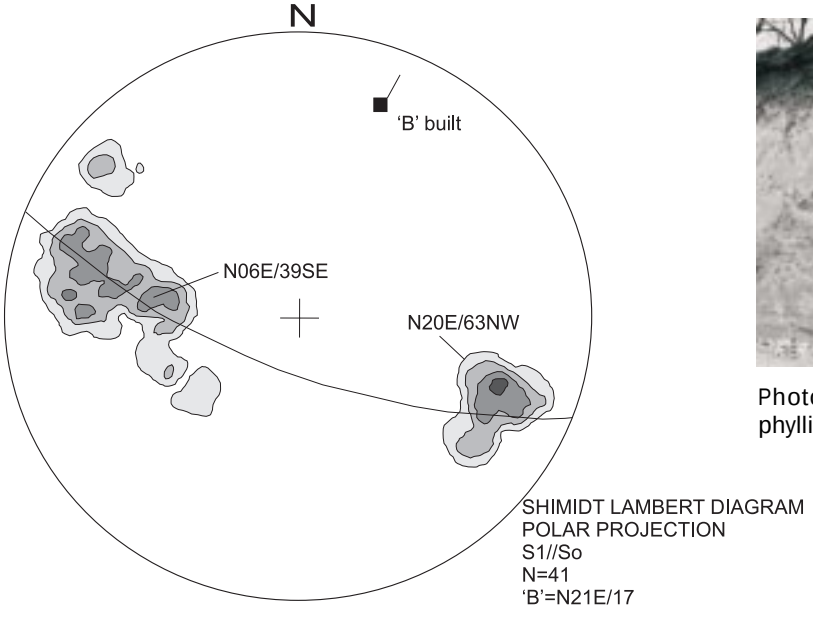

Figure 2. Stereogram of D_2 folds standard in metavolcanic rocks (northern portion of Itaiacoca Group - PR).

Photo 4. D_2 fold (axis direction = S60W/40) in phyllites of Itaiacoca Group, PR.

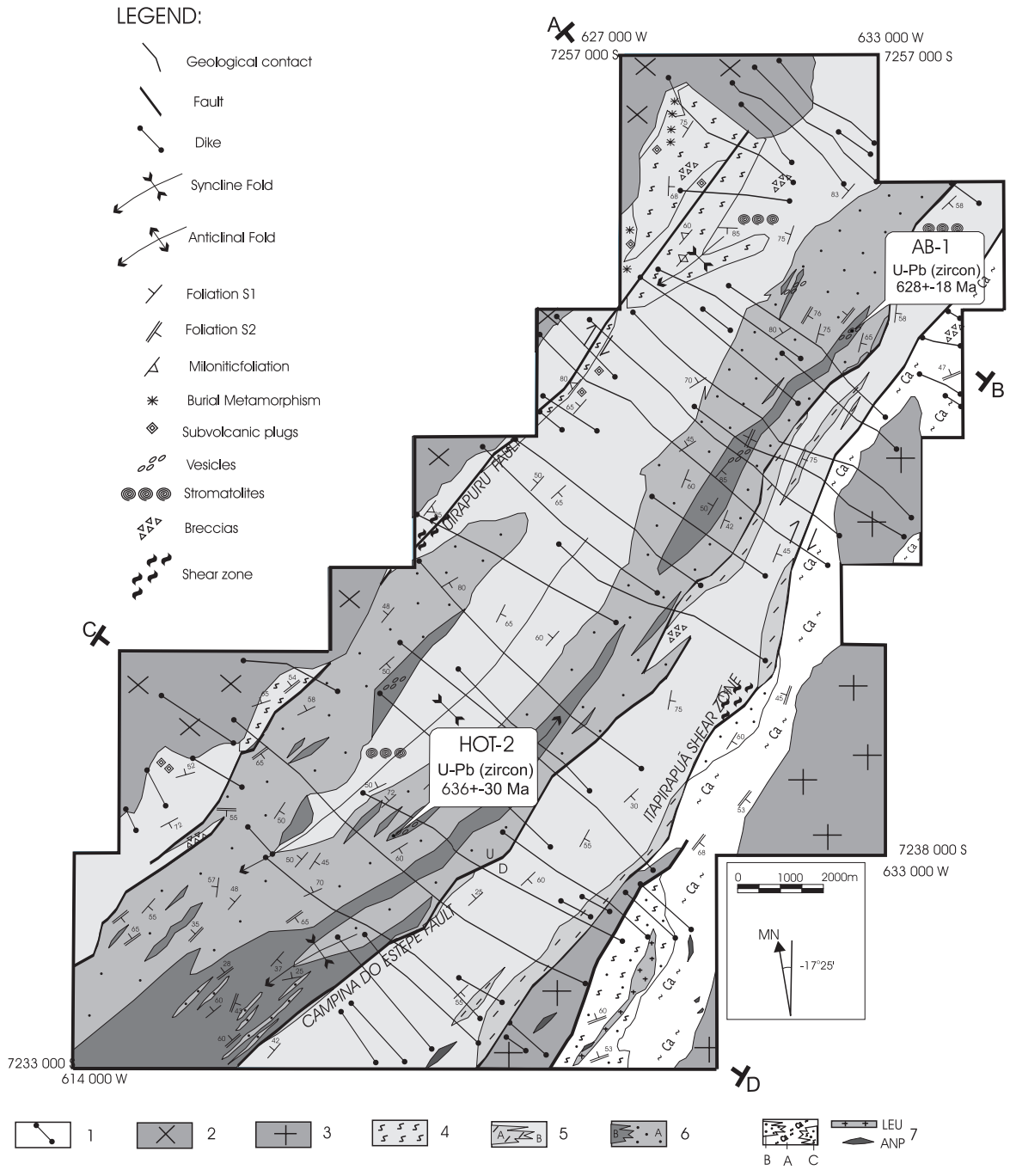

Figure 3. Geological map of Itaiacoca Group, southeastern Paraná (Prazeres Filho et al., 1998; Siga Jr. et al., 2001).

1 - Mesozoic dykes; **2 -** Cunhaporanga Granitic Batholith; **3 -** Três Córregos Granitic Batholith; *Itaiacoca Group (4 a 6):* **4 - upper unit -** quartz-shists, mica-shists, phyllites, metapelitic rocks with andaluzite; **5 - intermediated unit** - A) metamarls, B) stromatolitic metadolomites and metabasic rocks; **6 - basal unit** - A) feldspathic metarenites and metaconglomerates (subordinated), B) interbedded metavolcanic and metavolcanoclastic rocks; **7 -** Água Clara Formation: A) Calc-silicate rocks with interbedded leuco syenogranites (Leu) and anphibolites (Anp), B) quartzites, C) muscovite garnet shists.

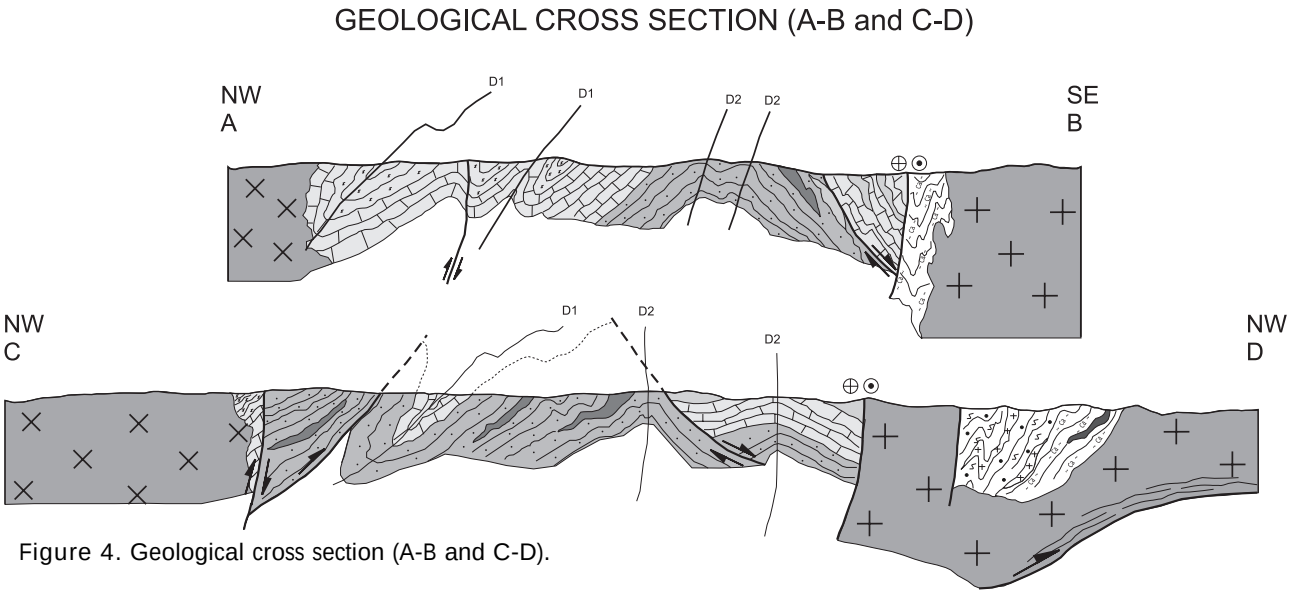

Figure 4. Geological cross section (A-B and C-D).

GEOCHRONOLOGICAL STUDIES

Available geochronological data based on Pb-Pb, Rb-Sr and Sm-Nd measurements in marbles and metavolcanic rocks (Figures 3 and 4) suggest that the age of sedimentation of the Itaiacoca Group is Mesoproterozoic, between 1250 and 1080 Ma (Reis Neto, 1994).

U-Pb analyses of zircon grains from metavolcanic rocks interbedded with metawackes collected at points AB-1 and Hot-2 (Figure 3, Table 3) yield ages significantly different from the Mesoproterozoic age preferred by Reis Neto (1994). Zircon grains from AB-1 were analysed by SHRIMP after examination using cathodoluminescence and back-scattered electron images (Research School of Earth Science – Australian National University, Canberra). Weakly tinted, euhedral, long prismatic crystals predominate. They present homogeneously distributed internal growth zones, and cloudy oscillatory zones at the borders. Analyses of points in the homogeneous growth zone, and in the center of the border zone yielded an age of 628 ± 18 Ma (MSWD = 1) using the Tera-Wasserburg diagram. This age is believed to represent the age of crystallization of the volcanic rocks. Points analysed in the oscillatory border zones of grains of irregular and short prismatic shapes yielded ages of 2480 Ma and 1990 Ma. These ages are thought to represent inherited material from Paleoproterozoic sources (Figure 5).

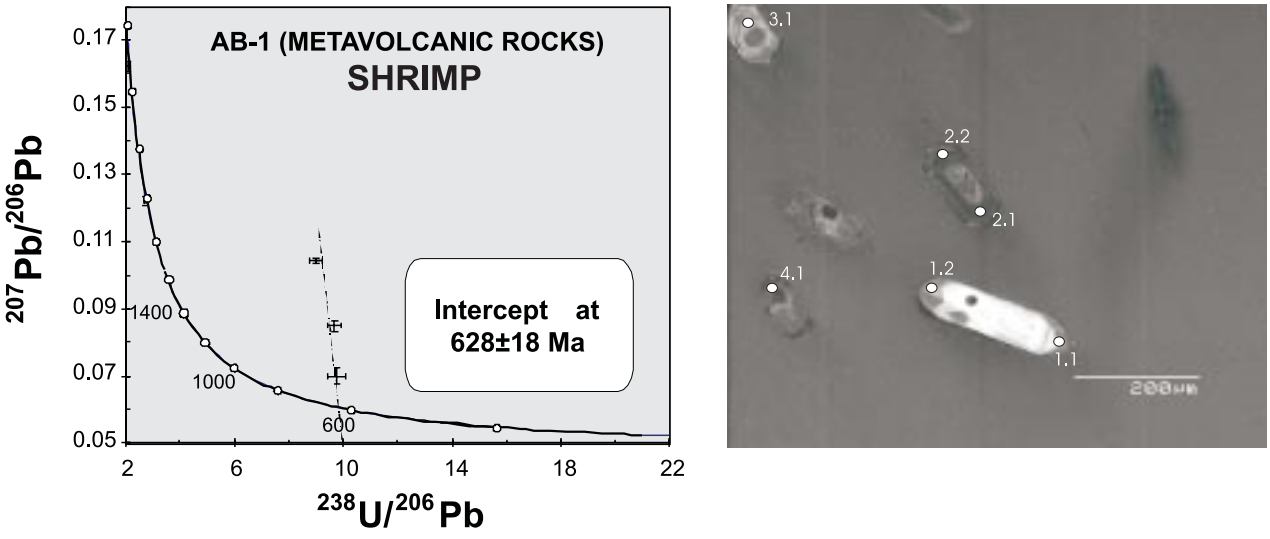

Figure 5. Tera-Wasserburg diagram and cathode-luminescence image of zircon grains from metavolcanic rocks at point AB-1 in the Itaiacoca Group (PR).

Zircon grains from point Hot-2 are colourless, inclusion-rich long prisms. The analytical points for three magnetic fractions fall close to the concordia, and define an upper intercept (crystallization) age of 636 ± 30 Ma (Figure 6), similar to that obtained for AB-01 point.

Although these Neoproterozoic ages must be considered as preliminary, nevertheless they represent the volcanic rocks formation time.

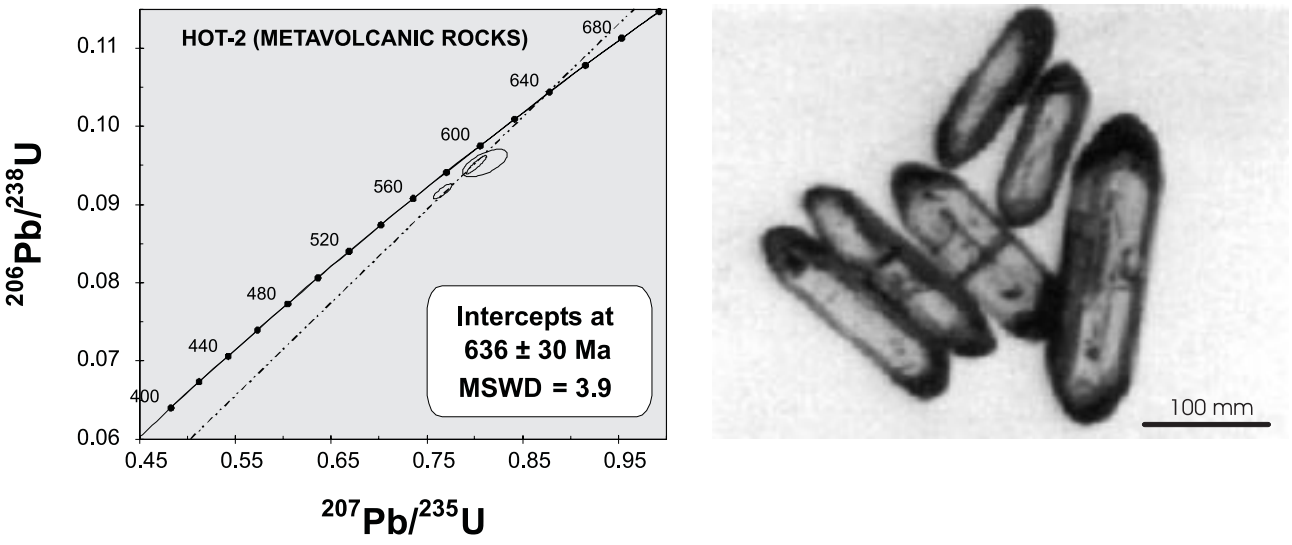

Figure 6. Concordia diagram and transmitted light photograph of zircon grains (215x) from metavolcanic rocks at point Hot 2 in the Itaiacoca Group (PR).

Table 3. Data for SHRIMP and conventional U-Pb zircon grain analyses.

AB-01 SHIRIMP U/Pb ZIRCON ANALYSIS

Labels	Grain type	Uppm	Thppm	Th/U	Comm. ^{206}Pb%	Ratio $^{238}U/^{206}Pb$	Ratio $^{207}Pb/^{206}Pb$	Date Ma±1δ	% disc	207-corr. (206/238)
1.1	e,osc,rex,p	35	40	1.12	1.33±0.29	9.777±0.330	0.0700±0.0024	620±20		620±20
1.2	og,hd,p	126	69	0.55	3.15±0.20	9.678±0.261	0.0849±0.0016	615±16		615±16
2.1	e,osc,p	1301	1053	0.81	9.29±0.08	13.927±0.285	0.1352±0.0007	407±8		
2.2	e,osc,p	755	701	0.93	5.49±0.05	9.019±0.206	0.1041±0.0004	642±14		642±14
3.1	e,osc,p	84	151	1.80	0.57±0.12	2.094±0.047	0.1622±0.0014	2479±14	2	
4.1	e,osc,p	211	329	1.56	0.41±0.11	2.706±0.063	0.1223±0.0012	1990±18	2	

labels (x,y) = grain number. analysis number
bold = used in pooled date

grain type legend:
p = prism; **e** = end on edge;
og = overgrow; **c** = core; **rex** = recrystallised;
osc = oscillatory finescale zoning;
h = homogeneous (**d**=dark or **b**=bright)

grains 1 & 2: uncorrected ratios and 207 corrected 206Pb/238U date;

grains 3 & 4: 204 corrected ratios and $^{207}Pb/^{206}Pb$ date corrected with model Pb of Cumming and Richards (1975) for likely age of rock

all errors are 1δ

628±18
mswd=1.0

HOT-02 CONVENTIONAL U/Pb ZIRCON ANALYSIS

Sample (SPU)	Grain type	$^{207}Pb/^{235}U$	Er.	$^{206}Pb/^{238}U$	Er.	Coeff.	$^{206}Pb/^{204}Pb$	Pb(ppm)	U(ppm)	Weigth	206/238 Age(Ma)	207/235 Age(Ma)	207/206 Age(Ma)
755	p,bt,cl	0.921362	±1.71	0.098227	±1.3	0.7697	162.21	44.93	317.8	35.79	604	663	869
756	pbt,inc	0.801021	±1.07	0.095156	±0.988	0.9229	1377.63	39.87	395.9	76.17	586	597	641
758	p,bt,cl	0.8423	±1.15	0.096217	±0.993	0.8663	1378.96	35.44	345.5	120.32	592	620	725
757	lp,inc	0.765822	±1.06	0.091754	±0.891	0.8472	1468.67	25.83	270.2	52.35	566	577	623

grain type legend: **p** = prism; **bt** = bi-terminated; **cl** = clear; **inc** = with inclusions.

FINAL REMARKS

When the conventional and SHRIMP zircon ages of the metavolcanic rocks intercalated in the basal metapsammites of the Itaiacoca Group are considered together with the lithostratigraphic sequence, the structural pattern and the tectonic position of the Group, the following observations can be made:

1. the rocks of Itaiacoca Group are pinched between the Cunhaporanga (NW) and Três Córregos (SE) granitic batholiths, which are thought to be parts of Neoproterozoic (630 - 590 Ma) magmatic arcs (Prazeres Filho, 2000);

2. the Três Córregos batholith is slightly older than the Cunhaporanga batholith, and the latter caused contact metamorphism in the Itaiacoca Group;

3. the basal unit of the Itaiacoca Group contains an important alkaline metavolcanic component, interbedded with metapsammites containing quartz and K-feldspar clasts suggestive of a granitic source region;

4. the geochronological data reported here show that the metavolcanic rocks were erupted at about 635-630 Ma;

5. the age of sedimentation of Itaiacoca Basin seems to lie near the Mesoproterozoic/Neoproterozoic limit according to Reis Neto (1994). This author suggests ages of about 1250 – 1080 Ma (Rb-Sr, Pb-Pb) for metabasic rocks and marbles of upper unit of Itaiacoca Group (Bairro dos Campos Formation);

6. the S_1 foliation, parallel to the compositional banding, contains sericite, chlorite and rare biotite, and is heterogeneously crenulated;

7. unpublished K-Ar analyses of neoformed fine-grained (< 2μm) sericites from phyllites and metavolcanic rocks showed that the metamorphism ocurred between 628 and 610 Ma (Basei, verbal communication).

The U-Pb (zircon) ages from metavolcanic rocks of the Itaiacoca Group (635 – 630 Ma) constitute an important geochronological bench mark in the evolution of this basin, once they should represent 'minimum ages' of Itaiacoca's sedimentation.

These ages are quite close to the metamorphic event recorded in the Itaiacoca Group (628 – 610 Ma), suggesting an interval between the formation of this rocks and closure of the basin. Furthermore, this volcanism is very close to the age of formation of Três Córregos and Cunhaporanga granitic batholiths, admitted as associated with a probable magmatic arc (Prazeres Filho, 2000) with ages between 630 Ma (Três Córregos Batholith) and 590 Ma (Cunhaporanga Batholith).

Such an isotopic pattern characterizes a Neoproterozoic tectonic scenario involving volcanism, metamorphism and granitic plutonism, interpreted here as the final stages in the evolution of the Itaiacoca Basin.

In addition, isotopic studies on metabasic rocks (upper unit) as well detritic zircons have been carried out in the Itaiacoca Group rocks, which provide a better understanding of the evolution of Itaiacoca Basin.

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