

**III INTERNATIONAL COLLOQUIUM
VENDIAN-CAMBRIAN OF W-GONDWANA**

**University of Cape Town
23-24 October 2003**

**PROGRAMME AND
EXTENDED ABSTRACTS**

**Editor:
Hartwig E. Frimmel**



**International Geological Correlation Programme
Project 478**

"Neoproterozoic-Early Paleozoic Events in SW-Gondwana"

Programme

Thursday, 23 October 2003

09:00 – 10:00

Registration

10:00 – 10:10

Welcome by H.E. Frimmel

10:10 – 10:30

Opening address by C. Gaucher, Leader of IGCP 478

10:30 – 11:00

M.A. Fedonkin: Metazoans of the Vendian Period in the aspects of palaeoecology and palaeogeography: White Sea, Russia

11:00 – 11:30

C.K. Brain, A.R. Prave, A.E. Fallick & K.-H. Hoffmann: Sponge-like microfossils from Neoproterozoic intertillite limestones of the Otavi Group in northern Namibia

11:30 – 12:00

C. Gaucher & G.J.B. Germs: Acritarch biostratigraphy and correlations of the late Vendian Cango Caves Group, Saldania Belt (South Africa)

12:00 – 12:30

G. Acenolaza & F. Acenolaza: Trace fossils, microbial mats and sedimentary structures in the Puncoviscana Formation of northwestern Argentina (Neoproterozoic – Lower Cambrian): Their record on a varied spectrum of palaeoenvironmental settings

12:30 – 14:00 Lunch break

14:00 – 14:30

J. Bossi, E. Pecoits & R. Navarro: Geological evidence of one allochthonous block attached to the east of Uruguay in the Cambrian: Cuchilla Dionisio Terrane

14:30 – 15:00

H.E. Frimmel, M.A.S. Basei & J. Jacob: The Missing Link between the Dom Feliciano and Gariep Belts

15:00 – 15:30

E. Pecoits: Age and preliminary correlation of the Las Ventanas Formation and Bom Jardim-Cerro do Bugio allogroups (Vendian, Uruguay and Brazil)

15:30 – 16:00 Coffee Break

16:00 – 16:30

V.U. Zimmermann & G.J.B. Germs: Black Sands as tracers of provenance: A heavy mineral case study of the Early Paleozoic Haribes Member (Nababis Formation, Fish River Subgroup) of the Nama Group in Namibia – first results

16:30 – 18:00

IGCP478 Planning session I: Nomination of national coordinators, formation of working groups, research strategies

Friday, 24 October 2003

09:00 – 09:30

P.C. Boggiani, A.N. Sial, M.Babinski, V.P. Ferreira: New carbon isotopic data from the Corumbá Group as a contribution to a composite section for the Neoproterozoic III in South America

09:30 – 10:00

T. T. Eerola: Neoproterozoic diamictites in southern Brazil: A preliminary survey in the Santa Catarina State

10:00 - 10:30

C.J.S. Alvarenga, R..V. Santos, M.A. Dardenne, E.L. Dantas, E.R. Brod & S.M.C.L. Gioia: C, O and Sr isotope evidence of Sturtian and Marinoan glaciations in Brazil

10:30 – 11:00 Coffee break

11:00 – 11:30

D.G. Poiré, P.D. González, J. M. Canalicchio & F. García Repeto: Stromatolites and stratigraphy of the Precambrian sedimentary succession of the Verdún Hill, Minas, Lavalleja Department, Uruguay

11:30 – 12:00

U. Zimmerman: Provenance study on Neoproterozoic rocks of NW Argentina: Puncoviscana Formation – first results

12:00 – 12:30

P.E. Zalba & R.R. Andreis: The Tandila System, Buenos Aires, Argentina

12:30 – 14:00 Lunch break

14:00 – 14:30

G. Viola: Quantitative constraints on the post-breakup evolution of the high-elevation Namibian passive margin shoulder: combined use of apatite fission track and (U-Th)/He geochronology

14:30 – 15:15

H.E. Frimmel: The Gariiep Belt

14:15 – 15:45

G.J.B. Germs: The Nama Basin

15:45 – 16:30

IGCP478 Planning session II: Post-graduate student projects within the IGCP478, Planning of next meeting in Brazil

Trace fossils, microbial mats and sedimentary structures in the Puncoviscana Formation of northwestern Argentina (Neoproterozoic – Lower Cambrian): Their record on a varied spectrum of palaeoenvironmental settings

G. Aceñolaza & F. Aceñolaza

INSUGEO.- Miguel Lillo 205. 4000 San Miguel de Tucumán. Argentina, insugeo@unt.edu.ar

The Puncoviscana Formation (*s.l.*) (Neoproterozoic - Lower Cambrian) constitutes a thick siliciclastic succession widely distributed in the NW region of Argentina. Strata are characterized by a varied spectrum of highly folded and slightly metamorphosed sediments. Schists, waques, pelagic clays, sandstones, turbidites, conglomerates, limestones and minor volcanics display the many palaeoenvironmental settings represented by these rocks.

Several stratigraphic and sedimentological papers have focused rocks of the Puncoviscana Formation. They have attempted detailed analysis on strata, with different goals, resulting on an preliminary knowledge of the unit (Salfity et al., 1975; Omarini and Baldis, 1984; Durand and Spalletti, 1986; Durand, 1990; Moya, 1998). Jezek (1990) highlights as an integrated proposal of sedimentological study in the formation, with a comprehensive work in the southern sector of the Cordillera Oriental of northern Argentina. Well-preserved bedding planes are displayed all along 800 km of outcrops from La Rioja province up to Jujuy province in the north. Few localities display the strata little affected by cleavage and metamorphic deformation, offering outstanding possibilities to observe bioturbation, microorganism related and sedimentary structures.

Ichnofossils

Ichnofossils are among the elements better known in the sequences, with an abundant bibliography resulting after 30 years of fieldwork. This research that started at the INSUGEO (National University of Tucumán- Conicet) during the 70's, has given an acceptable knowledge of the trace fossils and the biodiversity of the Puncoviscana sea. Several papers have recently summarized these data, as Aceñolaza et al. (1999) and Aceñolaza and Alonso (2001), highlighting a proposed zonification of the basin on the basis of ichnoassociations:

a) *Beltanelliformis* Ichnoassociation, with *Helminthopsis* isp. *Treptichnus* cf. *aequalternus*, *Monomorphichnus* isp. and an enigmatic "annelid tube" regarded as *Sphenotallus* ? sp. Several wrinkle structures probably related to biomats have also been described in the area (formerly interpreted as *Squamodictyon*, *Protopaleodictyon*, *Kinneya* and others) (Aceñolaza & Aceñolaza, 2001). This area is represented as well in the northern sector of Tucumán (La Higuera area), including the southwards La Cébila - Angulos areas in La Rioja province.

b) The originally though distinct "*Nereites* Ichnoassociation", widely distributed between the Sierra de Mojotoro and Cachi, in Salta province, may be unified to the first one on the basis on new findings of trace fossils.

Nereites saltensis accompanying by several ichnogenera: *Cochlichnus*, *Helminthoidichnites*, *Taphrelminthopsis*, *Glockerichnus*, *Neonereites*, *Dimorphichnus*, *Asaphoidichnus*, *Tasmanadia* are some remarkable trace fossils in the association.

c) Lastly, the "*Oldhamia* Ichnoassociation" is well represented in the Sierra de la Ovejera of Catamarca province, and in the western border of the Cordillera Oriental of Salta (Muñano, Abra Blanca and San Antonio de los Cobres). Particularly this ichnoassociation is integrated by *Monomorphichnus*, *Dimorphichnus*, *Cochlichnus*, "*Scolicia*", *Neonereites*, *Helminthoidichnites*, *Didymaulichnus* and three *Oldhamia* isp (*O.flabellata*, *O.radiata* and *O.antiqua*). Normally *O. flabellata* is more frequent in San Antonio de los Cobres while *O.radiata/antiqua* in Muñano and

La Ovejería. This association is generally vinculated to heterolithic and shaly facies interpreted by Jezek (1990) as intermediate and distal facies of on shore fan.

"Wrinkle" structures are common elements during the Proterozoic-Cambrian marine siliciclastic sediments. Their knowledge has increased during the last decade, and now their genesis is mostly regarded as microbial mat related (Hagadorn & Bottjer, 1999) Many elements recorded in the Puncoviscana Formation are now interpreted as biomat related structures (Aceñolaza & Aceñolaza, 2001). This situation, together with the ichnological record of the unit display the "agronomic revolution" of Seilacher & Pflüger (1994). This revolution is reflected in the Precambrian/Cambrian transition, by the record of microbial mat dominated substrates, or matgrounds, being displaced by the bioturbated substrates, or mixgrounds. The Precambrian biotas of the Puncoviscana Formation possibly had microbial mat related life stiles. Normally represent undertracks of different organism produced above or between sedimentary layers. Several outcrops of Salta and Jujuy display this situation, represented by the *Oldhamia* and *Nereites* ichnoassociation suite. In the first one, appendages penetrated and impressed the bedding planes (as *Diplichnites*, *Dimorphichnus*, or *Tasmanadia*), while in the second are frequent crawling traces (as *Cochlichnus*, *Helmithoidichnites*).

Varied sedimentary structures produced by a current moving on the muddy bottom are also frequent elements in the record of the Puncoviscana Formation, always associated to the different facial characteristics of the strata. Tool marks may have been caused by the impact of solid particles driven by currents (inorganic material or sclerotized parts of the biota) in the Puncoviscana sea. Chevron casts are common in the slates, and they may have resulted by the hidroplasticity of pelites, that generates a series of crests towards the opposite direction of current. If the object/animal is light, it is pulled up by currents, resulting on discontinuous and short crests as recorded in the unit. Ripple marks, rill moulds, linguiform flute casts, crescent moulds, grooves are common elements in ceirtan areas of the Puncoviscana Formation as in the Escoipe, Tilcara and Purmamarca creeks.

References

- Aceñolaza, F. & Aceñolaza, G. 2001, Ichnofossils and microbial activity in the Precambrian/ Cambrian transition of Northwestern Argentina. *Paleoworld*, v. 13, p. 241-244.
- Aceñolaza, F., Aceñolaza, G. & Esteban S. 1999 Bioestratigrafía de la Formación Puncoviscana y unidades equivalentes en el NOA. *In: González Bonorino, G. (Ed.), Geología del Noroeste argentino. Relatorio del 14° Congreso Geológico Argentino (Salta) v. 1, p. 91-114.*
- Aceñolaza, F. and Alonso R. 2001, Ichnoasociaciones de la transición Neoproterozoico/Cámbrico inferior en el Noroeste de Argentina.
- Durand, F. & Aceñolaza, F.G. 1990, Caracteres biofaunísticos, paleoecológicos y paleogeográficos de la Formación Puncoviscana (Precámbrico superior-Cámbrico inferior) del Noroeste argentino. *In: Aceñolaza et al (Eds.), El Ciclo Pampeano en el Noroeste Argentino. Serie Correlación Geológica 4, 9-36.*
- Durand, F. & Spalletti, 1986, Las facies turbidíticas del Precámbrico superior-Cámbrico inferior en la zona de Corralito, provincia de Salta. *Resúmenes expandidos 1° Reunión Argentina de Sedimentología*, p. 113-116.
- Hagadorn J. & Bottjer, D. 1999, Restriction of a Late Neoproterozoic biotopes suséct. microbial structures and trace fossils at the Vendian.Cambrian Transition. *palaios* 14, v.1, p.73-86.
- Jezek, P. 1990, Análisis sedimentológico de la Formación Puncoviscana entre Tucumán y Salta. *In: Aceñolaza et al (Eds) El Ciclo Pampeano en el Noroeste Argentino. Serie Correlación Geológica, v. 4, p. 9-36.*
- Moya, C. 1998, El Paleozoico inferior de la Sierra de Mojotoro, Salta-Jujuy. *Revista de la Asociación Geológica Argentina*, v. 53, p. 219-238.

- Omarini, R. & Baldis, B. 1984, Sedimentología y mecanismos deposicionales de la Formación Puncoviscana (Grupo Lerma, Precámbrico-Cámbrico del noroeste argentino. Actas 9° Congreso Geológico Argentino, v. 1, p. 384-398.
- Salfity, J., Omarini, R., Baldis, B. & Gutierrez, W. 1975, Consideraciones sobre la evolución geológica del Precámbrico y Paleozoico del Norte argentino. Actas 2° Congreso Latinoamericano de Geología Económica, v. 4, p. 341-353.
- Seilacher, A. & Pflüger, F. 1994, From biomats to bentic agriculture: A biohistoric revolution, in: Krumbein, W. Paterson, D. and Stal, L. (Eds), Biostabilization of Sediments: Bibliotheks und informationssystem der Carl von Ossietzky Universität Oldenburg, p. 97-105.

C, O and Sr isotope evidence of Sturtian and Marinoan glaciations in Brazil

C.J.S. Alvarenga, R.V. Santos, M.A. Dardenne, E.L. Dantas, E.R. Brod & S.M.C.L. Gioia

Instituto de Geociências, Univ. de Brasília, Campus Universitário, ICC-centro, Brasília, DF, Brazil
 alva1@unb.br, rventura@unb.br, marceldardenne@yahoo.fr, elton@unb.br, manubrod@yahoo.com.br,
 sgioia@unb.br

Introduction

Glacial facies related to the Sturtian-Rapitan (~760-700 My) and to the Varanger-Marinoan (620-580 My) periods have been identified widely in Central Brazil, respectively on and around the São Francisco Craton and on the southeastern border of the Amazonian Craton, where they are overlain by thick carbonate sequences (Fig. 1). The older carbonate sequence covers large areas of the São Francisco Craton (São Francisco and Irecê basins) and of the surrounding Brasileiro fold belts (Rio Preto, Araçuaí, Ribeira and Brasília). These carbonate rocks, which are correlated to the Bambuí and Una groups overlie the glacial diamictites of the Jequitaí and Bebedouro Formations (Dardenne, 1978; Misi & Veizer, 1998; Uhlein et al., 1999; Santos et al., 2000). These diamictites are considered to be ca. 700-800 My old and were, therefore, attributed to the Sturtian glaciation.

The younger carbonate sequence, which is recognized in the Paraguay Belt along the southeastern border of the Amazonian Craton and is described as Corumbá Group and Araras Formation, that overlie glacial diamictites of the Puga Formation and the Fe-Mn banded-iron formations of the Jacadigo Group (Boggiani, 1998; Alvarenga & Trompette, 1992). In the Corumbá Group, the Tamengo Formation presents an Ediacarian-like fauna with *Corumbella weneri* and *Cloudina Lucianoi* (Hahn et al., 1982; Zaine & Fairchild, 1985), suggesting an Upper Vendian age (590-545 My) for the late Neoproterozoic Varanger-Marinoan glacial sediments (Alvarenga & Trompette, 1992; Zaine & Fairchild, 1985).

In this study we present new C-O and Sr-isotope data for samples collected systematically along continuous limestones profiles of the Bambuí Group on the São Francisco Craton and of the Araras Formation on the border of the Amazonian Craton. The main objective is to compare the isotopic signature obtained for these rocks with the isotopic record available for similar sequences around the world.

Results

In the Bambuí Group, negative $\delta^{13}\text{C}$ values are found only within the lowermost meters of the sequence, which are immediately followed by positive values (+0.9‰ to +3.3‰) within upper portion of the Sete Lagoas Formation (Fig. 1). Similar results have been obtained by Martins (1999) and Misi (2001) for other geologic sections in the Bambuí Basin and for the Salitre Formation in the Irecê Basin, where the negative values are restricted to the basal red cap

dolomites (Fig. 1). The upper carbonate rocks of the Bambuí Group (upper portion of the Sete Lagoas and Lagoa do Jacaré formations) present an extensive positive carbon isotope excursion (values ranging from +6.9‰ to +16‰). The $^{87}\text{Sr}/^{86}\text{Sr}$ ratios in limestones of the Bambuí Group range from 0.7058 to 0.7076 are comparable with the data obtained in other studies for the Bambuí and Una groups (Misi & Veizer, 1998).

In the Alto Paraguay Group, the carbonates of the Araras Formation show $\delta^{13}\text{C}$ negative values between -10.5‰ and -2.7‰ within a short stratigraphic interval of cap dolomite (12m) near the border of the basin and between -5.3‰ and $+0.6\text{‰}$ across more or less 200m of laminated microcrystalline limestones and clay-limestones overlying diamictites and interpreted as deposited in a deep shelf environment. In contrast, the deep-water limestones are covered by a thick horizon of shallow-water dolostones, which present uniform and positive $\delta^{13}\text{C}$ values ($+1.9\text{‰}$ to $+2.4\text{‰}$) for more than 800m. In the upper portion of the Araras Formation, dolostones and sand-bearing dolostones have high $\delta^{13}\text{C}$ values ($+4.1\text{‰}$ to $+9.6\text{‰}$). This horizon is followed by an abrupt decrease in $\delta^{13}\text{C}$ values, down to -1.0‰ . Cap carbonate of the Araras Formation has $^{87}\text{Sr}/^{86}\text{Sr}$ ratios ranging from 0.70753 to 0.70803 (Alvarenga et al., 2003).

Discussion and conclusions

The carbon isotope profile of the Paraguay Belt (Araras Formation) is very different from that of the Bambuí Group carbonates, although both carbonate sequences overlie glacial sediments. The $\delta^{13}\text{C}$ profile observed across the Araras Formation exhibits an approximately 200m thick section of carbonates with low negative $\delta^{13}\text{C}$ values while in the Bambuí Group the negative values are found only across a few meters of transgressive cap carbonate (Alvarenga et al., 2003).

Strontium isotope evolution curves for Neoproterozoic carbonates show that post-Sturtian sediments present Sr ratios ranging between 0.7063 and 0.7074, whereas post-Marinoan carbonates present ratios ranging between 0.7068 and 0.7087 (Jacobsen & Kaufman, 1999). Our isotopic data support the hypothesis that diamictites underlying the Bambuí sequence are related to the Sturtian glacial event, whereas diamictites below the Araras Formation are related to the Marinoan glacial age. These conclusions are reinforced by the presence of the Ediacara-like fauna in the carbonate rocks of the Tamengo Formation (Corumbá Group), allowing to suggest a Marinoan age for the Puga glaciation, and agree with the more recent datation of the basal Sete Lagoas Formation (Bambuí Group), which has furnished a Pb-Pb age of 740 ± 22 My (Babinsky & Kaufman, 2003).

References

- Alvarenga, C.J.S., Santos, R.V., Dantas, E.L., Brod, E.R. & Gioia, S.M.C.L., 2003. C, O and Sr isotope in the cap carbonate sequence overlying Sturtian-Rapitan and Varanger-Marinoan glacial events in Brazil. *South American Symposium on Isotope Geology*, 4, Salvador, Brazil, v.1, p.313-316.
- Alvarenga, C.J.S. & Trompette, R., 1992. Glacial influenced turbidite sedimentation in the uppermost Proterozoic and Lower Cambrian of the Paraguay Belt (Mato Grosso, Brazil). *Palaeogeogr., Palaeoclimatol., Palaeoecol.*, v. 92, p. 85-105.
- Babinsky, M. & Kaufman, A.J., 2003. First direct dating of a Neoproterozoic post-glacial carbonate. *South American Symposium on Isotope Geology*, 4, Salvador, Brazil, v. 1, p.321-323.
- Boggiani, P.C., 1998. Análise estratigráfica da Bacia Corumbá (Neoproterozoico) – Mato Grosso do Sul, PhD Thesis, Universidade de São Paulo, Brazil, 181 pp.
- Dardenne, M.A., 1978. Síntese sobre a estratigrafia do Grupo Bambuí no Brazil Central, *in*: Congresso Brasileiro de Geologia, 30, Recife, Brazil, SBG, v. 2, p. 597-610.

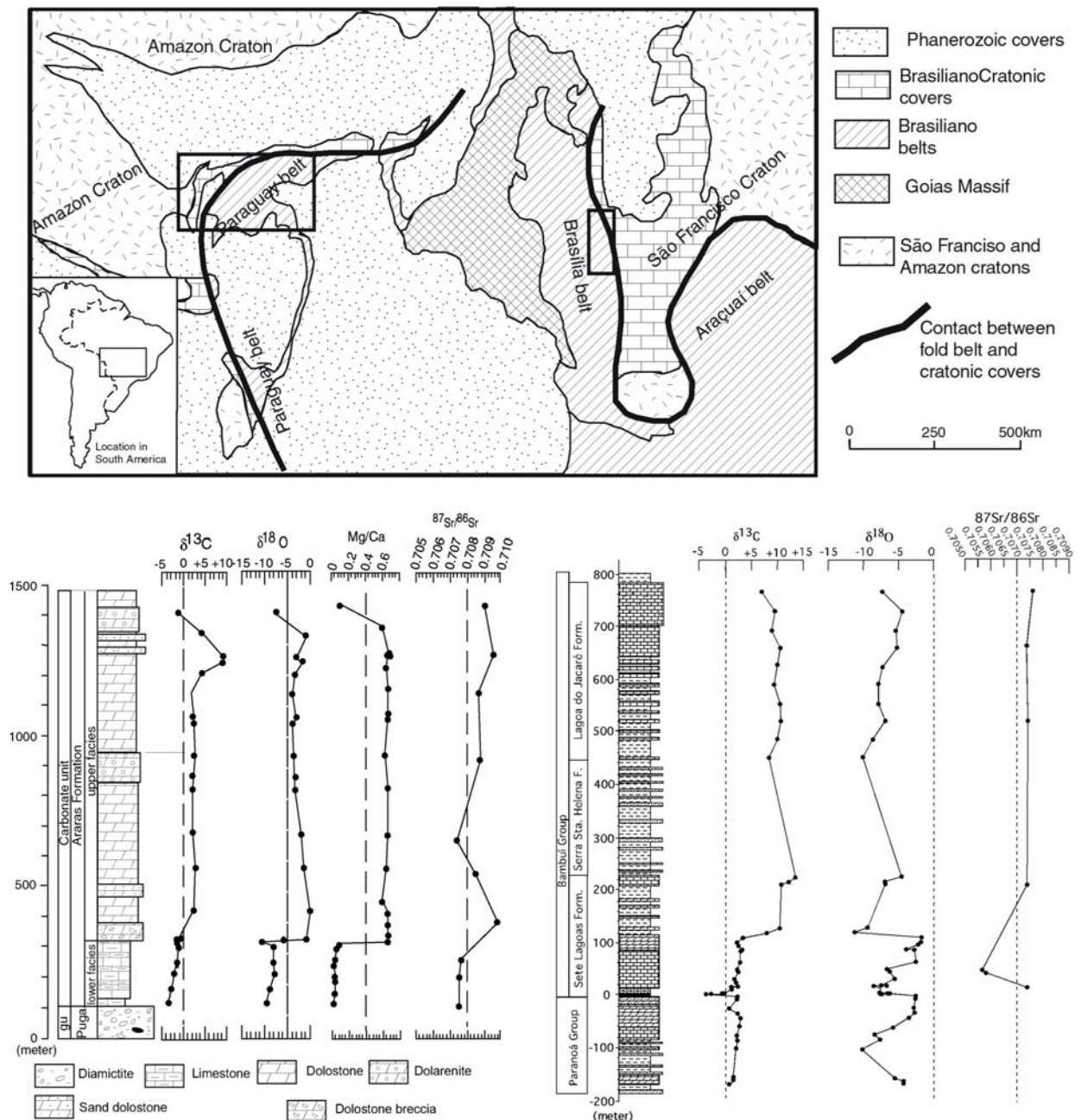


Fig. 1. C, O and Sr data obtained along carbonate sequences of the Araras Formation (Paraguay Belt) and of the Bambuí Group (São Francisco Craton) in Central Brazil.

- Hahn, G., Hahn, R., Leonardos, O.H., Pflug, H.D. & Walde, D.H.G., 1982. Körperlich erhaltene Scyphozoen-Reste aus dem Jungpräkambrium Brasiliens.
- Jacobsen, S.B. & Kaufman, A.J., 1999. The Sr, C and O isotope evolution of Neoproterozoic seawater. *Chem. Geology*, v. 161, p. 37-57.
- Martins, M., 1999. Análise estratigráfica das seqüências mesoproterozóicas (borda oeste) e neoproterozóicas da Bacia do São Francisco. Msc Universidade Federal do Rio Grande do Sul, Porto Alegre, Brazil, 214pp.
- Misi, A., 2001. Estratigrafia isotópica das seqüências do Supergrupo São Francisco, coberturas neoproterozóicas do Craton do São Francisco. Idade e correlações, in: Pinto, C.P. & Martins-Neto, M.A. (Eds), *Bacia do São Francisco: Geologia e Recursos Naturais*. SBG/MG, Belo Horizonte, pp. 67-92.
- Misi, A. & Veizer, J., 1998. Neoproterozoic carbonate sequence of the Una Group, Irecê Basin: chemostratigraphy, age and correlations. *Precambrian Research*, v. 89, p. 87-100.
- Santos, R.V., Alvarenga, C.J.S., Dardenne, M.A., Sial, A.N. & Ferreira V.P., 2000. Carbon and oxygen isotope profiles across Meso-Neoproterozoic limestones from central Brazil: Bambuí and Paranoá groups. *Precambrian Research*, v. 104, 107-122.
- Uhlein, A., Trompette, R. & Alvarenga, C.J.S., 1999. Neoproterozoic glacial and gravitacional sedimentation on a continental rifted margin: The Jequitai-Macaúbas sequence (Minas Gerais, Brazil). *Journal of South America Earth Sciences*, v. 12, p. 435-451.
- Zaine, M.F. & Fairchild, T.R., 1985. Comparaison of *Aulophycus Lucianoi* Beurlen and *Sommer* from Ladario (MS) and the genus *Cloudina* Germs, Ediacaran of Namíbia. *Anais Acad. Brasileira Ciências*, Rio de Janeiro, v. 57, p. 180.

Provenance studies on Neoproterozoic to Early Paleozoic clastic successions in Uruguay: first results

G. Blanco¹, C. Gaucher¹ & U. Zimmermann²

¹Departamento de Paleontología, INGEPA, Facultad de Ciencias. Iguá 4225, 11400 Montevideo, Uruguay. gaucher@chasque.apc.org

²Department of Geology, Rand Afrikaans University, P.O. Box 524, Auckland Park, 2006 Johannesburg, South Africa

Introduction

The Neoproterozoic-Cambrian of Uruguay is characterized by a number of sedimentary and volcano-sedimentary basins (Fig. 1), which represent different sedimentary environments and geotectonic settings. These successions comprise shelf deposits overlying deeply eroded, cratonic areas (Arroyo del Soldado Group and Piedras de Afilar Formation), volcanosedimentary successions (Cerros de Aguirre Formation and probably Las Ventanas Formation); and deep water sedimentary sequences, with no basement exposed (Rocha Group and Playa Hermosa Formation). The Lavalleja Group, an important volcanosedimentary succession of southern Uruguay (Fig. 1) will not be discussed here, due to great uncertainties regarding age of deposition. Considering the complex structure of the Precambrian basement of Uruguay, which consists of three (Bossi et al., 1998; Fig. 1) or four (Basei et al., 2000) different terranes, determination of provenance of the mentioned sedimentary successions is key to understand the palaeogeographic evolution of the region in the Neoproterozoic-Cambrian. A brief outline of the data obtained so far is provided below.

Arroyo del Soldado Group

The first provenance studies for this unit were reported by Gaucher (2000). Conglomerate clasts clearly show provenance from underlying Palaeoarchean (3.41 Ga) to Mesoproterozoic metamorphic and igneous complexes. Bossi et al. (2001) reported an U-Pb SHRIMP dating of 633 ± 10 Ma for the Puntas del Santa Lucía pluton, which is overlain with erosional unconformity by the Arroyo del Soldado Group. Paleocurrents indicate provenance from areas located to the W (Gaucher, 2000). Sandstones in the Arroyo del Soldado Group are mainly subarkoses to mature quartz arenites, except for the Barriga Negra Formation. These petrographic data point to provenance from a peneplainized craton under tropical climate, as also suggested by thick carbonate deposits. Ongoing research will focus on: (a) determine the relative importance of the different basement units as source areas, mainly by means of LA-ICP MS on detrital zircons, and (b) apply different petrographic and isotopic methods to assess importance of chemical weathering, specially considering recurrence of colder periods postulated by Gaucher (2000).

Piedras de Afilas Formation

This unit comprises predominant quartz arenites, which pass up section into pink to dark gray siltstones (Bossi & Navarro, 1991). At the top, thin carbonate deposits occur. The unit overlies Transamazonian (2100-1900 Ma) basement, representing the only sedimentary cover preserved in the Piedra Alta Terrane (Fig. 1). The Piedras de Afilas Formation lithologically resembles the upper Arroyo del Soldado Group and a correlation between both units cannot be ruled out (Gaucher, 2000). A correlation with the Neoproterozoic lower Sierras Bayas Group of Argentina seems probable, in view of lithologic similarity and same structural relationships to Transamazonian basement (Cingolani & Dalla Salda, 2000). Detrital zircon LA-ICP MS will provide age constraints for the deposition of this succession, and a detailed palaeocurrent analysis will allow a better understanding of basin shape and evolution.

Las Ventanas Formation

This thick, mainly conglomeratic unit, shows provenance mainly from a mixed volcanic (basic and acid) and granitic source area. Both rhyolitic and basic volcanic flows occur in the succession, with an evolution from basic to acid volcanics towards the top. Intraclasts (pelites, sandstones) occur mainly at the top, but are always subordinate. Faceted sandstone clasts occur sporadically and may imply glacial conditions in the basin or immediate source area. K-Ar datings of 572 ± 7 Ma obtained for syn-kinematic muscovites (Cingolani, in Bossi and Campal, 1992) crystallized along the Puntas del Pan de Azúcar Thrust, suggest a minimum Vendian age for the unit (Fig. 1). On the other hand, sinusoidal structures here interpreted as trace fossils (aff. *Cochlichnus* isp.) occur in interbedded siltstones, suggesting a maximum Vendian age (Fedonkin & Runnegar, 1992).

Cerros de Aguirre Formation

It is made up of tuffs, ignimbrites of rhyolitic-dacitic composition and reworked tuffs. An U-Pb SHRIMP dating of 571 ± 8 Ma (Hartmann et al., 2002) of dacitic tuffs allows to place this unit in the Vendian. Its geotectonic setting, however, markedly differs from that of the contemporaneous Arroyo del Soldado Group, despite present distance between outcrops of only 70 km (Fig. 1). A possible explanation is the allochthonous nature of the Cuchilla Dionisio Terrane with respect to the Río de la Plata Craton (Basei et al., 2000).

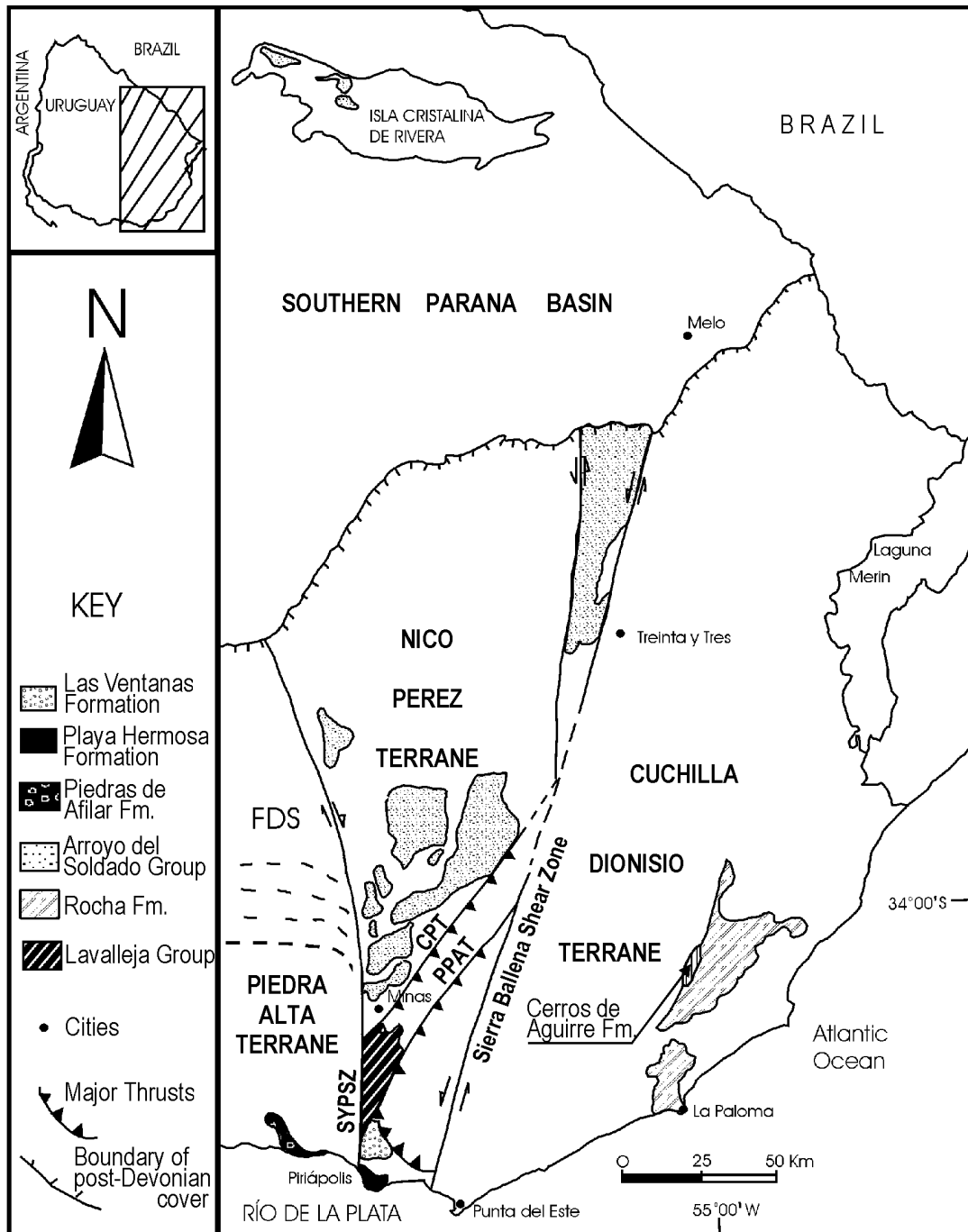


Fig. 1. Neoproterozoic-Cambrian (volcano) sedimentary successions in Uruguay. SYPSZ: Sarandí del Yí-Piriápolis Shear Zone, CPT: Cerro Partido Thrust, PPAT: Puntas del Pan de Azúcar Thrust, FDS: Florida Dyke Swarm (1.8 Ga). Modified from Gaucher (2000).

Playa Hermosa Formation

This unit crops out along the coast in the vicinity of Piriápolis (Masquelín & Sánchez Bettucci, 1993; Fig. 1). While conglomerates of Las Ventanas Formation mainly represent alluvial fans, conglomerates and interbedded sandstones/pelites of the Playa Hermosa Formation represent

deposition in a slope environment. Mass flow deposits and slumps, represented by breccias and diamictites, are dominant (Masquelín & Sánchez Bettucci, 1993; Pazos et al., 2003). Downslope direction was to the NE, as indicated by slumps and convolute bedding. Outsized clasts up to 80 cm in length are restricted to these mass flow deposits, their long axes being mostly subparallel to bedding (maximum angle measured: 38°). No striated or faceted clasts were found by the authors. Interbedded pelites and rhythmites show no outsized clasts, strongly suggesting that large clasts described above were brought into the basin by mass flow deposits, rather than being ice-rafted, as suggested by Pazos et al. (2003). The Playa Hermosa Formation is older than the intrusive syenites of the Sierra de Animas Formation, which yielded a Rb-Sr age of 520 ± 5 Ma (Bossi et al., 1993). Age of deposition, however, is uncertain due to a lack of maximum age constraints, which can be obtained by datings of detrital zircons by LA-ICP MS.

References

- Basei, M., Siga, JR. O., Masquelin, H., Harara, O., Reis Neto, J. & Preciozzi, F., 2000. The Dom Feliciano Belt of Brazil and Uruguay and its foreland domain, the Rio de la Plata Craton, *in*: Cordani, U., Milani, E., Thomaz Filho, A., & Campos, D. (Eds.), Tectonic evolution of South America. Rio Janeiro, p. 311-334.
- Bossi, J. & Campal, N., 1992. Magmatismo y tectónica transcurrente durante el Paleozoico Inferior en Uruguay, *in*: Gutierrez- Marco, J. G., Saavedra, J. & Rabano, I. (Eds), Paleozoico Inferior de Iberoamérica. Mérida, p. 343- 356.
- Bossi, J., Cingolani, C., Llambías, E., Varela, R. & Campal, N., 1993. Características del magmatismo post-orogénico finibrasiliano en el Uruguay: formaciones Sierra de Ríos y Sierra de Animas. *Rev. Bras. Geoc.*, v. 23, p. 282-288.
- Bossi, J., Ferrando, L., Montaña, J., Campal, N., Morales, H., Gancio, F., Schipilov, A., Piñeyro, D. & Sprechmann, P., 1998 Carta Geológica del Uruguay, Escala 1/500.000. Versión 1.0 Digital. Geoeditores-Facultad de Agronomía, Montevideo.
- Bossi, J., Campal, N., Hartmann, L.A. & Schipilov, A., 2001. Predevoniano en el Uruguay: terrenos y SHRIMP II.- XI Congreso Latinoamericano y III Congreso Uruguayo de Geología, Actas (CD-ROM), Montevideo, No. 94.
- Cingolani, C. & Dalla Salda, L., 2000. Buenos Aires Cratonic region, *in*: Cordani , U., Milani, E., Thomaz Filho, A., and Campos, D. (Eds), Tectonic evolution of South America. Rio Janeiro, p. 139-147.
- Fedonkin, M.A. & Runnegar, B.N., 1992. Proterozoic metazoan trace fossils, *in*: Schopf, J. W. & Klein, C.(Eds.), The Proterozoic Biosphere - A Multidisciplinary Study. Cambridge University Press, Cambridge, p. 389-395.
- Gaucher, C., 2000. Sedimentology, palaeontology and stratigraphy of the Arroyo del Soldado Group (Vendian to Cambrian, Uruguay). *Beringeria*, v. 26, p. 1-120.
- Hartmann, L.A. , Santos, J.O. Bossi, J., Campal, N., Schipilov, A., & Mac Naughton, N. J., 2002. Zircon and titanite U-Pb SHRIMP geochronology of Neoproterozoic felsic magmatism on the eastern border of the Rio de la Plata Craton, Uruguay. *Jour. South Am. Earth Sci.*, v.15, p. 229-236.
- Masquelin, H. & Sánchez Bettucci, L., 1993. Propuesta de Evolución tectono-sedimentaria para la fosa tardi-brasiliana en la región de Piriápolis, Uruguay. *Rev. Bras. Geoc.*, v. 23, p. 188-198.
- Pazos, P.J., Sánchez-Bettucci, L. & Tófaló, O.R., 2003. The record of the Varanger glaciation at the Río de la Plata Craton, Vendian-Cambrian of Uruguay. *Gondwana Res.*, v. 6, p. 65-77.

New carbon isotopic data from the Corumbá Group as a contribution to a composite section for the Neoproterozoic III in South America

P.C. Boggiani¹, A.N. Sial², M.Babinski¹, V.P. Ferreira²

¹Instituto de Geociências, Universidade de São Paulo, Rua do Lago, 562, CEP 05508-080 São Paulo, SP, Brazil, boggiani@usp.br; babinski@usp.br

²NEG-LABISE – Departamento de Geologia, Universidade Federal de Pernambuco, C.P. 7852, CEP 50.670-000 Recife, PE, Brazil, ans@ufpe.br, valderez@ufpe.br

Introduction

The discovery of extreme variation of C- isotope values in Neoproterozoic (~1000 – 543 Ma) carbonate sequences, first identified by Magaritz (1986), Tucker (1986) and Knoll et al. (1986), has opened new possibilities for stratigraphic correlations between them. A proposed composite section for the Neoproterozoic, encompassing data from various successions from different regions, has been proposed by Jacobsen & Kaufman (1999) and Hayes *et al.* (1999). Recently, Halverson et al. (2003) presented a $\delta^{13}\text{C}_{\text{PDB}}$ composite curve using data from only two stratigraphic successions: Otavi Group (Namibia) and Akademikerbreen and Polarisbreen Groups (Svalbard). However, none of these composite curves includes South American Neoproterozoic data.

In order to establish a composite section to improve the correlations among South America Neoproterozoic sections, we have obtained new $^{87}\text{Sr}/^{86}\text{Sr}$ and $\delta^{13}\text{C}_{\text{PDB}}$ values, derived from continuous exposures of marine carbonate strata from the Corumbá Basin, which have significant paleontological occurrences (*Cloudina*) and stratigraphic marks.

Geological Setting of the Corumbá Basin

The Corumbá Basin (300-km-long and NNW oriented) was developed along the eastern border of the Rio Apa Block, in the context of the Amazon Craton (Gaucher et al. 2003). It comprises Varanger glaciomarine sediments of the Puga Formation (Alvarenga & Trompette 1992) and the terrigenous and carbonatic sediments of the Corumbá Group (Almeida 1965). The lower units of the Corumbá Group (Cadiueus and Cerradinho Formations) were deposited in a fault-limited, confined basin. The shallow-water dolomitic and phosphatic rocks of the overlying unit (Bocaina Fm.) are spread along a larger area, covering the other units and over the peneplaned granitic-gneissic basement (Pedra Branca erosional surface). Subsequent regression eroded part of these sediments and re-deposited them as slope breccia. Carbonaceous limestones and shales from the Tamengo Formation, with *Cloudina* and *Corumbella*, cover these deposits. These limestones are overlain by shales of the Guaicurus Fm., formed under open marine conditions. In this context, the Corumbá Basin is interpreted as associated with the contemporaneous Iapetus Ocean opening.

Associated with the Corumbá Basin, are BIFs of the Jacadigo Group, in the Urucum Massif, with discrete ice-rafted debris intervals. In the northern Paraguai Belt, there is another carbonatic section, named Araras Group (Almeida 1964), where Nogueira et al. (2003) described a cap carbonate over the Puga Formation. Sr and C isotope studies on the Araras carbonates show a different behavior of $\delta^{13}\text{C}$ values than that observed in the Corumbá Group.

Neoproterozoic Chemostratigraphy of Corumbá Basin – a discussion

An integrated C and Sr curve using data from the Puga Hill cap carbonate, Bocaina Formation as well as new C-isotope data from the fossiliferous Tamengo Formation is presented in this study. The $^{87}\text{Sr}/^{86}\text{Sr}$ values range from 0.70773 (Puga Hill cap carbonate) to 0.7086 (top of Tamengo Formation), an interval of 140 meter interval. This increase in Sr ratios is in agreement with the sharp rise observed in the terminal Neoproterozoic to early Cambrian section (600-535 Ma), interpreted as corresponding to an enhancement of continental input to the oceans associated with a Pan-African-Brasiliano continental collision (Jacobsen & Kaufman 1999).

C-isotope values display a large variation, ranging from -5.3‰ to $+5.5\text{‰}$. Negative values were on the cap carbonate from the Puga Hill (-5‰). Dolomites from the Bocaina Formation present C isotope values close to 0‰ . An increase on the C values is observed at the base of the Tamengo Formation, followed by a negative incursion (-3‰), which is abruptly followed by a strongly positive ($+5\text{‰}$) excursion, associated with the first metazoan fossil occurrence. After that, C values decrease to around $+3\text{‰}$ and remain constant upsection (Fig. 1).

The presence of metazoan fossils, along with other geological constraints, indicates that the first negative C incursion is related to the Varanger/Marinoan glaciation. The second negative C incursion could be related to a second Varanger glacial event (sensu Jacobsen & Kaufman 1999) or to Glaciation III (Glaskier) of Halverson et al. (2003). According to this latter interpretation, the Puga Fm. would record the Glaciation II (Marinoan) event. In this scenario, the second negative peak would be the reflection of the third glaciation, which probably was not of global extent.

The possibility of a third Neoproterozoic glaciation is proposed by Grey & Corkeron (1998) in Australia, where in the context of post-Marinoan planktonic blooms flourish, atmospheric CO_2 is sequestered and carbonate diminishes the greenhouse effect, implying deposition of carbonate from cold water, and possibly leading to local glaciation after 574 Ma. According to Saylor et al. (1998), the first Varanger Ice age would have occurred at 590 Ma and the second Varanger at 575 Ma, while the end of latest positive excursion of $\delta^{13}\text{C}_{\text{PDB}}$ would have been at 549 Ma ago (Grotzinger et al. 1995).

Conclusion

The C- and Sr- isotope values from the Corumbá Basin section (Fig. 1) are consistent with the post-Varanger/Marinoan isotopic record. According to the C isotope values, the Puga Formation can be correlated with Glaciation II (the first Varanger or Marinoan) while the second negative shift of $\delta^{13}\text{C}_{\text{PDB}}$ (base of Tamengo Fm.) would be a reflection of Glaciation III (Glaskier or second Varanger). The close agreement between C-isotope behavior and the fossil record makes the Corumbá Basin a key unity in the South America for correlation with other Neoproterozoic III sequences worldwide.

Acknowledgements

This project has been partially financed by VITAE (B-11487/10B00), and IGCP (UNESCO) 478 “Neoproterozoic-Early Palaeozoic Events in SW – Gondwana”

References

- Almeida, F.F.M. 1964. Geologia do Centro-oeste mato-grossense. Boletim da Divisão de Geologia e Mineralogia, DNPM, v. 215, p. 1-137.
- Almeida, F.F.M. 1965. Geologia da Serra da Bodoquena (Mato Grosso), Brasil. Boletim da Divisão de Geologia e Mineralogia, DNPM, v. 219, p. 1-96.
- Alvarenga, C.J.S. & Trompette, R. 1992. Glacially influenced sedimentation in the later Proterozoic of the Paraguay Belt (Mato Grosso, Brazil). Palaeogeography, Palaeoclimatology, Palaeoecology, v. 92, p. 85-105.

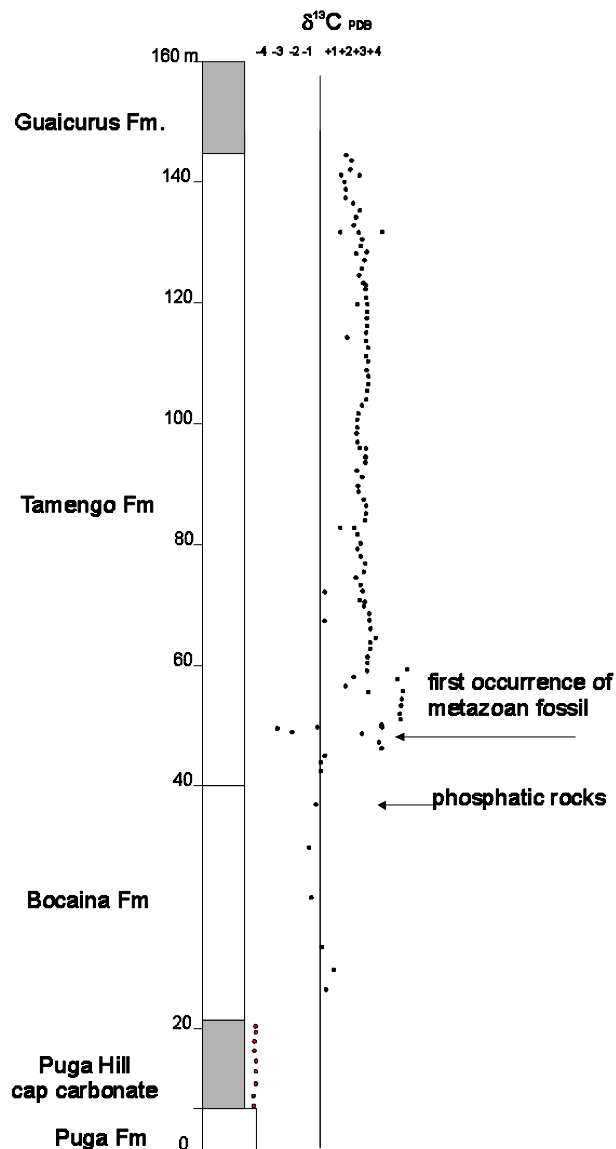


Fig 1. Composite carbon isotopic section for the Corumbá Group, Amazonian Craton, Brazil

- Gaucher, C., Boggiani, P.C., Sprechmann, P., Sial, A.N. & Fairchild, T.R. 2003. Integrated correlation of Vendian to Cambrian Arroyo del Soldado and Corumbá Groups (Uruguay and Brazil): palaeogeographic, palaeoclimatic and palaeobiologic implications. *Precambrian Research*, v. 120, p. 241-278.
- Grey, K. & Corkeron, M. 1998. Late Neoproterozoic stromatolites in glaciogenic successions of the Kimberley region, Western Australia: evidence for a second Marinoan glaciation. *Precambrian Research*, v. 92, p.65-87.
- Grotzinger, J.P.S., Bowring, S.A., Saylor, B.Z., Kaufman, A.J. 1995. Biostratigraphic and geochronologic constraints on early animal evolution. *Science*, v. 270, p. 598-604.
- Halverson, G.P., Hoffman, P.F., Maloof, A.C., Rice, A.H.N., 2003. Towards a composite carbon isotopic section for the Neoproterozoic. In: *IV South American Symposium on Isotope Geology, Short Papers*, Salvador, Brazil, v. 1, p.14-17.

- Hayes, J.M., Strauss, H., Kaufman, A.J., 1999. The abundance of $\delta^{13}\text{C}$ in marine organic matter and isotopic fractionation in the global cycle of carbon during the past 800 Ma. *Chemical Geology*, v. 161, p. 103-126.
- Jacobsen, S.B. & Kaufman, A.J. 1999. The Sr, C and O isotopic evolution of Neoproterozoic seawater. *Chemical Geology*, v. 161, p. 37-57.
- Knoll, A.H., Hayes, J.M., Kaufman, A.J., Swett, K., Lambert, I.B., 1986. Secular variation in carbon isotope ratios from Upper Proterozoic successions of Svalbard and East Greenland. *Nature*, v. 321, p. 832-838.
- Magaritz, M., Holser, W.T., Kirschvink, J.L., 1986. Carbon-isotope events across the Precambrian/Cambrian boundary on the Siberian Platform. *Nature*, v. 320, p. 258-259.
- Nogueira, A. C.R.N., Riccomini, C., Sial, A. N., Moura, C. & Fairchild, T., 2003. Soft-sediment deformation at the base of the Neoproterozoic Puga cap carbonate (southwestern Amazon Craton, Brazil): Confirmation of rapid icehouse-greenhouse transition in snowball earth. *Geology*, 31, p. 613-616.
- Saylor, B.Z., Kaufman, A.J., Grotzinger, J.P. & Urban, F., 1998. A composite reference section for Terminal Proterozoic strata of Southern Namibia. *Journal of Sedimentary Research*, v. 68, p. 1223-1235.
- Tucker, M.E. 1986. Carbon isotope excursions in the Late Precambrian-Cambrian boundary beds, Anti-Atlas, Morocco. *Nature*, v. 319, p. 48-50.

Geological evidence of one allochthonous block attached to the east of Uruguay in the Cambrian: Cuchilla Dionisio Terrane

J. Bossi¹, E. Pecoits² & R. Navarro³

¹Cátedra de Geología, Facultad de Agronomía, Av. Garzón 780, 11900 Montevideo-Uruguay.

E-mail: jbossi@fagro.edu.uy

²Instituto de Geología y Paleontología, Facultad de Ciencias, Iguá 4225, 11400 Montevideo-Uruguay.

³Capurro 789, Montevideo-Uruguay.

It is known that macrocontinents as Gondwana have been formed as consequence of accretion of small blocks due to plate tectonic action. Although general agreement exist regarding this, different points of view appear when each area is analysed in detail and the direction of subduction and collision type are considered.

Today the geochemistry and geochronology methods correctly applied enable one to determine the geotectonic position of lithological associations and stratigraphic sequences of metamorphic and igneous rocks. In Uruguay accurate and synthetical geological mapping has provided valuable elements with palaeogeographic implications to the amalgamation of western-Gondwana. In this way there are plenty petrographical data that support this but there are not enough geochemical and geochronological data.

This paper is based on more than 300 geological maps (scale 1:50.000, 20 km² each) and a lot of geologic cross-sections (scale 1:500,000) across the entire country. Likewise, we dispose with aerial 1:20.000 and 1:40.000 photographs with excellent resolution, topographical maps (1:50.000) and satellital images. The adequate treatment of all this information has permitted to establish hypotheses, whose attestation is encouraged to realise a Vendian-Cambrian model of palaeogeographic evolution with many possibilities of succes.

The pre-Devonian basement of Uruguay consists of tectonostratigraphical terranes joined by continental-scale megashear zones, with different stratigraphy, lithological asociations and

evolution (Bossi et al., 1998; Fig. 1). The occidental Terrane (Piedra Alta) contains only one small alkaline A-type granitic body (Oyhantçabal et al., 1990).

The central Terrane (Nico Pérez) has the most complex and abundant succession of Vendian-Cambrian events and there has been acquired the most voluminous geological information. Comprise a multiplicity of granitic bodies, whose Rb/Sr and U/Pb (one) geochronological data has enabled to identify two important groups of ages: 630 ± 30 and 540 ± 20 Ma (Umpierre & Halpern, 1971; Preciozzi et al., 1993; Hartmann et al., 2002). Between both events of magmatogenesis an important episode of sedimentation took place (Arroyo del Soldado Group). The sequence was deposited on a stable, Atlantic-type continental shelf, which deepened to the southeast, with a palaeo-shoreline roughly N-S (Gaucher, 2000). Although the ages of the granites are coincident with two episodes of Brasiliano Cycle (Dom Feliciano Orogeny and Río Doce Event; see Basei & De Brito Neves, 1992), the Nico Pérez Terrane has not metamorphic rocks of this age.

The easternmost portion of the Uruguayan Shield, eastward of the Sierra Ballena Lineament, is considered as a third Terrane namely Cuchilla Dionisio. Geological evidence, obtained by the geological mapping outlined above, suggests that this terrane is allochthonous and has been joined with the Nico Pérez Terrane by a sinistral shear zone.

The geological mapping has made it possible to obtain eight geologic arguments to support this proposal which establishes that the Cuchilla Dionisio Terrane is an allochthonous block whose limit is the Sierra Ballena Shear Zone:

I. The Sierra Ballena Shear Zone consists of a band, 4,000m wide, with NNE strike, integrated by an alternance of proto-mylonitic, mylonitic and ultra-mylonitic rocks whose kinematic indicators shows sinistral movement (Gómez Rifas, 1995).



Fig. 1. Tectonostratigraphic subdivision of the Uruguayan crystalline basement.

II. The Carapé Group is clearly curved near the transcurrence conforming a large drag fold confirming a sinistral sense along this fault.

- III. The Arroyo del Soldado Group covers a great extension of the Nico Pérez Terrane but does not occur in the Cuchilla Dionisio Terrane, being cut by the Sierra Ballena Lineament (Gaucher, 2000).
- IV. The Cerro Olivo Complex (*sensu* Masquelin, 2002), eastward of the Sierra Ballena transcurrence, is integrated by one metamorphic lithological association of granulite facies which shows thrusts with SE vergence resting over ortho- and parametamorphic rocks of amphibolite facies and migmatites. The Carapé Group (*sensu* Bossi, 1983), westward of the Sierra Ballena Shear Zone, is integrated by lithologies that are radically different. Pure limestones, BIF, fuchsite quartzites, mica-schists and amphibolites intruded by large granitic bodies and overthrusting migmatites occur.
- V. The Rocha Group consists of low grade metasediments (meta-pelites and meta-arenites) intruded by the polyintrusive Santa Teresa Batolite, which also represents a unit that exist eastward of the Lineament only, cropping out in the SE of the Cuchilla Dionisio Terrane (Bossi & Navarro, 1991).
- VI. The Cerros de Aguirre Formation includes volcanic and pyroclastic rocks with a thickness of 1,200 m and an age of 571 ± 8 Ma (Bossi et al., 2001). This unit represents an explosive volcanism located around 80 km from the Arroyo del Soldado Group, which shows a complete absence of volcanic, pyroclastic and volcanoclastic rocks. It seems logical to suggest that ca. 570 Ma ago both units were far apart and not in their present position.
- VII. The Sierra Ballena suture zone separates terranes that are isotopically distinct, confirming the geological and geochronological data. The Sm-Nd results show that there is a remarkable decrease of the model ages eastwards, with Cuchilla Dionisio Terrane and African rocks presenting the youngest ages (Basei et al., 2001).
- VIII. The age of this sinistral displacement is between 532 ± 11 Ma, because it cuts the Guazunambí Granite (Kawashita et al., 1999), and 520 ± 5 Ma - the age of anorogenic magmatism of the Sierra de las Ánimas Formation (Bossi et al., 1993).

This geological evidence is consistent enough to begin a program of detailed geological mapping coupled with geochemical and geochronological study of the 64 granitic bodies of Uruguay. We consider that the knowledge of this data and the age of each shear zone and the nature of basic and ultrabasic body rocks, is the best solution to resolve the Vendian–Cambrian palaeogeography of W-Gondwana.

Acknowledgements

The authors wish to thank Nestor Campal for participation in field work and useful comments. A grant by CSIC to E.P. (Project: “Lithostratigraphy of the Fuente del Puma Group and their correlation with other units of Uruguay and southwest of Africa”) helped finance field work. This paper is a contribution to project IGCP 478 (Neoproterozoic-Early Palaeozoic events in SW-Gondwana).

References

- Basei, M. A. S. & De Brito Neves, B. B. 1992. Características geológicas da transição Proterozóico-Fanerozóico no Brasil. *In*. Gutiérrez Marco, J. G., Saavedra, J. & Rábano, I. (Eds.). Paleozoico Inferior de Iberoamérica, Mérida, p. 331-342.
- Basei, M. A. S., Siga Junior, Harara, O. M., Preciozzi, F., Sato, K. & Kaufuss, G. 2001. Precambrian Terranes of african affinities in the southeastern part of Brazil and Uruguay, v. 1, p. 98-101.
- Bossi, J. 1983. Breve reseña sobre el conocimiento geológico del Escudo Predevoniano en Uruguay, Sud América. *Zentralblatt für Geologie und Palaëontologie*, v. 1, p. 417-429.

- Bossi, J., Campal, N., Hartmann, L. A. & Schipilov, A. 2001. Predevoniano en el Uruguay: Terrenos y SHRIMP II. XI Congreso Latinoamericano de Geología. Actas, resumen N° 94, 5 pp.. Montevideo, Uruguay.
- Bossi, J., Cingolani, C., Lambias, E., Varela, R. & Campal, N. 1993. Características del magmatismo post-orogénico finibrasiliano en el Uruguay: formaciones Sierra de Ríos y Sierra de Ánimas. *Revista Brasileira de Geociências*, v. 23, p. 282-288.
- Bossi, J., Ferrando, L., Montaña, J., Campal, N., Morales, H., Gancio, F., Schipilov, A., Piñeyro, D. & Sprechmann, P. 1998. Carta Geológica del Uruguay. Escala 1:500.000. Montevideo, Geoeditores, versión digital.
- Gaucher, C. 2000. Sedimentology, paleontology and stratigraphy of the Arroyo del Soldado Group (Vendian to Cambrian, Uruguay). *Beringeria*, v. 26, p. 1-120.
- Gómez Rifas, C. 1995. A zona de cisalhamento sinistral de “Sierra Ballena” no Uruguai. Unpublished Ph.D. thesis, Instituto de Geociências, Universidade de São Paulo, 244 pp.
- Hartmann, L. A., Santos, J. O. S., Bossi, J., Campal, N., Schipilov, A., & McNaughton, N. J. 2002. Zircon and titanite U-Pb SHRIMP geochronology of Neoproterozoic felsic magmatism on the eastern border of the Río de la Plata craton, Uruguay. *Journal of South American Earth Sciences*, v. 15, p. 229-236.
- Kawashita, K., Gaucher, C., Sprechmann, P., Teixeira, W. & Victória, R. 1999. Preliminary chemostratigraphic insights on carbonate rocks from Nico Pérez Terrane (Uruguay). II South American Symposium on Isotope Geology, Córdoba, Argentina, Actas, p. 399-402.
- Masquelin, H. 2002. Evolução estrutural e metamórfica do Complexo Cerro Olivo, sudeste do Uruguay. Tese de Doutorado, CpGeo, Universidade Federal do Rio Grande do Sul, 342 pp.
- Oyhantçabal, P., Derregibus, M. & Muzio, R. 1990. Contribución al conocimiento petrográfico, geoquímico y estructural del granito de la Paz. 1° Congreso Uruguayo de Geología. Resúmenes Ampliados, Montevideo, v. 1, p. 81-87.
- Preciozzi, F., Masquelin, H. & Sánchez Bettucci, L. 1993. Geología de la porción sur del Cinturón Cuchilla Dionisio. *In*: Guía de Excursión, I Simposio Internacional del Neoproterozoico-Cámbrico de la Cuenca del Plata. Montevideo, pp. 1-39.
- Umpierre, M. & Halpern, M. 1971. Edades Rb-Sr de la República Oriental del Uruguay. *Revista Asociación Geológica Argentina*, v. 26, p. 133-155.

Sponge-like microfossils from Neoproterozoic intertillite limestones of the Otavi Group in northern Namibia

C.K. Brain¹, A.R. Prave², A.E. Fallick³ & K.-H. Hoffmann⁴

¹Transvaal Museum, P. O. Box 413, Pretoria, 0001, South Africa, brainnew@iafrica.com

²School of Geography and Geosciences, University of St. Andrews, Fife KY 16 9AL Scotland.

³Scottish Universities Environmental Research Centre, East Kilbride, Glasgow G75 0QF, Scotland

⁴ Geological Survey of Namibia, P. O. Box 2168, Windhoek, Namibia.

For the last few years, one of the authors (C.K.B.) has been engaged in a search for micro-invertebrate fossils in Neoproterozoic limestones of Namibia, initially in the Nama Group but, more recently, in the Otavi Group further to the north of the country. Many samples of limestone from the Otavi-Tsumeb-Grootfontein area were examined in thin section and as acetic acid-treated residues, but recrystallisation of these limestones from the folded Otavi Mountainland appeared to mitigate against the finding of well-preserved microfossils there. But, to the north, on the flat, calcrete-covered plain of the Etosha Basin, several limestone hills make their appearance, well away from the metamorphic folded belt. These limestones apparently accumulated on a Bahamas-type carbonate platform on the Congo Craton in Late Proterozoic times. When C.K.B. examined acetic acid residues of some of these carbonate grainstones he

found numerous sponge-like objects (referred to here as ‘Otavias’) that proved to have been phosphatised. Detailed geological mapping of these outcrops had not been done, but it was clearly important to establish just where within the Group’s stratigraphy the sequence is positioned. The outcrops were therefore examined in detail in the field by K.-H.H., A.R.P. and C.K.B. and samples were taken at close intervals for carbon isotope analysis and interpretation by A.E.F. and A.R.P.

A lithostratigraphic subdivision and correlation of the Otavi Group in the Otavi Mountainland and eastern Kaokoveld, as proposed by Hoffmann & Prave (1996), demonstrated the presence of *two* stratigraphically and lithologically distinct glacial diamictite intervals, each succeeded by an unique cap-carbonate (Hoffmann, 1989, 1994, Prave & Hoffmann, 1995). Prior to this, a single glacial interval only, within the Otavi Group had been known for a considerable time (e.g. Le Roex, 1941) but the presence of the two diamictites is now generally accepted. Although evidence for severe glacial conditions during Neoproterozoic time has been recognised for many years (Harland, 1965), and the concept of a “Snowball Earth” was proposed by Kirschvink in 1992, the application of this scenario to the two Otavi Group glacial episodes is much more recent (Hoffman et al, 1998). It postulates extreme glacial conditions, even in the equatorial regions, a cessation of continental runoff and virtual shutdown of biological activity. Such conditions would have had a dramatic effect on the evolution of early animals, whose lineages apparently go back considerably further in time on the basis of molecular evidence (Doolittle et al, 1996; Wray et al, 1996). It is therefore of interest to note that the Etosha carbonate sequence that we are concerned with here falls within the Auros Formation (or Ombaatjie Formation further to the west) of the Abenab Subgroup, well below the later of the two glacial episodes, the Ghaub, which apparently occurred about 590 million years ago. Lithological details of the composite Etosha profile, together with results of the carbon isotope analyses of 77 samples, undertaken under the supervision of A.E.F, have been published (Brain et al, 2001). These values show a sharp rise from initially slightly negative ones to mostly +2 to +4, while several singular excursions to around 0 punctuate this trend. Further up the sequence the isotope values rise to +8 and remain constant for the rest of this succession. This overall trend mirrors that known from the Ombaatjie Formation in the eastern Kaokoveld and the Auros Formation in the Otavi Mountainland. Thus, the combined lithostratigraphic and chemostratographic data for the Etosha rocks indicate that these, and any microfossils they might contain, are pre-Ghaub glaciation in age.

The ‘Otavia’ microfossils, with which we are concerned here, vary in size from 300 micrometers to about 5 mm and are variable in shape, but have several features in common. When viewed as isolated objects, sorted from acetic acid residues and imaged with a scanning electron microscope, each Otavia appears as a hollow bag, with several large openings usually on raised volcano-like mounds. These openings penetrate the phosphatic wall and lead directly into the internal cavity. The wall is also pieced by numerous smaller openings that generally lead into a ‘peripheral labyrinth’, made up of a network of irregularly interlinked spaces that also has openings to the internal cavity. In thin sections, the outer envelope and peripheral labyrinth appear dark, or almost opaque; the walls of these structures are composed of calcium phosphate in an amorphous or cryptocrystalline form. Thin sections show the interior of the otavia structure to be filled with crystalline calcium carbonate, very similar to that of the surrounding matrix, which can perhaps be described as a sparite.

In view of the superficial similarity in appearance of these objects to small sponges, special attention has been given to the outer walls for the possible presence of spicules, characteristic of many later sponges. Elongate crystals do occur occasionally in the walls, but they are not convincing as spicules and are more likely to be inorganic with a diagenetic origin.

In the initial draft of the paper (Brain et al., 2001) mentioned above, it was proposed that each *Otavia* represented a phosphatised calcareous sponge, in which the larger openings, on their raised eminences, were equivalent to the excurrent oscula of later sponges, while the numerous smaller openings represented the incurrent ostia. These ostia led first into the peripheral labyrinth, where the flagellated collar cells were presumably housed, and then into the internal cavity, as is the case in many living sponges. The draft of this paper was then sent for comment to various specialists and useful comments were received from Andrew Knoll, Stefan Bengtson and Bruce Runnegar who pointed out some of the difficulties involved in the interpretation of phosphatised objects preserved in ancient limestones.

In particular, the issue of “microphytolites” must be taken into consideration. These are clusters of calcareous grains that were held together by a bacterial or algal film, that could subsequently have been phosphatised. They have often been reported in Proterozoic limestones, presumably because grazing metazoans, such as molluscs, were rare at that time and the algal films could consequently survive. If an *Otavia* had, in fact, been a microphytolite, then the “internal cavity”, seen in an *Otavia* from an acetic acid residues had, originally, not been a cavity at all. Instead, it had been a cluster of grains and Stefan Bengtson suggested that each large opening, on its raised mound, shown by an *Otavia*, was where one of the clustered grains protruded through the phosphatic sheath. This possibility has now been investigated in detail and, although grain-clusters can occasionally be seen in the Etosha limestones they are certainly not the basis of typical *Otavia* structures. It is not unusual for an *Otavia* to be attached to one or more carbonate grains, but such cases are easily recognisable and it can now be said with confidence that a typical *Otavia* originally had a hollow interior within its peripheral labyrinth.

Another point that Bengtson raised was that, for a sponge to function effectively, the whole structure, and the incurrent ostia in particular, cannot be smaller than a critical minimum. For instance, the force necessary to pump water through a tube is inversely proportional to the 4th Power of its diameter. This means that very small ancestral sponges must have been much less efficient than their later successors. But among the *Otavia* specimens, occasional specimens attain a length of 5mm, which is larger than some contemporary sponges living today.

Investigations on the *Otavia* question are continuing, but it is now the opinion of one of the authors (C.K.B.) that we are, in fact, dealing here with fossils of small ancestral sponges. If so, the evidence indicates that some of these survived the second of the Snowball Earth glacials. Sponges are now known to be part of the subsequent Ediacaran fauna in Australia (Gehling & Rigby, 1996) and possibly occur also in the Nama Group of Namibia, in the form of *Namapoikia* (Wood et al., 2002).

Acknowledgements

C.K.B. would like to thank the organisers of the III International Colloquium on the Vendian-Cambrian of W-Gondwana for their invitation to him to make a presentation there. May the IGCP Project 478 have a bright future!

References

- Brain, C. K., Hoffmann, K.-H., Prave, A. R. & Fallick, A. E., 2001. Interpretive problems in a search for micro-invertebrate fossils from a Neoproterozoic limestone in Namibia. *Palaeontologia Africana*, v. 37, p. 1-12.
- Doolittle, R. F., Feng, D. F., Tsang, S., Cho, G. & Little, E., 1996. Determining divergence times of the major Kingdoms of living organisms with a protein clock. *Science*, v. 271, p. 470-477.
- Gehling, J. G. & Rigby, J. K., 1996. Long expected sponges from the Neoproterozoic Ediacara fauna of South Australia. *Journal of Paleontology*, v. 70, p.185-195.
- Harland, B. W., 1965. Evidence for late Precambrian glaciation and its significance, *in*: A. E. M. Nairn (Ed.), *Problems in Palaeoclimatology*. Interscience, London, pp.119-149.

- Hoffman, P. F., Kaufman, A. J., Halverson, G. P. & Schrag, D. P., 1998. A Proterozoic Snowball Earth. *Science*, v. 281, p. 1342-1346.
- Hoffmann, K.-H., 1989. New aspects of lithostratigraphic subdivision and correlation of late Proterozoic to early Cambrian rocks of the southern Damara belt and their correlation with the central and northern Damara Belt and Gariiep Belt. *Communications of the Geological Survey of Namibia*, v. 5, p. 59-67.
- Hoffmann, K.-H., 1994. New constraints on the timing of continental breakup and collision in the Damara Belt. Abstr., Proterozoic Crustal and Metallogenic Evolution. Geological Society and Geological Survey of Namibia, Windhoek, p. 30.
- Hoffmann, K.-H. & Prave, A. R., 1996. A preliminary note on the revised subdivision and regional correlation of the Otavi Group based on glaciogenic diamictite and associated cap dolostones. *Communications of the Geological Survey of Namibia*, v. 11, p. 77-82.
- Kirschvink, J.L., 1992. Late Proterozoic low-latitude global glaciation: the Snowball Earth, *in*: J. W. Schopf & C. Klein (Eds.), *The Proterozoic Biosphere. A Multi-disciplinary Study*, Cambridge University Press, Cambridge, pp. 51-52.
- Le Roex, H.D., 1941. A tillite in the Otavi Mountains, S.W.A. *Transactions of the Geological Society of South Africa*, v. 44, p. 207-218.
- Prave, A.R. & Hoffmann, K.-H., 1995. Unequivocal evidence for two Neoproterozoic glaciations in the Damara succession of Namibia. *Geological Society of America. Abstracts with Program* v. 27, p. 380.
- Wood, R. A., Grotzinger, J. P. & Dickson, J.A.D., 2002. Proterozoic modular biomineralized metazoan from the Nama Group, Namibia. *Science*, v. 296, p. 2383-2386.
- Wray, G.A., Leventon, J.S. & Shapiro, L.H., 1996. Molecular evidence for deep Precambrian divergences among metazoan phyla. *Science*, v. 274, p. 568-573.

Neoproterozoic diamictites in southern Brazil: A preliminary survey in the Santa Catarina State

T. T. Eerola

Department of Geosciences, CFH, Federal University of Santa Catarina, Campus Universitário, B. Trindade, 88010-970 Florianópolis, SC, Brazil, teerola@cfh.ufsc.br

Introduction

The Neoproterozoic is characterized by extensive diamictite deposits. Many of them have been regarded as glacial in origin (Hambrey & Harland 1985). This led Hambrey & Harland (1985) and Hoffman et al. (1998) to advocate worldwide glaciations in the Neoproterozoic, the so-called “snowball Earth”. However, glacial influence has not been found in all coeval basins. In many cases, diamictites are signs of gravity processes in unstable slopes of tectonically active basins. Neoproterozoic diamictites are also found in southern Brazil, namely in the states of Rio Grande do Sul (RS) and Santa Catarina (SC, Eerola, 2002). This work presents preliminary results of a survey on Neoproterozoic diamictites in SC.

Geological setting of the Neoproterozoic diamictites in Santa Catarina

The oldest Neoproterozoic diamictites of the SC are found in the deformed metamorphic sequence of the Brusque Group, part of the Tijucas Belt. The group is characterized by schists, quartzites, marble, phyllites, metalimestones, minor felsic and mafic metavolcanic rocks and metaconglomerates (Krebs & Lopes 1995, Silva et al., 2002).

Presently, there are no reliable geochronological constraints on the depositional age for the Brusque basin, but a coarse estimation from ca. 1000 Ma to ca. 650 Ma can be preliminarily

assumed (L.C. Silva, pers. comm. 2003). The same author interpreted the evolution of the basin in terms of a continental margin succession with late felsic volcanics dated at ca. 640 Ma (Silva et al., 2002). This thrust and fold belt is related to the SW-NE trending Dom Feliciano Belt. It was intruded by several granitoids during the Brasiliano Orogeny.

Neoproterozoic diamictites are also found in the Itajaí Basin, with age of ~600 Ma (Basei et al., 1998). It was installed onto and between the Brusque Group and Luís Alves Granulites, in the final stage of the Brasiliano Orogeny during the Vendian-Cambrian (Gresse et al., 1997, Krebs & Lopes 1995, Basei et al., 1998, Caruso et al., 1998). The Itajaí Basin is one of the molassic Neoproterozoic basins that are found in SC and Paraná State (Basei et al., 1998). It is correlative with the Camaquã-Santa Bárbara Basin in RS. Gresse et al. (1997) interpreted the Itajaí-Camaquã deposits as foreland basins correlated with the Nama Group in Namibia.

Metadiamictites in the Brusque Group

Metadiamictites that belong to the Brusque Group were recently found by the author at the Cabeçudas Beach, near the town of Itajaí. They are folded pebbly phyllites, with eventual metasandstone lenses. Quartzites and marbles occur nearby. The sparse clasts of the metadiamictite are of quartzite, phyllite, dolomite, and granite, oriented parallel with the schistosity (N60°E). The size of the clasts varies from some centimeters to 25 cm in length. They resemble limestones. However, the deformation makes it difficult to determine their origin. The metadiamictite may be glacial, but may also represent gravity flow. Their total extension is unknown and the sequence is under investigation. Metadiamictites associated with metarhythmites are also found in the Botuverá region (Krebs & Lopes 1995).

Similar rocks are found in the Chuos Formation of the Damara Belt in Namibia, where they represent the Sturtian glaciation (750-700 Ma, Germs 1995). The Brusque Group is also coeval with the Açungui Group in the Paraná State, where Sturtian glacial deposits were described by Perdoncini & Soares (1992). However, no glacial influence has been observed in the Brusque Group.

Diamictites in the Itajaí Group

The Itajaí Group is composed by shales, sandstones, turbidites, conglomerates, minor diamictites, and local occurrences of felsic volcanoclastics, deposited in alluvial fan, fan delta and marine/lacustrine and subaqueous fan environments, associated with acid volcanism (Krebs & Lopes 1994, Basei et al., 1998, Caruso et al., 1998). Diamictites are composed by sandy and muddy matrix, with quartz, granulitic, granitic, volcanic and sandstone clasts. Some of the diamictites present crude stratification, fining upward, and local imbrication, but are mainly disorganized. The clast size varies from granule to boulder size. The diamictites are regarded as having been deposited by gravity flows in subaqueous and alluvial fans and in some places they form channel structures (Krebs & Lopes 1994, Basei et al., 1998, Caruso et al., 1998).

The Itajaí Group was deposited during the Varangerian glaciation (~600 Ma, Basei et al., 1998), roughly coeval with the Gariep Belt and the Nama Group in Namibia, where there are glacial deposits (Germs 1995). In fact, there are some suggestions on glacial origin in the Itajaí Basin (e.g. Guimarães 1933, Carvalho & Pinto 1938), but those were contested by De Freitas (1945). Rocha Campos (1981) mentioned the Itajaí Group as having conglomerates of uncertain origin. However, no glacial evidences were observed in this preliminary survey.

Discussion

During the deposition of the Brusque and Itajaí Groups, there was glacial influence in closely located areas, including Namibia. It seems that southern Brazil formed an anomalous ice-free area in the middle of this record during the Sturtian and Varangerian glaciations and there are some possible reasons for this paradox (Eerola 2002): 1. Location in low paleolatitude, where tropical climate dominated (Hyde et al., 2000); 2. Restriction of the glacial influence in high altitudes; 3. Non-preservation, or 4. Unfinding or unrecognition of the glacial influence.

Together with tectonics, the Neoproterozoic climates must have influenced the deposition. If there was glacial influence in the case of the Itajaí Group, it may have been restricted to high altitudes at the borders of the basin, where this record was not preserved. So, the deposits in the basin may be only its distal expression. In this case, a possible glacial influence might be difficult to recognize, as the sediments are strongly reworked during the transport, and resemble those of common alluvial, fluvial, deltaic, and marine deposits (Eyles & Kocsis 1988, Martini 1990, Lønne 1995, Fort 2000).

Conclusion

Neoproterozoic diamictites are found in the Brusque and Itajaí Groups in the Santa Catarina State. They seem to have been deposited by gravity flows in slope settings, where most of the Neoproterozoic diamictites are found, including those with glacial influence.

Although the diamictites of the region were deposited during the Sturtian and Varangerian glaciations, and there are some suggestions on glacial influence, no such evidences were detected in this preliminary survey. However, the study is in its beginning and new data will be collected in a further work.

References

- Basei, M.A.S., Citroni, S.B. and Siga Júnior, O. 1998. Stratigraphy and age of Fini-Proterozoic Basins of Paraná and Santa Catarina States, southern Brazil. *Boletim IG/USP*, v. 29, p. 195-216.
- Caruso Jr., F., Araújo, S.A. and Krebs, A.S.J. 1998. Roteiro geológico. Sistemas deposicionais da Bacia do Itajaí. Editora da Universidade do Vale do Itajaí, Itajaí, 77 pp.
- Carvalho, P.F. and Pinto, E.A. 1938. Reconhecimento geológico no Estado de Santa Catarina. *Boletim do Serviço Geológico e Mineralógico do Brasil*, 92, 30 pp.
- De Freitas, R.O. 1945. O Conglomerado Baú (Série Itajaí-Santa Catarina). *Boletim da Faculdade de Filosofia, Ciências e Letras, Geologia*, v. 2, p. 37-115.
- Eerola, T.T. 2002. "A tropical paradise"? Neoproterozoic glaciations from the southern Brazilian perspective. In: Gaucher, C. (Editor) *II International Colloquium Vendian-Cambrian of W-Gondwana, Extended Abstracts*. Facultad de Ciencias-UNESCO, Montevideo, pp. 18-20.
- Eyles, N. and Kocsis, S. 1988. Sedimentology and clast fabric of subaerial debris flow facies in a glacially-influenced alluvial fan. *Sedimentary Geology*, v. 59, p. 15-28.
- Fort, M. 2000. Glaciers and mass wasting processes: their influence on the shaping of the Kali Gandaki valley (higher Himalaya of Nepal). *Quaternary International*, v. 65/66, p. 101-119.
- Germis, G.J.B. 1995. The Neoproterozoic of southwestern Africa, with emphasis on platform stratigraphy and paleontology. *Precambrian Research*, v. 73, p. 137-151.
- Grasse, P., Chemale Jr., F., Silva, L. C., Walraven, F., Hartmann, L. A. 1996. Late- to post-orogenic basins of the Pan-Africa/Brazilian collision orogen in southern Africa and southern Brazil. *Basin Research*, v. 8, p. 157-171.
- Guimarães, D. 1933. A Província magmática do Brasil Meridional. Departamento de Serviço Geográfico e Geológico de Minas Gerais. Belo Horizonte, Monografia, 1, 65 pp.
- Hambrey, M.J. and Harland, W.B. 1985. The late Proterozoic glacial era. *Palaeogeography, Palaeoclimatology, Palaeoecology*, v. 51, p. 255-272.
- Hoffman, P.F., Kaufman, A.J., Halverson, G.P. and Schrag, D.P. 1998. A Neoproterozoic snow-ball Earth. *Science*, v. 281, p. 1342-1346.
- Hyde, W.T., Crowley, T.J., Baum, S.K. and Peltier, W.R. 2000. Neoproterozoic "snowball Earth" simulations with a coupled climate/ice-sheet model. *Nature*, v. 405, p. 425-429.

- Krebs, A.S.J. and Lopes, C.R. 1995. Estratigrafia, *in*: Krebs, A.L.S., Da Silva, M.A.S., Camozzato, E. & Ramgrab, G.E. (Eds.) Programa de Levantamentos Geológicos Básicos do Brasil. Botuverá. Folha SG.22-Z-D-I-2. Estado de Santa Catarina. Escala 1:50.000. CPRM, Brasília, p. 100-125.
- Lønne, I. 1995. Sedimentary facies and depositional architecture of ice-contact glaciomarine systems. *Sedimentary Geology*, v. 98, p. 13-43.
- Martini, I.P. 1990. Pleistocene glacial fan deltas in southern Ontario, Canada. *Special Publication of the International Association of Sedimentologists*, v. 10, p. 281-295.
- Perdoncini, L. C. and Soares, P.C. 1992. Depósitos glaciogênicos do Proterozóico Superior no leste do Paraná. In: Congresso Brasileiro de Geologia, 37, Boletim de Resumos Expandidos. SBG, São Paulo, v. 2: 452-453.
- Rocha-Campos, A.C. 1981. Other Paleozoic and Precambrian conglomerate beds of uncertain origins in Brazil, *in*: Hambrey, M.J. and Harland, W.B. (Eds.) *Earth's Pre-Pleistocene glacial record*. Cambridge University Press, London, p. 939-940.
- Silva, L. C. da, McNaughton, N.J., Santos, J.O. S. 2002. Datações U-Pb SHRIMP do vulcanismo félsico da bacia Brusque, Orógeno Pelotas, Santa Catarina, *in*: Congresso Brasileiro de Geologia, 41, João Pessoa, 2002, SBG. Anais p. 510.

Metazoans of the Vendian Period in the aspects of palaeoecology and palaeogeography: White Sea, Russia

M.A. Fedonkin

Paleontological Institute, Russian Academy of Sciences, Profsoyuznaya ul. 123, Moscow 117997, Russia,
mfedon@paleo.ru

The most representative fossil record of the Late Precambrian multicellular animals (Metazoa) has been documented in the siliciclastic succession of the Vendian in the White Sea region, north of the East-European Platform (Fedonkin, 2003). Sandstone, mudstone and clay members with rare volcanic ash beds represent the regressive sedimentary succession which has been formed in the relatively shallow water conditions of the open marine basin, predominantly below the wave base and under influence of active transportation of the sediments from the former land on the north-west and north-east of the Russian Plate. Essential part of the regional Vendian succession corresponds to the vast deltaic system that gradually developed southwest from the Kanin–Timan foreland. Total thickness of the Vendian deposits in the region is about 550 m, though it may reach 1000 meter in the Mezen' Depression. Most part of the succession is exposed in the natural outcrops. Neither Varanger tillite at the base of the succession, nor Cambrian sediments stratigraphically above the Vendian rocks have been identified in the region yet. Radiometric U-Pb dating of zircon from the ash beds of the section shows that the potential time range of the regional succession of the Vendian may reach 20 Ma at least. Comparative study of the stratigraphic distribution of the metazoan species and U-Pb radiometric data (though still poor) from the major Vendian sections worldwide shows that the Ediacara-type biota included both long-life taxa that persisted about 10 Ma and some short-living species.

In spite of a presumably narrow time range of the succession it contains the faunal elements that are known separately in the Vendian rocks of SW Newfoundland, NW Canada, Great Britain, Namibia, South Australia, north of Siberia, Middle Urals and Ukraine. This shows high potential of the Ediacara-type fossils for biostratigraphy and paleogeography. The faunal distribution over the regional succession shows taxonomic diversity growth in time (including diversity inside some clades and in bioturbations), stepwise character of this process, changing faunistic connections of the paleobasin in time, strong paleoecological and taphonomic control

over the composition and abundance of the metazoan communities. Biodiversity growth in time may reflect the overall evolutionary explosion in the eukaryotic realm during the Vendian. Appearance of the species known from the other regions of the world may reflect the change in the faunal connections of the paleobasin due to the paleogeographic or/and climatic change. Reappearance of some rare species (such as *Charnia* and *Rangaea*) in the stratigraphically distant fossil assemblages may reflect the episodes of expansion of the natural habitats of the species with different climatic preference. Decreasing biodiversity and body size of the metazoan fossils and bioturbations in the relatively deep sedimentary facies may indicate to low oxidation of the deeper habitats. No metazoan fossils have been discovered in the sediments that have been deposited in the brackish waters. Active colonization of the deep-sea habitats and the terrestrial environments by the metazoans seemed to begin later in Early Paleozoic time.

At least six faunal assemblages named after the dominating fossil are identified in a sequence: *Calyptrina-Beltanelloides*, *Ventogyrus*, *Pteridinium*, *Charnia*, *Yorgia*, and *Dickinsonia lissa*. The faunal succession demonstrates the potential for establishing the globally correlatable biostratigraphic units (stages and biozones). A uranium-lead zircon age 555.3 Ma for a volcanic ash by the top of the *Charnia* fossil assemblage in the sea cliffs of Zymnie Gory (Martin et al., 2001) indicates a minimum age of the triploblastic metazoans because the bilaterian body fossils (such as *Kimberella*) and trace fossils occur stratigraphically below. Biodiversity dynamics through the Vendian stratigraphic succession reflect the evolutionary, paleoecological and paleogeographic events but it has not any evident connection to the carbon isotope excursions in the Vendian ocean. This study is supported by the Russian Fund for Basic Research (Grant 05-02-64658).

References

- Fedonkin M.A., 2003. The origin of the Metazoa in the light of the Proterozoic fossil record. *Paleontological Research*, v. 7, p. 9-41.
- Martin, M.W., Grazhdankin, D.V., Bowring, S.A., Evans, D.A.D., Fedonkin, M.A., and Kirschvink, J. L., 2000. Age of Neoproterozoic bilaterian body and trace fossils, White Sea, Russia: implications for metazoan evolution. *Science*, v. 288, p. 841-845.

The Missing Link between the Dom Feliciano and Gariep Belts

H.E. Frimmel¹, M.A.S. Basei² & J. Jacob³

¹Department of Geological Sciences, University of Cape Town, Rondebosch 7701, South Africa,
hef@geology.uct.ac.za

²Instituto de Geociencias, Universidade de Sao Paulo, Rua do Lago 562, CEP-05508-900, Brazil,
baseimas@spider.usp.br

³Resource Management Department, Namdeb, Oranjemund, Namibia

Introduction

Ever since Du Toit's (1937) visionary recognition of the former amalgamation of South America and Africa, geologists have been engaged in establishing tectonic and stratigraphic links between the eastern part of South America and the western part of Africa. While the correlation of Phanerozoic units, such as the Cretaceous Parana and Etendeka flood basalt provinces, is not being questioned anymore, that of older, Precambrian, pre-Gondwana units remains enigmatic. A major obstacle in the correlation of individual units across the South Atlantic has been the fundamentally different nature of the Dom Feliciano Belt and its counterparts in southwestern Africa: the former consists predominantly of magmatic rocks that bear the mineralogical,

lithological and geochemical characteristics of a magmatic arc, whereas the latter are dominated by metasedimentary successions and contain only few or no arc-related magmatic rocks. The problem of correlation across the South Atlantic has been even more exacerbated by the recognition that the Dom Feliciano Belt is not a single coherent tectonic belt but contains remnants of several independent Neoproterozoic basins and Palaeo- to Mesoproterozoic basement fragments, which were juxtaposed during at least three orogenic phases that are related to collision events around 700, 640 and 530 Ma (Basei et al., 2000). In contrast, only one continental collision event around 545 Ma has been recognized in the Gariep Belt (Frimmel & Frank, 1998).

Recent age data obtained on the various basement blocks within and around the Dom Feliciano Belt indicate Palaeoproterozoic ages throughout the region (summarized by Basei et al., 2000), except for the Punta del Este Terrane in eastern Uruguay. The latter consists of high-grade metamorphic rocks yielding ages around 1.0 Ga (Preciozzi et al., 1999) that are overlain by supracrustal rocks of the Rocha Group. Considering the dominance of late Mesoproterozoic rocks in the basement rocks of southwestern Africa (summarized by Frimmel, 2003), this fundamental difference in the basement ages offers a good opportunity to test the extent, to which the various Neoproterozoic units of the Dom Feliciano and Gariep Belts can be correlated. We therefore are engaged in a provenance study of the clastic units within the Punta del Este Terrane and the Marmora Terrane (Gariep Belt) in order to assess test whether the crustal blocks, from which the various clastic sediments in the Neoproterozoic successions of the Dom Feliciano/Gariep Belt were derived, are of different age and possibly also different composition. Here we present first results on the Rocha Group of the Punta del Este Terrane and the Oranjemund Group of the Marmora Terrane. Both units are lithologically very similar in that they are predominantly composed of siliciclastic successions of turbiditic character and chlorite phyllite. Both follow a similar structural trend and display a similar deformational history and both are of similar low metamorphic grade.

Geochemistry

The samples from the Oranjemund Group have relatively low CIA values, namely 67 and 73 for respectively arenite and argillite of the upper part of the group, and as little as 58 for the chlorite phyllite of the lower group. Theoretically, the finer grained rocks should show a stronger degree of chemical weathering than associated arenite, but the opposite is the case in our sample set. The siliciclastic samples from the Oranjemund Group deviate somewhat from the modern weathering trend of continental clastic material, but follow a trend that points to a source rock with extremely low $K_2O/(Na_2O+CaO)$ ratio, as can be expected for gabbroic or tonalitic material.

The low CIA values would indicate a very low degree of chemical weathering, but a certain distortion due to post-depositional Na-metasomatism, as evidenced by the growth of metamorphic albite porphyroblasts, is indicated. As no significant correlation exists in the analysed samples between CIA values and Th/U ratios, the variability in CIA is ascribed mainly to variable Na-metasomatism and not to variations in the intensity of source rock weathering. The source for the post-depositionally introduced Na is suspected to be palaeo-evaporite deposits that have been documented in the Chameis Subterrane (Frimmel & Jiang, 2001).

When compared to the immediate vicinity, i.e. the oceanic within-plate mafic rocks of the Schakalsberge and Chameis Subterrane, the Oranjemund Group rocks show remarkably similar Zr/Y ratios and REE abundance and distribution. In terms of their La-Sc-Th-Zr distribution, the Oranjemund Group arenite and argillite samples conform to a continental island arc and/or passive continental margin environment. The Sc/Cr and La/Y ratios of the Oranjemund Group rocks cover the entire data field for passive margins, but extend to La/Y of as much as 4.5. These

ratios overlap entirely with those obtained for the mafic rocks of the adjacent Schakalsberge and Chameis Subterrane.

The Rocha Group argillite displays, in comparison, a similar degree of chemical weathering but derivation from a even less potassic source than its equivalents from the Oranjemund Group. Furthermore, it was not affected significantly by Na-metasomatism.

Detrital zircon geochronology

Single zircon U-Pb isotope analyses by SHRIMP revealed very similar age patterns for detrital zircon grains from both the Rocha and Oranjemund Groups. Most of the detrital zircon grains are derived from a 1.0 to 1.2 Ga source, which can be located in the Bushmanland Terrane of the Namaqua-Natal Belt (Frimmel, 2003). A few grains have ages between 1.7 and 2.0 Ga, which corresponds to the age range of the Eburnian Andean-type arc material that is widespread to the northwest of the Kalahari Craton. A further zircon population yielded ages between 600 and 800 Ma, thus highlighting that these sediments must have been deposited after 600 Ma. This is in agreement with an earlier study (Frimmel and Fölling, 2003), in which it could be shown that the Oranjemund Group sediments were laid down in a syn-orogenic basin during the closure of the Gariep Basin some time between 600 and 550 Ma.

Conclusions

Lithological, geochemical and geochronological comparison between the Rocha and the Oranjemund Groups revealed that both units can be correlated and most likely formed in the same basin. Thus the Rocha Group is considered the westernmost part of the Gariep Belt. The lower part of the respective group seems to reflect a direct erosion product from oceanic islands, whereas the upper parts reflects a wider source area that spans from a passive continental margin to oceanic seamounts of within-plate character. Considering the proximity between the depositional environment for the upper Oranjemund/Rocha Group turbidites and the eastern basin margin, the inferred passive margin as source area was most likely located along the western flank of the Kalahari Craton. The oceanic within-plate basaltic source presents itself by the nearby Schakalsberge and Chameis oceanic islands. The youngest ages obtained on detrital zircon in both groups indicate derivation from the magmatic arc of the Dom Feliciano Belt, which must have existed already at the time of Oranjemund/Rocha sedimentation. Consequently, formation of the Dom Feliciano volcanic arc cannot be explained by the closure of the Gariep Basin. The latter is regarded as a narrow oceanic basin, possibly in a back-arc position relative to the Dom Felician arc, and the major suture between the South American cratonic masses and the Kalahari Craton was most likely not within the Gariep Basin but further to the west, possibly reflected by the Sierra Ballena Shear Zone along the western margin of the Punta del Este Terrane.

References

- Basei, M. A. S., Siga Jr., O., Masquelin, H., Harara, O. M., Reis Neto, J. M. & Preciozzi, P. F., 2000, The Dom Feliciano Belt of Brazil and Uruguay and its foreland domain, the Rio de la Plata Craton, *in*: Cordani, U. G., Milani, E. J., Thomaz Filho, A., and Campos, D. A. (Eds.), *Tectonic Evolution of South America*, Rio de Janeiro, p. 311-334.
- Du Toit, A. L., 1937, *Our Wandering Continents*, Oliver & Boyd, 366 p.
- Frimmel, H. E., 2003, Formation of a late Mesoproterozoic supercontinent: The South Africa - East Antarctica connection, *in*: Eriksson, P.G., Altermann, W., Nelson, D.R., Mueller, W.U. & Catuneanu, O. (Eds.), *The Precambrian Earth: Tempos and Events*, Amsterdam, Elsevier, in press.
- Frimmel, H. E. & Fölling, P. G., 2003, Late Vendian closure of the Adamastor Ocean: Timing of tectonic inversion and syn-orogenic sedimentation in the Gariep Basin. *Gondwana Research*, in press.

- Frimmel, H. E. & Frank, W., 1998, Neoproterozoic tectono-thermal evolution of the Gariep Belt and its basement, Namibia/South Africa. *Precambrian Research*, v. 90, p. 1-28.
- Frimmel, H. E. & Jiang, S.-Y., 2001, Marine evaporites from an oceanic island in the Neoproterozoic Adamastor ocean. *Precambrian Research*, v. 105, p. 57-71.
- Preciozzi, F., Basei, M. A. S. & Masquelin, H., 1999, New geochronological data from the Piedra Alta Terrane (Rio de la Plata Craton): II South American Symposium on Isotope Geology, Actas, Cordoba, Argentina, 1999, p. 341-343.

Acritarch biostratigraphy and correlations of the late Vendian Congo Caves Group, Saldania Belt (South Africa)

C. Gaucher¹ & G.J.B. Germs²

¹Departamento de Paleontología, INGEPA, Facultad de Ciencias. Igua 4225, 11400 Montevideo, Uruguay. gaucher@chasque.apc.org

²Department of Geology, Rand Afrikaans University, P.O. Box 524, Auckland Park, 2006 Johannesburg, South Africa. gagerms@global.co.za

Lithostratigraphy and age constraints

The Congo Caves Group (CCG) is exposed as a basement inlier along the core of a mega-anticline of the Permo-Triassic Cape Fold Belt (Le Roux, 1999, 1997). The succession, previously named Goegamma Subgroup, is part of the Pan-African Saldania Belt, which marks the southern margin of the Kalahari Craton. From base to top, the CCG comprises (Fig. 1) the Matjies River, Groenefontein and Huis Rivier Formations (Le Roux 1997, 1999). The succession is made up of interbedded siliciclastic and carbonate deposits at the base, which pass into siliciclastic turbidites up section (Fig. 1).

Carbonates of the Kombuis Member yielded a Pb-Pb double-spike isochron age of 553 ± 30 Ma (Fölling et al., 2000; Fig. 1). While detrital zircons of the CCG yield ages around 1100 Ma, those from the overlying Kansa Group also contain a 518 ± 9 Ma component (Barnett et al., 1997). These datings suggest a Vendian age for the Kombuis Member of the CCG, and a late Cambrian or younger age for the overlying Kansa Group. On the basis of C, O and Sr isotope chemostratigraphy, and a difference of 100 °C in thermal overprint between the Nooitgedagt and Kombuis members, a pre-Vendian age for the Nooitgedagt Member and a Vendian age for the rest of the CCG has been postulated (Frimmel et al., 2001; Fölling & Frimmel, 2002). We report here the occurrence of organic-walled microfossils in the Congo Caves Group. 32 samples of organic-rich shales and limestones of the CCG were studied following standard palynological methods, 22 of which yielded identifiable remains.

Micropalaeontology

While microfossils occurring in samples of the Matjies Rivier Formation are mostly opaque and carbonized, microfossils of the Groenefontein and Huis Rivier Formations are predominantly middle to dark brown in colour. Corresponding thermal alteration index (TAI, Hunt, 1996) values imply temperatures in excess of 250 °C for the Nooitgedagt Member, between 170-250 °C for the Kombuis Member (with local variations), and 120-170°C for the Groenefontein and lower Huis Rivier Formations. Metamorphism temperatures calculated by Frimmel et al. (2001) using carbon isotope geothermometry are considerably higher for the Nooitgedagt Member (388 ± 8 °C) but comparable for the Kombuis Member (<270 to 289 °C).

The assemblage recovered from the CCG is characterized by its low diversity (12 species), high abundance of fossils and dominance of *Bavlinella faveolata*, *Soldadophycus bossii* and

Leiosphaeridia spp (Fig. 1). In the Nooitgedagt Member, *Bavlinella faveolata* strongly dominates the microflora and becomes rarer up section, the assemblage of the Kombuis Member being dominated by mainly spheroidal and saucer-shaped colonies of *Soldadophycus bossii* (Gaucher, 2000). This *Soldadophycus*-dominated assemblage is replaced up section (Groenefontein and Huis Rivier Formations) by an essentially *Leiosphaeridia*-dominated microflora. The only acanthomorphic acritarchs found in the CCG are rare *Micrhystridium* cf. *M. tornatum* Volkova occurring in the Kombuis Member. Acritarchs are small (<150 µm), largest sphaeromorphs (up to 200-400 µm) occurring in the upper CCG. Occurrence of fossils in the different units of the CCG is partly controlled by palaeobathymetry and facies. While in the shallower deposits of the Matjies River Formation filament mats and larger spheroid colonies occur, the assemblage occurring in the turbiditic Groenefontein and Huis Rivier Formations is composed of planktonic sphaeromorphs and small *Soldadophycus bossii*-colonies. Spherical to flask-shaped bodies 20-60 µm in diameter, consisting of agglutinated, fine-grained rutile crystals occurring in palynological macerations of the Matjies River Formation are regarded with doubts to *Titanotheca* sp. (Gaucher, 2000).

Biostratigraphy and correlations

The depauperate palynomorph assemblage preserved in the CCG is typical for the Vendian. The microflora matches the Kotlin-Rovno assemblage of Vidal & Moczydlowska (1997), which is characterized by low diversity, abundance of *Bavlinella faveolata*, rarity or absence of acanthomorphs and absence of large (> 500 µm) sphaeromorphs (Volkova 1985, Vidal & Moczydlowska 1997). Neoproterozoic, pre-Vendian assemblages are more diverse and distinctly different from Vendian assemblages (R3 and R4 of Vidal & Moczydlowska, 1997; Knoll, 2000). According to the stratigraphic scheme of Grey et al. (2003), the assemblage of the CCG matches the simple leiosphere palynoflora characteristic for the late Vendian. Occurrence of *Micrhystridium* cf. *M. tornatum* in the Kombuis Member and absence of acritarchs attributable to the Ediacaran complex acanthomorph palynoflora (Grey et al., 2003) suggests a latest Vendian age for the unit (Volkova 1985), in accordance with a Pb-Pb age of 553 ± 30 Ma (Fölling et al., 2000). As for the *Bavlinella faveolata*-dominated assemblage preserved in the Nooitgedagt Member, it can be confidently assigned to the Vendian because no *Bavlinella*-dominated assemblages pre- or postdate this period.

There is a striking similarity between the palynomorph assemblages preserved in the CCG and those recovered from the Nama, Arroyo del Soldado (Uruguay) and Corumbá (Brazil) Groups (Gaucher et al, 2003). Almost 70 % of the species recovered from the CCG occur in the Nama Group (Germs et al, 1986) and Arroyo del Soldado Group (Gaucher, 2000). This implies that apart from being roughly coeval and having similar lithologies, these units were deposited in basins that had ample connection and similar climates. The available data suggest correlation of the CCG with the Nama Group, but we cannot definitely rule out a correlation of the Nooitgedagt Member with Vendian, pre-Nama units, eg. the Holgat Formation of the Port Nolloth Group.

References

- Barnett, W., Armstrong, R.A. & De Wit, M.J., 1997. Stratigraphy of the upper Neoproterozoic Kango and lower Paleozoic Table Mountain Groups of the Cape Fold Belt revisited. S. Afr. Jour. Geol., v. 100, p. 237-250.
- Fölling, P.G., Zartman, R.E. & Frimmel, H.E., 2000. A novel approach to double-spike Pb-Pb dating of carbonate rocks: examples from Neoproterozoic sequences in southern Africa. Chem. Geol., v. 171, p. 97-122.
- Fölling, P.G. & Frimmel, H.E., 2002. Chemo-stratigraphic correlation of carbonate successions in the Gariiep and Saldania Belts, Namibia and South Africa. Basin Research, v. 13, p. 1-37.

- Frimmel, H.E., Fölling, P.G. & Diamond, R., 2001. Metamorphism of the Permo-Triassic Cape Fold Belt and its basement, South Africa. *Mineralogy and Petrology*, v. 73, p. 325-346.
- Gaucher, C., 2000. Sedimentology, palaeontology and stratigraphy of the Arroyo del Soldado Group (Vendian to Cambrian, Uruguay). *Beringeria*, v. 26, p. 1-120.

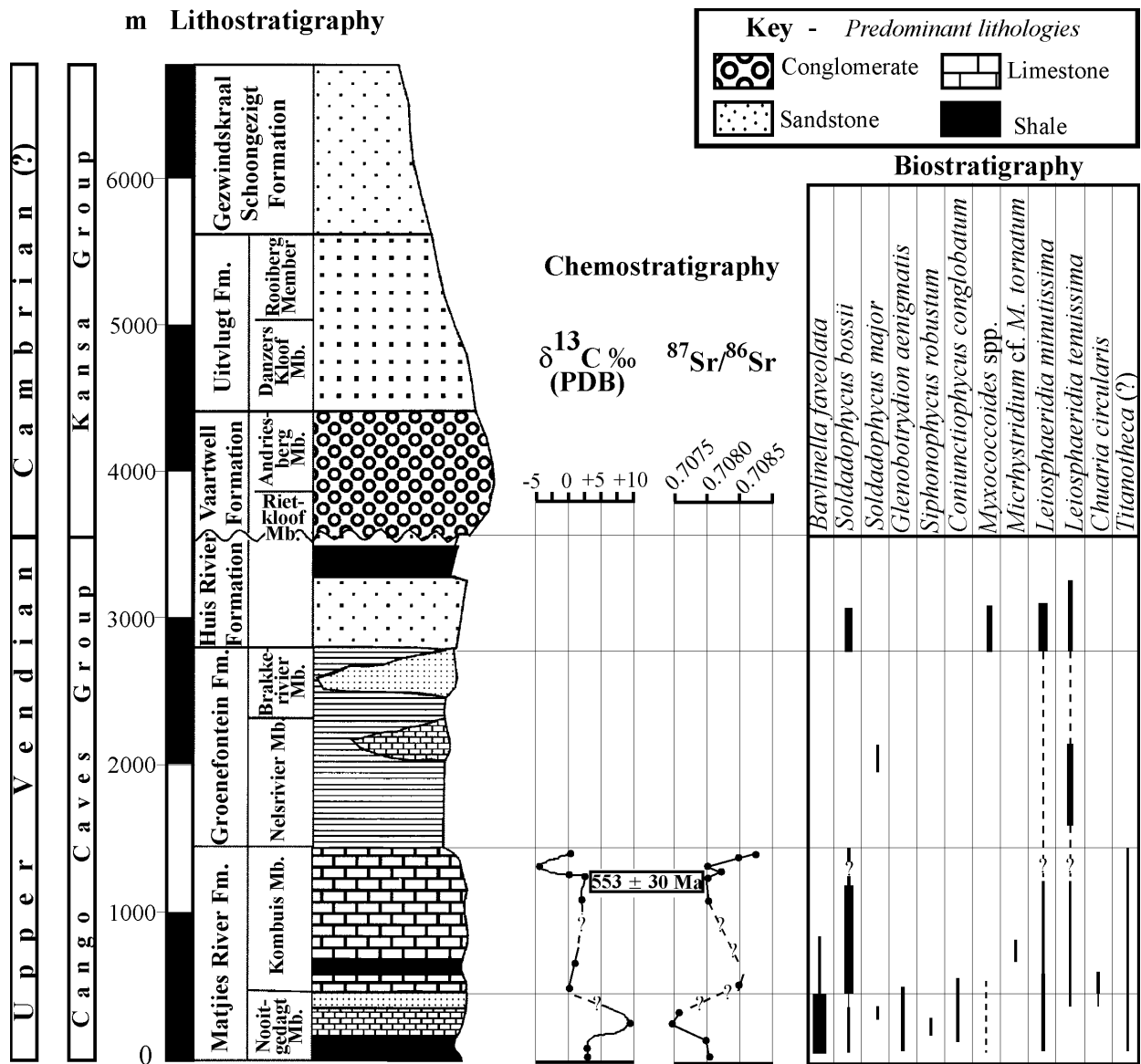


Fig. 1. Generalized stratigraphic column of the Congo Caves and Kansa Groups modified after Le Roux & Gresse (1983) and Frimmel et al. (2001), showing biostratigraphic (Gaucher & Germs, this work) and chemostratigraphic data (Fölling & Frimmel, 2002). Pb-Pb dating (Kombuis Member) after Fölling et al. (2000).

- Gaucher, C., Boggiani, P.C., Sprechmann, P., Sial, A.N. & Fairchild, T.R., 2003. Integrated correlation of the Vendian to Cambrian Arroyo del Soldado and Corumbá Groups (Uruguay and Brazil): palaeogeographic, palaeoclimatic and palaeobiologic implications. *Precamb. Res.*, v. 120, p. 241-278.
- Germs, G.J.B., Knoll, A.H. & Vidal, G., 1986. Latest Proterozoic microfossils from the Nama Group, Namibia (South West Africa). *Precamb. Res.*, v. 32, p. 45-62.
- Grey, K., Walter, M.R. & Calver, C.R., 2003. Neoproterozoic biotic diversification: Snowball Earth or aftermath of the Acraman impact? *Geology*, v. 31, p. 459-462.

- Hunt, J.M. 1996. *Petroleum Geochemistry and Geology*. Second Edition. W.H. Freeman & Co., New York, xx + 743 pp.
- Knoll, A.H., 2000. Learning to tell Neoproterozoic time. *Precamb. Res.*, v. 100, p. 3-20.
- Le Roux, J.P. & Gresse, P.G. 1983. The sedimentary-tectonic realm of the Kango Group, *in*: A.P.G. Söhne & I.W. Halbich (Eds.), *Geodynamics of the Cape Fold Belt*. Spec. Publ. Geol. Soc. S. Afr., v. 12, p. 33-46.
- Le Roux, J.P. 1997. Cycle hierarchy of a Neoproterozoic carbonate-siliciclastic shelf: Matjies River Formation of the Kango Group, South Africa. *South Afr. J. Geol.*, v. 100, p. 1-10.
- Le Roux, J.P. 1999. Cango Caves Group, *in*: Johnson, M.R. (Ed.), *Catalogue of South African Lithostratigraphic Units*. SACS, Council for Geoscience, 6, Pretoria, p. 1-2.
- Vidal, G. & Moczydlowska-Vidal, M. 1997. Biodiversity, speciation, and extinction trends of Proterozoic and Cambrian phytoplankton. *Paleobiology*, v. 23, p. 230-246.
- Volkova, N. A. 1985. Acritarchs and other plant microfossils of the East European Platform, *in*: Sokolov, B. S. & A. B. Iwanowski (Eds.), *The Vendian System*. Springer, Berlin, p. 155 - 165.

Age and preliminary correlation of the Las Ventanas Formation and Bom Jardim-Cerro do Bugio allogroups (Vendian, Uruguay and Brazil)

E. Pecoits

Instituto de Geología y Paleontología, Facultad de Ciencias, Iguá 4225, 11400 Montevideo-Uruguay,
epecoits@montevideo.com.uy

Recently an accurate sedimentological study of the Las Ventanas Formation was carried out. According to this one proximal and one distal facies associations were recognized and characterized. The first one, is integrated by clast-supported conglomerates, diamictites and massive sandstones. The second one, contains laminated siltstones and rhythmites (sandstone-pelite). However, sandstones and conglomerates also occur. These deposits are interpreted as product of sheetflood-dominated alluvial fans (Pecoits, 2002). Although this unit was defined as an Ordovician sedimentary sequence (Midot, 1984), intercalated basalts and rhyolites have been found. Since well rounded clasts of conglomerates and sandstones are practically unweathered, it is inferred that arid environmental conditions prevailed at the time of deposition (Pecoits, 2002).

Based on detailed geological mapping of the Las Ventanas Formation in its type area it was possible to recognize that this unit has been affected by the Puntas del Pan de Azúcar Thrust (Pecoits, 2002). Next to this thrust, located to the east of the study area, the sequence shows a more intense deformation, no cropping out towards the east. This suggests that the sedimentation of the Las Ventanas Formation is older than the thrust. K/Ar age of 572 ± 7 Ma (Cingolani, *in* Bossi & Campal, 1992) was obtained for synkinematic muscovites crystallized along this thrust-plane.

On the other hand, the late orogenic Pan de Azúcar Granite (Preciozzi et al., 1993; renamed El Renegado Granite by Sánchez Bettucci, 1998) has defined intrusive relationships with the Las Ventanas Formation. This granitic body was dated by the Rb-Sr method at 559 ± 28 Ma (Preciozzi et al., 1993). The trachytes and synites of the Sierra de Las Ánimas Formation intrude the study sequence and were dated by the Rb-Sr method at around 520 ± 5 Ma (Bossi et al., 1993).

In Uruguay have been documented an important Vendian magmatism, related to extensional events. Indicative volcanism of this episode is represented by the Sierra de Ríos and Cerros de

Aguirre formations. The former consists of ignimbritic and rhyolitic flows and dykes which were dated at 575 ± 14 Ma (Bossi et al., 1993). The Cerros the Aguirre Formation is composed of pyroclastic and rhyolite rocks with an age of 571 ± 8 Ma (Hartmann et al., 2002). The outlined above enabled to suggest an important tectonomagmatic activity during this period.

By contrast, the Arroyo del Soldado Group was deposited on a stable continental margin with a composite thickness of approximately 5000 m and no volcanics and pyroclastics rocks occur (Gaucher, 2000). This would be indicating tectonic quiescence during the upper Vendian (Valdaian)-lowermost Cambrian. This unit has been correlated by Gaucher et al. (2003) with the Corumbá Group in Brazil. According to this scheme the Arroyo del Soldado Group would be younger than the Las Ventanas Formation.

The Las Ventanas Formation occupies a strategic location in order to correlate Neoproterozoic successions of Uruguay and Brazil. In this sense, the Las Ventanas Formation is correlated with the Cerro do Bugio and Bom Jardim allogroups from the Camaquã Basin, located in Río Grande del Sur, southern Brazil. This correlation is based on very similar ages of magmatogenesis, deformation and lithologies.

The Camaquã Supergroup was deposited on a long lived (620? to 470? Ma) basin named Camaquã which is made up, from base to top, of the Maricá (ca. 630-610 Ma), Bom Jardim (ca. 592-573 Ma), Cerro do Bugio (573-559 Ma), Santa Bárbara (559-540 Ma) and Guaritas (470-450 Ma) allogroups (Paim et al., 2000). The Camaquã Basin has been commonly associated with a late- to post-orogenic system of basins, related to the final stages of the Brasiliano-Pan African Orogeny.

The Bom Jardim Allogroup is composed of basic to intermediate volcanic rocks (Andesito Hilário), alluvial conglomerates and turbidites (Paim et al., 1995). SHRIMP dating of the “Andesito Hilário” by Remus et al. (1999) yielded an age of ca. 580 Ma. The Cerro do Bugio Allogroup consists of acidic and basic rocks (Acampamento Velho Alloformation), alluvial conglomerates, rhythmites (sandstone-pelite) and pelites (Santa Fé Alloformation). Geochronologic studies on acidic fuffs of the Acampamento Velho Alloformation yielded a U-Pb age of 573 ± 18 Ma (Paim et al., 2000). Finally, these units were deformed by a sinistral transcurrence with an age of ca. 570 Ma and intruded by granitic bodies of 559 ± 7 Ma (São Sepé Granitic Complex; Remus et al., 1997) and 565 ± 14 to 561 ± 6 Ma (Caçapava Granitic Complex; Remus et al., 1997; Leite et al., 1998).

Taking into account this new geological evidence the tectonosedimentary models proposed at the moment and the depositional age of the sequence change substantially. Although more data are necessary, the available information facilitates in future Vendian palaeogeographic reconstructions of SW-Gondwana.

Acknowledgements

Funding by research project “Lithostratigraphy of the Fuente del Puma Group and their correlation with other units of Uruguay and southwest of Africa” of the Comisión Sectorial de Investigación Científica” (CSIC, Uruguay) is gratefully acknowledged. This paper is a contribution to project IGCP 478 (Neoproterozoic-Early Palaeozoic events in SW-Gondwana).

References

- Bossi, J. & Campal, N. 1992. Magmatismo y tectónica transcurrente durante el Paleozoico Inferior en Uruguay. In: Gutiérrez-Marco, J.G., Saavedra, J. & Rabano, I. (Eds.), Paleozoico Inferior de Iberoamérica. Universidad de Extremadura, Mérida, pp. 343-356.
- Bossi, J., Cingolani, C., Lambias, E., Varela, R. & Campal, N. 1993. Características del magmatismo post-orogénico finbrasiliano en el Uruguay: formaciones Sierra de Ríos y Sierra de Ánimas. Revista Brasileira de Geociências, v. 23, p. 282-288.

- Gaucher, C. 2000. Sedimentology, paleontology and stratigraphy of the Arroyo del Soldado Group (Vendian to Cambrian, Uruguay). *Beringeria*, v. 26, p. 1-120.
- Gaucher, C., Boggiani, P. C., Sprechmann, P., Sial, A. N. & Fairchild, T. 2003. Integrated correlation of the Vendian to Cambrian Arroyo del Soldado and Corumbá Groups (Uruguay and Brazil): palaeogeographic, palaeoclimatic and palaeobiologic implications. *Precambrian Research*, v. 120, p. 241-278.
- Hartmann, L. A., Santos, J. O. S., Bossi, J., Campal, N., Schipilov, A. & McNaughton, N. J. 2002. Zircon and titanite U-Pb SHRIMP geochronology of Neoproterozoic felsic magmatism on the eastern border of the Rio de La Plata craton. Uruguay. *Journal of South American Earth Sciences*, v. 15, p. 229-236.
- Leits, J. A. D., Hartmann, L. A., McNaughton, N. J. & Chemale Jr. F. 1998. Shrimp U/Pb zircon geochronology of Neoproterozoic juvenile and crustal-reworked terranes in southernmost Brazil. *International Geological Review*, v. 40, p. 688-705.
- Midot, D. 1984. Etude géologique et diagnostic métallogénique pour l'exploration du secteur de Minas (Uruguay). Université Pierre et Marie Curie, Paris. Diplôme de Docteur de 3e Cycle, 175 p.
- Paim, P. S. G., Chemale Jr. F. & Lopes, R. da C. 2000. A Bacia do Camaquã, *in*: Holz, M. & De Ros, L. F. (Eds.), *Geología do Rio Grande do Sul*. Sigo-Universidade Federal Rio Grande do Sul, pp. 231-274.
- Paim, P. S. G., Lopes, R. da C. & Chemale Jr. F. 1995. Stratigraphic framework and depositional systems of the Camaquã Basin (Upper Vendian to Lower Ordovician of southern Brazil), *in*: The geology and metallogeny of the south-western corner of Africa, University of Stellenbosch, South Africa.
- Pecoits, E. 2002. Análisis faciológico y aspectos geológicos de la Formación Las Ventanas; un nuevo enfoque, *in*: Pecoits, E. & Masquelin, H. (Eds.), *II Taller Sobre la Estratigrafía del Precámbrico del Uruguay*. Facultad de Ciencias, Montevideo, pp. 34-36.
- Preciozzi, F., Masquelin, H. & Sánchez Bettucci, L. 1993. Geología de la porción sur del Cinturón Cuchilla Dionisio, *in*: Preciozzi, F., Masquelin, H. & Sánchez, L. (Eds.), *Guía de Excursión, I Simposio Internacional del Neoproterozoico-Cámbrico de la Cuenca del Plata*. Montevideo, pp. 1-39.
- Remus, M. D. V., Hartmann, L. A., McNaughton, M. J., Fletcher, I. R. 1999. Shrimp U-Pb zircon ages of volcanism from the São Gabriel Block, southern Brazil, *in*: *Simpósio sobre vulcanismo e ambientes associados*. Brazil: *Boletim de Resumos*, v. 1, p. 83.
- Remus, M. D. V., McNaughton, M. J., Hartmann, L. A., Groves, D. L. & Reischel, J. L. 1997. Pb and S isotopes signature of sulphide and constrains on timing and sources of Cu (Au) mineralization of the Camaquã and Santa Maria Mines, Caçapava do Sul, southern Brazil, *in*: *South-American Symposium on Isotope Geology*. São Paulo, Brazil. Extended Abstracts, p. 235-255.

Stromatolites and stratigraphy of the Precambrian sedimentary succession of the Verdún Hill, Minas, Lavalleja Department, Uruguay

D.G. Poiré¹, P.D. González¹, J. M. Canalicchio² & F. García Repeto³

¹Centro de Investigaciones Geológicas. UNLP-CONICET, calle 1 n° 644, 1900 LA PLATA, Argentina

²Cementos Avellaneda SA, Paraje San Jacinto, Olavarría, Argentina

³CUCPSA, Minas, Uruguay

Columnar stromatolites in limestones from the Precambrian sedimentary succession of the Verdún Quarry have been recently reported (Poiré, et al, 2003) as one of the products of a very detailed mining study. This quarry, owned by the Compañía Uruguaya de Cementos Portland SA, is located on the basal eastern side of Verdún Hill, 3 km to the west of Minas, Lavalleja Department, Uruguay. The stratigraphic position and the composition of this sedimentary succession used to be uncertain (Bossi & Navarro, 2000) and the limestone unit from the Verdún

Quarry was alternatively considered part of the Lavallega Group (Caorsi & Goñi, 1958), Minas Formation (Mac Millan, 1933; Midot, 1984), Barriga Negra Group (Preciozzi et al., 1985), or “Fuente del Puma-type Limestones” (Bossi & Navarro, 2000) from the Fuente del Puma Formation (Midot 1984; Sánchez Betucci, 1998). The aim of this contribution is to deal about the stratigraphic framework of the quarry and the sedimentological significance of these stromatolites.

From the base to the top, this succession consists of (Fig. 1): Don Mario Formation (40 m thick, base not exposed) composed by black shales, metashales and slates, which pass transitionally to the La Toma Formation (15 m thick) formed by dark green marls and heterolithic facies, which is conformably covered by the El Calabozo Formation (150 m thick). This unit shows grey and black stromatolite limestones, grey and grey greenish laminated and massive limestones, with some collapse breccias as resulting of probably karstic phenomena. The Gibraltar Formation (60 m thick, top not exposed) covers unconformable that limestones, and it is consisting of light yellow, green, black and grey dolomites, pink limestones, and black marls and shales). The unconformity between the El Calabozo and the Gibraltar formations is interpreted as a karstic palaeorelief. These four stratigraphic units are informally grouped in the Cucpsa Group, which is overlying by red polymictic conglomerates and sandstones of the Del Camino Formation (Fig. 1).

This sedimentary sequence is affected by diagenetic features (stylolites) and a fragile deformation (cleavage foliation, shears zones) which are slightly hiding the stromatolites morphologies, but the main features of the stromatolites from El Calabozo Formation are still well preserved. Columnar stromatolites assignable to *Conophyton* fm. is the most abundant group of these organic sedimentary structures. This *Conophyton* fm. consists of unbranching subcylindrical columnar stromatolite with strikingly conical internal laminae whose apexes define a distinctive axial zone and their horizontal section display a conspicuously and regularly concentric structure. The internal laminae are commonly continuous from one column to another, in which case vertical sections show upward as well as downward laminae apexing. Their profile is angulate to geniculate and their plant outline could be round circular to oblong, in which case the axes are strongly orientated. The attitude of the columns is usually straight but sometimes they adopt a recumbent and sinuous posture. The column height is up to 70 cm and the column weight is 5 to 20 cm. However, scarce bud preserved dendroid branching style stromatolites have been recorded on the field, as well as small, rounded plant outline columnar stromatolites have been observed in cores, which could represent digitate branching stromatolite.

In a sedimentological point of view, the group *Conophyton* has been assigned as a deeper subtidal stromatolite by Poiré (1987, 2002) based on Precambrian stromatolite cycles from Villa Mónica Formation, Buenos Aires province, Argentina, and Logan et al. (1974) and Donaldson (1976) ideas. In this sense, the low biodiversity, *Conophyton* abundance and the plant view axes orientation allow to suggest a subtidal marine environment for the El Calabozo Formation, with tide current influence.

The age of the Cucpsa Group is Precambrian but there are not major precisions about that. The quartzites of the Cerro Espuelita Formation on the top of the Verdún Hill is considered as Vendian (Gaucher, 2000), but the contact between the Cucpsa Group and Cerro Espuelita Formación is covered, so, it could be normal, unconformable or by faulting. In the first two cases, this succession could be considered as pre-Vendian. Unfortunately, the group *Conophyton* has a wide range during the Precambrian, from Early Proterozoic to Vendian, being not possible to fit the age of this limestones. More detailed future studies about microstructure of this *Conophyton* could be useful to distinguish the taxonomy and to determinate the possible age.

Pre-Vendian stromatolites have also been described 30 km to the north by Sprechamn et al. (1994) and Gaucher et al (1996) in the Villalba Formation of the Basal Group (Gaucher and

Sprechman, 1995), but their morphologies are completely different. They have recorded stratiform, nodular-stratiform (LLH-C, LLH-V) and columnar (SH-V) stromatolites associated with stromatolitic breccias, which were interpreted as intertidal to supratidal deposits. It could represent shallower stromatolite assemblages than the stromatolites from the Cucpsa Group. Unfortunately, there are no radiometric data to prove this idea.

Very well developed Conophyton ?ressotti and Conophyton fm. have been also recorded in the dolomites of the Villa Mónica Formation (Poiré, 1993) companied by Colonella fm., Cryptozoon fm., Gongylina fm., Gymnosolem fm., Inzeria fm., Jacutophyton fm., Jurusonia nisvensis, Katavia fm., Kotuikania fm., Kussiella fm., Minjaria fm., Parmites fm., Parmites cf. cocrescens and Stratifera fm. (Poiré, 1989; 1993), which radiometric age for diagenesis is 795 My. This sequence could be correlated with El Calabozo Formation but this one shows a poor biodiversity.

References

- Bossi, J. & Navarro, R. 2000. Recursos minerales del Uruguay. Departamento de Publicaciones de la Universidad de la República, Montevideo, 416 pp.
- Caorsi, J. & Goni, J. 1958. Geología Uruguaya. Boletín Instituto Geológico del Uruguay 37. Montevideo.
- Gaucher, C., 2000. Sedimentology, palaeontology and stratigraphy of the Arroyo del Soldado Group (Vendian to Cambrian, Uruguay). *Beringeria*, v. 26, p. 1-120.
- Gaucher, C. & Sprechmann, P. 1995. Paleontología, sedimentología y paleogeografía del Proterozoico medio y superior del Terreno Nico Pérez, Uruguay. Boletim de Resumos Expandidos, 6° Simposio Sul-Brasileiro de Geología. 1° Encontro de Geología del Cono Sur, 101-104. Porto Alegre.
- Gaucher, C., Sprechmann, P. & Schipilov, A. 1996. Upper and Middle Proterozoic fossiliferous sedimentary sequences of the Nico Pérez Terrane of Uruguay: Lithostratigraphic units, paleontology, depositional environments and correlations. *Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen*, v. 199, p. 339-367.
- Donaldson, J.A. 1976. Paleoecology of Conophyton and associated stromatolites in the Precambrian Dismal Lake and Rae Groups, Canada, *in*: M.R. Walter (Ed.), *Stromatolites*, Elsevier, Amsterdam, p. 523-534.
- Logan, R.W., Rezak, R. & Ginsburg, R.N. 1974. Classification and environmental significance of algal stromatolites. *The Journal of Geology*, v. 72, p. 68-83.
- Mac Millan, J. G. 1933. Terrenos precámbricos del Uruguay. Boletín Instituto de Geología y Perforaciones, v. 18, p. 1-61, Montevideo.
- Midot, D. 1984. Etude géologique et diagnostique métallogénique pour l'exploration du secteur Minas (Uruguay). Thesis, 3eme Cycle, Univ. P. et M. Curie, París, Francia.
- Poire, D.G. 1989. Stromatolites of the Sierras Bayas Group, Upper Proterozoic of Olavarría, Sierras Septentrionales, Argentina. *Stromatolite Newsletter*, v. 14, p. 58-61.
- Poire, D.G. 1993. Estratigrafía del Precámbrico sedimentario de Olavarría, Sierras Bayas, provincia de Buenos Aires, Argentina. Actas, XII Congreso Geológico Argentino y II Congreso de Exploración de Hidrocarburos II, Mendoza, p. 1-11.
- Poire, D.G. 2002. Sea level changes and Precambrian stromatolite cycles from Villa Mónica Formation, Tandilia System, Argentina. Abstract, 16th International Sedimentological Congress, Johannesburg, p. 295.
- Preciozzi, F., Sportuno, J., Heinzen, W. & Rossi, P., 1985. Carta geológica del Uruguay a escala 1:500.000. Dirección Nacional de Geología y Minería, Montevideo, 92 pp.
- Sanchez Betucci, L. 1998. Evolución tectónica del Cinturón Dom Feliciano en la región de Minas - Piriápolis, República Oriental del Uruguay. PhD Thesis. Facultad de Ciencias Exactas y Naturales. Universidad de Buenos Aires. 234 pp.
- Semikhatov, M.A. 1976. Experience in stromatolites studies in the USSR, *in*: M.R. Walter (Ed.), *Stromatolites*, Elsevier, Amsterdam, p. 337-357.
- Sprechmann, P., Gaucher, C., Montana, J. & Schipilov, A. 1994. Fósiles del Precámbrico del Uruguay: Unidades litoestratigráficas, edades, correlaciones y ambientes de depositación. I Jornada de

Paleontología del Uruguay "Prof. Dr. Rodolfo Méndez-Alzola", Resúmenes Ampliados. Paleociencias del Uruguay (Serie Didáctica) v. 2, p. 6- 9.

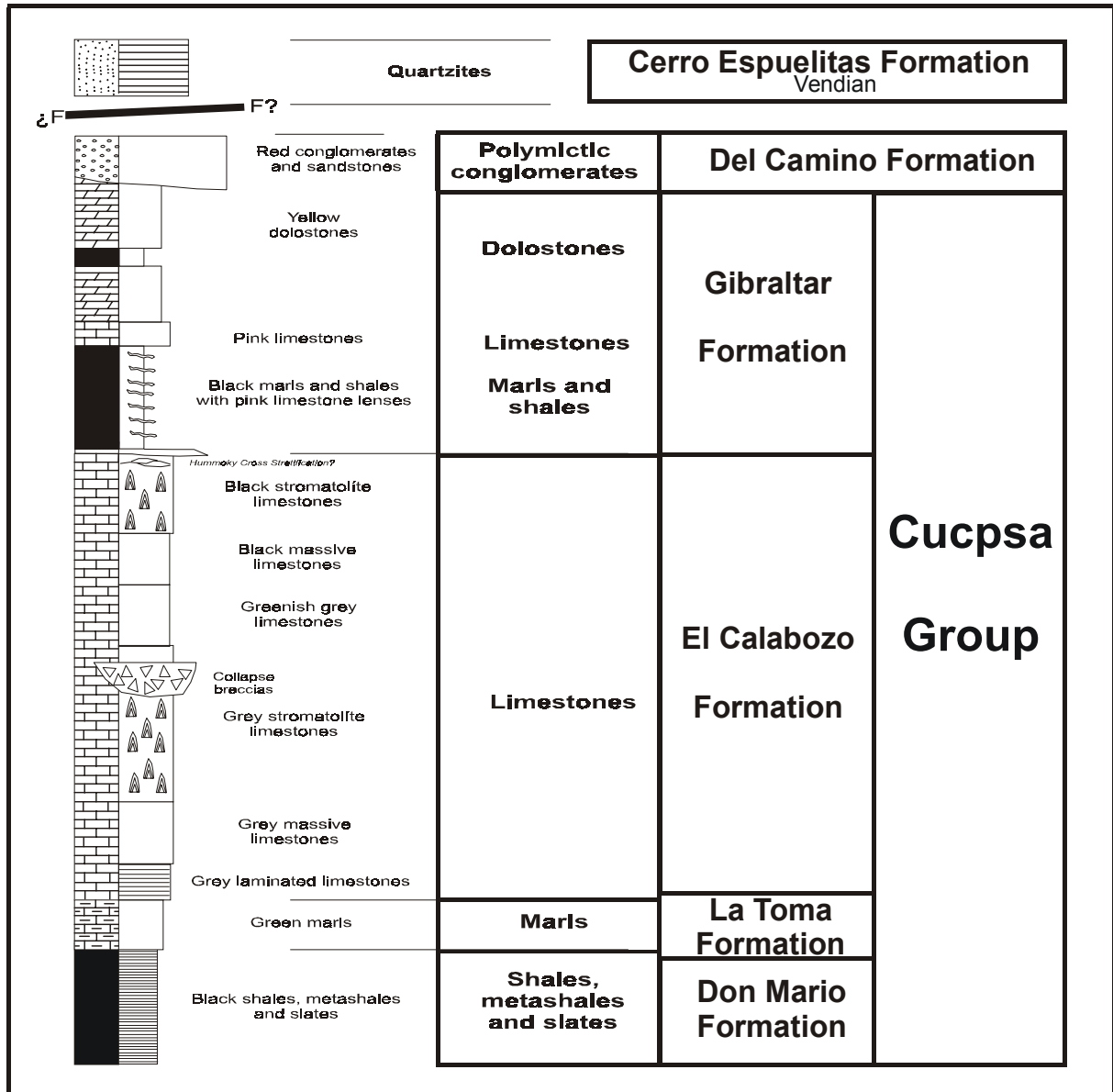


Fig. 1 Stratigraphic subdivision and lithology of the Cucpsa Group and Cerro Espuelitas Formation.

Quantitative constraints on the post-breakup evolution of the high-elevation Namibian passive margin shoulder: combined use of apatite fission track and (U-Th)/He geochronology

G. Viola¹, O. Burgeois², R. Pik² & M.Ford²

¹Department of Geological Sciences, University of Cape Town, South Africa

²C.R.P.G., Nancy, France

High elevation passive margins are first order geological structures that arise from continental breakup, rifting and ocean basin formation. They are generally characterized by the presence of an escarpment, a remarkable macrogeomorphological feature that abruptly divides a low relief upland plateau from a usually low relief, low altitude coastal plane.

A complete understanding of the formation and evolution of escarpments is a crucial key to a better definition of the mechanisms and timing of rifting/drifting processes and landscape evolution. Low-temperature geochronometers such as apatite fission track analysis and (U-Th)/He dating provide invaluable data to constrain the amount of denudation occurred since breakup time across the margins.

In this contribution we report the preliminary results of an ongoing project. We investigate the evolution of the Namibian passive margin by combining fission track and (U-Th)/He analysis along three roughly east-west trending, coast-perpendicular traverses.

Cretaceous fission track ages (in good agreement with the existing literature) indicate that erosion at the time of breakup was rapid. Cretaceous (U-Th)/He ages confirm that denudation was very high during the immediate post-breakup evolution and that it reached its maximum at the present coast line. Minimum amount of denudation are instead detected in the internal plateau.

The Tandilia System, Buenos Aires, Argentina

P.E. Zalba¹ and R.R. Andreis²

¹Comisión de Investigaciones Científicas Prov. de Buenos Aires-CETMIC. Facultad de Ciencias Naturales y Museo (UNLP). Camino Centenario y 506, (18979 M. B. Gonnet, pezalba@netverk.com.ar

²Museo Paleontológico "Egidio Feruglio". Av. Fontana 130, Trelew, Chubut (9100), Argentina, renatito35@hotmail.com

The Tandilia System (Fig. 1) is a discontinuous NW-SE range, which extends 300 km in the Province of Buenos Aires. Its maximum width is 60 km in its central part, with heights varying from 50 to 490 m over the sea-level. It comprises Paleo- to Neoproterozoic crystalline basement rocks (2200-600 Ma; Stipanovic and Linares, 1969), named Complejo Buenos Aires by Di Paola and Marchese (1974), which are covered by different sedimentary cycles of Neoproterozoic to Early Ordovician age (Iñiguez et al., 1989).

Located near great consumer centers, Tandilia is the first mining area of the Province of Buenos Aires, being limestones and shales the principal mining commodities. The crystalline basement rocks have experienced hydrothermal overprint, weathering and diagenetic processes, whereas the detrital deposits have undergone weathering and diagenetic processes which led to different clay assemblages. The main interesting feature of the clay deposits is that they have preserved the necessary physicochemical characteristics for their industrial application.

The effects of horst and graben structures developed during Tertiary time led, for more than a hundred years, to the wrong idea of the existence of a unique basin and a solely sedimentary cycle named La Tinta Formation by Heusser and Claráz in 1863. In the last 30 years, most of the evolution story of the Sierras has been enlightened. Yet, some stratigraphical problems are still to be solved. The old basins, only preserved in Tandilia as “patches” of the original ones are, however, well developed and preserved in South Africa and Namibia (Nama Group), after the continental break during Mesozoic time.

The first Neoproterozoic sedimentation occurred after a slow sea-level rise which permitted the deposition of the Villa Mónica/La Juanita Formation (quartzites), that covered a probable embayment at Sierras Bayas locality (near Olavarría) and extends to Barker and San Manuel areas. Poiré et al. (1984) defined two associations in this unit: a) quartz-arkosian (16 m) and b) dolomitic and pelitic (36 m). The first one (Cuarcitas Inferiores) is mainly composed of quartzites. The dolomitic deposit is biogenic (stromatolitic) and pelitic to the top. Green illitic clays are interbedded between the dolomites and the succession culminates with red laminated clays. Borrello (1966) and Poiré (1987) recognized the presence of *Cruziana* ichnofacies.

In the Barker area, Poiré (1987) found littoral and platform “nearshore” environments. The dolomitic unit is related to a progressive lowering of the sea level with the development of biostromes in subtidal to supratidal environment in an extended platform (800-900 Ma, Tonian to Cryogenian).

Poiré (1987) described a quartzitic succession (Cuarcitas Superiores), 22 m in thickness, with ripple-marks, trough beds and bioturbation of the *Cruziana* ichnofacies, deposited under a second transgression. He also described claystones and siltstones in this unit deposited under nearshore to tidal conditions (Cerro Largo Formation).

Andreis and Zalba (1996) separated the quartzites of the Cerro Largo Fm. from the overlying clays, which they recognized as deposited by a renewed third sea-level rise, allowing the deposition of a single parasequence, the Olavarría Formation (Cryogenian). Later on, with the progressive lowering of the sea-level, the deposition of laminated or rippled marls and massive black micrites, with minor lenticular, dark gray or black calcipelites (Loma Negra Formation), took place. Iñiguez et al. (1989) gathered the Villa Mónica, Cerro Largo and Loma Negra Formations in the Sierras Bayas Group (Fig. 1).

Sea-level fall allowed the development of a karstic paleorelief on these carbonate rocks (dolines). A fourth transgression allowed the deposition of the Cerro Negro Formation over the calcareous sequence, including shaly, heterolithic and sandy facies (Cryogenian, 680 Ma). The successions deposited in an epeiric-sea under subtidal conditions followed by an open-sea sedimentation. The Las Aguilas Formation (Zalba, 1979), correlated (with doubts) with the previous unit, includes cherty limestone breccia, reddish claystones and an heterolithic cycle affected by longshore and tidal currents. (The Las Aguilas and the Cerro Negro Formations are not represented in Fig. 1 due to scale problems).

During Early Ordovician time (Dalla Salda e Iñiguez, 1979), a fifth discontinuous transgression occurred with the deposition of cross-bedded quartzites and minor massive siltstones and claystones, recognized as the Balcarce Formation (Fig. 1). The sediments covered a regolith already weathered to kaolinite (Iñiguez and Zalba, 1974). The maximum sediment thickness of this unit, between Balcarce and Mar del Plata areas, is about 90 m. (claystones and scarce siltstones), with several ichnofossils corresponding to the *Cruziana* and *Skolithos* facies (Poiré et al., 1984).

Weathering processes occurred in the basement rocks which supplied the material for the Villa Mónica Fm. (Tonian-Cryogenian) and Olavarría Fm. (Cryogenian), reached the stage of illitization and, consequently, illite is their main component in the clayey fraction, with detrital micas (1M and 2M polytypes) attesting to inherited material. Illitic material (ISII) found, with

less than 15% expansive layers, formed during diagenetic processes in both units. Clays of the Cerro Negro Fm. are also illitic in composition (Md/1M polytypes), but with irregular chlorite-smectite (Zalba et al., 1984; Zalba and Andreis, 2001). The Las Aguilas Formation is still a problem in the stratigraphic column. The presumption of its correlation with the Cerro Negro Fm. is based on the stratigraphic position of the two units. The clay composition of the Las Aguilas Fm. is different from any other Neoproterozoic deposit, being mainly kaolinitic, with pyrophyllite, illite, ISII with < 15% of expansive layers and thin, distinct levels of alunite, halloysite and dispore, considered of diagenetic origin. Pyrophyllite and kaolinite are detrital, derived from the erosion of crystalline basement rocks. Finally, the clays of the Early Ordovician Balcarce Fm. are kaolinitic and illitic, (1M/2M polytypes), with ISII of similar characteristics and with traces of detrital pyrophyllite at the base of the deposits. (Zalba and Andreis, 2001).

The recognition of the Olavarría Fm. suggests an important transgression which modifies the classical stratigraphical scheme of Iñiguez et al. (1989). Moreover, in addition to the three major paleosurfaces recognized by Zalba et al. (1992): a) between Precambrian crystalline basement rocks and Neoproterozoic sediments (Olavarría area); b) between Neoproterozoic sediments (Olavarría) and c) between Precambrian basement rocks and Early Ordovician sediments (Chillar area) it is necessary to add a fourth paleosurface between Neoproterozoic sediments (Olavarría and Barker areas), which precisely separates the Cerro Largo Fm. from the Olavarría Formation.

Paleosurfaces and related paleoweathering records studied are important in the understanding of the resulting clay mineral composition of the sedimentary deposits. In fact, the basement rocks underlying Neoproterozoic sediments of the Sierras Bayas Group are always weathered to illite, while the saprolite underlying Ordovician sedimentary deposits (the Balcarce Formation) was weathered mainly to kaolinite. The basement rocks of the Barker and San Manuel areas (Fig. 1) are the only ones bearing “in situ” formed pyrophyllite and also kaolinite. (Zalba et al., 1992).

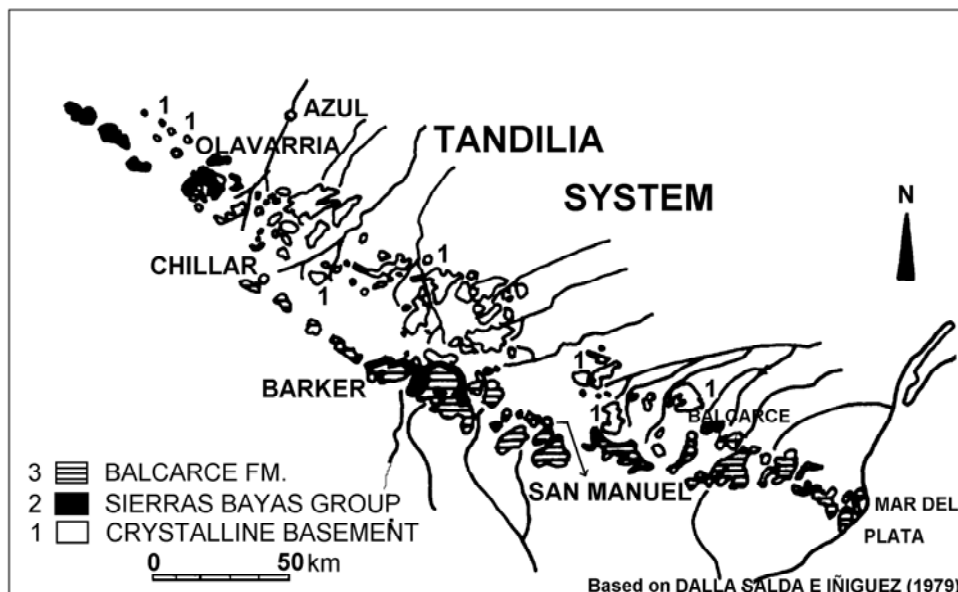


Fig. 1. Geologic map of the Tandilia System, Province of Buenos Aires.

References

- Borrello, A., 1966. Trazas, restos tubiformes y cuerpos fósiles problemáticos de la Formación la Tinta. Sierras Septentrionales de la Provincia de Buenos Aires. Paleontografía Bonaerense Comisión de Investigaciones Científicas, La Plata, v. 5, p. 1-42.

- Dalla Salda, L. & Iñiguez Rodriguez, A. M., 1979. "La Tinta", Precámbrico y Paleozoico de Buenos Aires. Actas VII Congreso Geológico Argentino. Neuquén, 1978. v. 1, p. 539-550
- Di Paola, E. & Marchese, H. 1974. Relación entre la tectosedimentación, litología y mineralogía de arcillas del Complejo Buenos Aires y la Formación La Tinta (Prov. de Buenos Aires). Revista de la Asociación Argentina de Mineralogía, Petrología y Sedimentología, Tomo V, N° 3-4, p. 45-58.
- Iñiguez Rodriguez, A. M. & Zalba, P. E. 1974. Geología de yacimientos de arcillas refractarias de la Provincia de Buenos Aires, Argentina. Revista Asociación Geológica Argentina, Buenos Aires, v. 29, p. 304-310.
- Iñiguez Rodriguez, A. M., Del Valle, A., Poire, D., Spalletti, L. & Zalba, P. E., 1989. "Cuenca Precámbrica-paleozoica Inferior de Tandilia, Prov. de Buenos Aires". Simposio Cuencas Sedimentarias de la República Argentina. X Congreso Geológico Argentino, Tucumán, 1987. Cuencas Sedimentarias Argentinas. Serie Correlación Geológica N° 6. Instituto Superior de Correlación Geológica Universidad Nacional de Tucumán, p. 245-263.
- Poire, D., 1987. Mineralogía y sedimentología de la Formación Sierras Bayas en el núcleo septentrional de las sierras homónimas, Olavarria, Provincia de Buenos Aires. Tesis Doctorado, Fac. Cienc. Nat. y Museo de La Plata. (inédito).
- Poire, D.; Del Valle, A. & Regalia, G., 1984. Trazas fósiles en cuarcitas de la Formación Sierras Bayas y su comparación con las de la Formación Balcarce (Cambro-Ordovícico), Sierras Septentrionales de la Provincia de Buenos Aires. IX Congreso Geol. Arg., Bariloche, IV, p. 249-266.
- Stipanovic, P. & Linares, E., 1969. Edades radimétricas determinadas para la República Argentina y su significado geológico. Boletín Academia Nacional de Ciencias Córdoba, v. 47, p. 51-96.
- Zalba, P. E. 1979. Clay deposits of Las Aguilas Formation Barker, Buenos Aires Province, Argentina, 27th Annual Conference on Clays and Clay Minerals. Bloomington, Indiana. E.E.U.U. Clay and Clays Minerals, v. 27, p. 433-439.
- Zalba, P.E., Poiré, D.G., Andreis, R.R. & Iñiguez Rodriguez, A.M., 1992. Precambrian and Lower Paleozoic paleoweathering records and paleosurfaces of the Tandilia System, Buenos Aires province, Argentina, *in*: J-M. Schmitt & Q. Gall (Eds.), Mineralogical and Geochemical Records of Paleoweathering, Ecole des Mines de París, Mémoires des Sciences de la Terre, v. 18, p. 153-161.
- Zalba, P. E. & Andreis, R. R., 2001. Stratigraphy, sedimentology and mineralogy of Neoproterozoic and Early Paleozoic clay deposits, Sierras de Tandilia, Province of Buenos Aires. Field Excursion. Guide Book. 12th International Clay Conference. Universidad Nacional del Sur, Bahía Blanca, Argentina, 79 pp.
- Zalba, P. E., Iñiguez, A. M., Volzone, C. & Morosi, M., 1996. Mineralogía y procesos post-depositacionales en la sucesión superior de la Formación Cerro Largo, Sierras Bayas (Bs. As., Argentina) Actas VI Reunión Argentina de Sedimentología, Bahía Blanca, prov. de Buenos Aires, p. 299-304.

Provenance study on Neoproterozoic rocks of NW Argentina: Puncoviscana Formation – first results

U. Zimmerman

Department of Geology, Rand Afrikaans University, Auckland Park 2092, South Africa, uz@na.rau.ac.za

Introduction

Since more than 20 years the western border of Gondwana is object of controversies related to the basic question if crustal growth is related to terrane accretion or to "recycling" of the same crustal rocks during the Vendian and Lower Paleozoic. One of the key elements to understand the crustal evolution, is the Vendian to Lower Cambrian so-called Puncoviscana Formation

(PVF) (e.g. Aceñolaza et al., 1988). Turner (1960) described rock successions in NW Argentina of Pre-Ordovician age comprising greywackes and sand- and siltstones, but dominated by pelites as the PVF. Widely distributed medium- to high-grade metasedimentary rocks, those rocks were interpreted as exhumed deeper crustal levels of the PVF (Willner, 1990). Other authors deny this opinion and interpret the different metamorphic rocks related to different events of different ages (Mon and Hongn, 1991). Few publications interpret the entire formation as a product of an evolution from passive margin to back-arc deposits (Omarini et al., 1999), or as foreland deposits (Kraemer et al., 1995; Keppie & Bahlburg, 1999). This contribution reviews new and published petrographic and geochemical data, based on modern approaches to provenance studies, including the modelling and quantification of alteration, rock composition and tectonic setting (e.g. McLennan et al., 1993).

Problems

The difficulty of understanding the metasedimentary deposits of the Puncoviscana Formation and equivalents is based on mainly four complex problems:

1. A complete lithostratigraphic column is lacking: The PVF is composed mainly of shales, siltstones, rare coarse-grained sandstones, greywackes, conglomerates and few carbonates. However, it is not clear if these lithofacies are repetitive or not.
2. The depositional and diagenetic age of the formation is controversial: Intrusive ages of mainly felsic plutonites pre-date the PVF to Lower Cambrian to Uppermost Vendian 500-530 Ma (comp. in Rapela et al., 1992, 1998). K/Ar data on whole rock samples of the sedimentary successions (Adams et al., 1990) coincide with trace fossil interpretations in some outcrops (e.g. Durand and Aceñolaza, 1990), and point to a similar depositional age. However, Do Campo et al. (1999) argue that their K-Ar age dating on authigenic single grains (K/Ar on mica) reflect an older age for deposition (630 Ma) and diagenesis (580 Ma).
3. Relation between medium- to high-grade and low-grade metasedimentary rocks: The Sierras Pampeanas s.l. contains a high amount of medium- to high grade metamorphic rocks, associated are gneisses and migmatites. Willner (1990) presents arguments that interpret those rocks as deeper crustal levels of the PVF, whereas Mon and Hongn (1991) find reasons to favor a different tectonic evolution. However, an unresolved problem, are the occurrences of low-grade (PVF and equivalents) metasedimentary rocks in the high grade terrains.
4. Unresolved geodynamic and paleotectonic setting of the Puncoviscana basin: The rocks of the PVF were interpreted using petrological, sedimentological and mainly major element data (e.g. Willner et al., 1985; Rossi Toselli, 1997) and sparse trace element data for the region in the Puna (Bock et al., 2000; Do Campo and Ribeiro Guevara, 2002) as passive margin deposits. Kraemer et al. (1995) and Keppie and Bahlburg (1999) interpret the same deposits as a foreland basin infill, evolved syntectonically during the collision of Pampia with the western border of Gondwana. However, the petrological, geochemical and isotopegeochemical dataset is too preliminary to model a provenance for the whole formation.

Sampling localities and description

Samples were taken from several localities in the southern region and combined with published geochemical data of outcrops in the central part and northern part (Willner et al., 1985, 1990, Bock et al., 2000) as well with data from Precambrian formations of the Famatina Range (Rossi et al., 1997, V.U. Zimmermann, unpubl. data) The sampling areas are: (i) Puna and Cordillera Oriental: Campo Volcán, Purmamarca, El Muñano, Rio Taique, San Antonio de los Cobres, Quebrada Randolpho, La Pedreda, El Corralito and Quebrada del Toro; (ii) Sierra Ambato and Ovejería: Siján, Concepción, Pomán, La Cébila and Suncho; (iii) Sierra Famatina: Negro Peinado and La Aguadita Formation; (iv) Valles Calchaquies: Cuesta de Obispo, Sierra de

Amblayo, Cachi, El Escoipe, Quebrada Don Bartolo, Seclantes, Molinos; (v) Tucumán: Sierra San Javier, Rio Choromoro, Rio Gonzalo and Sierra de Nogalito close to Tucumán.

Results and conclusions

Different outcrops of low-grade metamorphic rocks of the PVF were sampled to model the provenance of and leads to following preliminary conclusions: Representative data for the entire PVF from sandstones using the quantifying petrographic method after Gazzi-Dickinson are not possible to carry through, because (i) of the low abundance of coarse grained sandstones and (ii) the immaturity of the rocks. The few petrographic data points to a mixed provenance, related to a collisional (?) orogen.

Major element geochemistry shows a high chemical index of alteration (CIA) between 70 and 82, which reflects a substantial K-metasomatism. The pronounced mobility of alkali and earth-alkali elements yield provenance discrimination diagrams based on major elements problematical.

Trace element geochemistry could define the rocks of all formations as mostly upper continental crust related with only a slight recycling component, and no significant geochemical trend in N-S or E-W directions. The siliciclastic rocks of the different formations were not deposited close to a volcanic arc setting. Three samples of the La Aguadita Formation are interpreted as probable retro-arc volcanic rocks or rift basalts in an arc related tectonic setting. This does not coincide with data of the siliciclastic rocks. These basic ashes could have been derived from an adjacent volcanic arc, probably the Sierra Córdoba.

The upper crustal composition combined with their low recycled component and the immature mineralogy does not support a passive margin setting, and instead suggests depositional areas like continental rifts or foreland basins. A strong argument against a rift interpretation is the absence of a typical rift sedimentation sequence. The rocks are characterized mainly by monotonous turbiditic sequences of different, but mainly fine, grain-sizes, more typical for deeper shelf regions. The introduced foreland basin model would favor the collision of Pampia and Western Gondwana during the Uppermost Neoproterozoic and the syntectonic evolution of the Puncoviscana basin.

Acknowledgements

This is a contribution to the IGCP 436 “Pacific Gondwana Margin” and 478 “ Neoproterozoic-Early Paleozoic events in SW-Gondwana”.

References

- Aceñolaza, F.G., Miller, H. & Toselli, A.J., 1988. The Puncoviscana Formation (Late Precambrian-Early Cambrian). Sedimentology, tectonometamorphic history and age of the oldest rocks of NW Argentina. In: H. Bahlburg, C. Breitkreuz and P. Giese, (Editors), The southern Central Andes: contributions to structure and evolution of an active continental margin. *Lecturer Notes on Earth Sciences*, v. 17, p. 25-38.
- Adams, C., Miller, H. and Toselli, A.J., 1990. Nuevas edades de metamorfismo por el método K-Ar de la formación Puncoviscana y equivalentes, NW de Argentina, *in*: F.G. Aceñolaza, H. Miller & Toselli, A.T. (Eds.), *El Ciclo Pampeano en el Noroeste Argentino. Correlación Geológico*, Tucumán, v. 4, p. 209-219.
- Bock, B., Bahlburg, H., Wörner, G. & Zimmermann, U., 2000. Tracing crustal evolution in the southern Central Andes from Late Precambrian to Permian with geochemical and Nd and Pb isotope data. *Journal of Geology*, v. 108, p. 515-535.
- Do Campo, M., Nieto, F., Omarini, R. & Ostera, H., 1999. Neoproterozoic K-Ar ages for the metamorphism of the Puncoviscana Formation, northwestern Argentina. III South American Symposium on Isotope Geology, Villa Carlos Páz, Abstracts, p. 37-42.

- Do Campo, M. & Ribeiro Guevara, S.R., 2002. Geoquímica de las secuencias clásticas de la Formación Puncoviscana (Neoproterozoico, NO Argentina), proveniencia y marco tectónico. XV Congreso Geológico Argentino. Calafate, II, p. 234-238.
- Durand, F.R. & Aceñolaza, F.G., 1990. Caracteres biofaunísticos, paleoecológicos y paleogeográficos de la Formación Puncoviscana (Precámbrico Superior-Cámbrico Inferior) del Noroeste Argentino, *in*: F.G. Aceñolaza, H. Miller & Toselli, A.T. (Eds.), El Ciclo Pampeano en el Noroeste Argentino, Correlación Geológico, Tucumán, v. 4, p. 71-112.
- Jezek, P., 1990. Analisis sedimentológico de la Formación Puncoviscana entre Tucumán y Salta, *in*: F.G. Aceñolaza, H. Miller & Toselli, A.T. (Eds.), El Ciclo Pampeano en el Noroeste Argentino, Correlación Geológico, Tucumán, v. 4, p. 9-35.
- Keppie, J.D. & Bahlburg, H., 1999. Puncoviscana Formation of northwestern and central Argentina: Passive margin or foreland basin deposits? *in*: V.A. Ramos & J.D. Keppie (Eds.), Laurentia-Gondwana connections before Pangaea. Geological Society of America, Special Publication, v. 336, p. 139-144.
- Kraemer, Escayola, M.P. & Martino, R.D., 1995. Hipótesis sobre la evolución tectónica neoproterozoica de las Sierras Pampeanas de Córdoba (30°40'-32°40'), Argentina. Revista de la Asociación Geológica Argentina, v. 50, p. 47-59.
- McLennan, S. M., Hemming, S., McDaniel, D.K. & Hanson, G.N., 1993. Geochemical approaches to sedimentation, provenance and tectonics *in*: M.J. Johnsson & A. Basu, (Eds.), Processes controlling the composition of clastic sediments. Geological Society of America, Special Publication, v. 284, p. 21-40.
- Mon, R. & Hongn, F., 1991. The structure of the Precambrian and Lower Paleozoic Basement of the Central Andes between 22° and 32° Lat.. Geologische Rundschau, v. 80, p. 745-758.
- Omarini, R.H., Sureda, R.J., Götze, H.J., Seilacher, A. & Pflüger, F., 1999. Puncovisca folded belt in northwestern Argentina: testimony of Late Proterozoic Rodinia fragmentation and pre-Gondwana collisional episodes. International Journal of Earth Sciences, v. 88, p. 76-97.
- Rapela, C.W., Coira, B., Toselli, A. & Saavedra, J., 1992. El magmatismo del Paleozoico en el Sudoeste de Gondwana, *in*: J.G. Gutiérrez Marco, J. Saavedra & I. Rabano (Eds.), Paleozoico Inferior de Ibero-América. Univ. de Extremadura, p. 21-68.
- Pankhurst, R., Rapela, C., Saavedra, J., Baldo, E., Dahlquist, J., Pascua, I. & Fanning, C., 1998. The Famatinian magmatic arc in the central Sierras Pampeanas: an Early to Mid Ordovician continental arc on the Gondwana margin, *in*: R.J. Pankhurst & C.W. Rapela (Eds.), The Proto-Andean Margin of Gondwana. Geological Society, London Special Publications, v. 142, p. 181-217.
- Rossi, J.N., Durand, F.R., Toselli, A.J. & Sardi, F.G., 1997. Aspectos estratigráficos y geoquímicos comparativos del basamento metamórfico de bajo grado del Sistema de Famatina, Argentina. Rev. de la Asociación Geológica Argentina, v. 52, p. 469-480.
- Turner, J.C.M., 1960. Estratigrafía de la Sierra de Santa Victoria y adyacencias, Boletín de la Academia Nacional de Ciencias, Córdoba, v. 41, p. 163-196.
- Willner, A., 1990. División tectonometamórfica del basamento del Noroeste Argentino, *in*: F.G. Aceñolaza, H. Miller & Toselli, A.T. (Eds.), El Ciclo Pampeano en el Noroeste Argentino, Correlación Geológico, Tucumán, v. 4, p. 113-159.
- Willner, A., Miller, H. & Jezek, P., 1985. Geochemical features of an Upper Precambrian-Lower Cambria greywacke/pelite sequence (Puncoviscana trough) from the basement of the NW-Argentine Andes. Neues Jahrbuch für Geologie und Paläontologie, v. 56, p. 498-512.

Black Sands as tracers of provenance: A heavy mineral case study of the Early Paleozoic Haribes Member (Nababis Formation, Fish River Subgroup) of the Nama Group in Namibia – first results

V.U. Zimmermann & G.J.B. Germs

Department of Geology, Rand Afrikaans University, Johannesburg, South Africa, uz@na.rau.ac.za,
gagerms@global.co.za

Heavy minerals include various silicates and oxides that are found in small quantities in sandstones, the total quantity of such constituents rarely making up more than one percent of the rock. They range from tourmaline and zircon which do not occur in large amounts in any source rock, but are resistant to mechanical and chemical attack, to the amphiboles and pyroxenes, which may be abundant constituents of some source rocks but show little resistance to decay. To the extent that the heavy minerals survive the hazards of weathering, transport and diagenesis and to the degree that they occur in a restricted range of provenance types they are most useful as indicators of provenance (Pettijohn et al., 1973). Since hydraulic controls at the time of deposition can cause modifications the most effective method is to examine the varieties of a small number of mineral species because this minimizes density and stability contrasts (Morton, 1985). The first step in a heavy mineral study is to quantify the heavy mineral composition followed by cathodoluminescence analysis. The interpretation of the data is considerably enhanced by determining the composition of individual detrital grains by geochemical studies (Morton, 1991). We selected the black sands of the Haribes Member of the Nababis Formation of the Nama Group on farm Narubis (Namibia) as our first heavy mineral case study of the “provenance” research project of the IGCP-Project 478. The reasons are that the stratigraphic position and depositional environment of these sandstones are well established and that it is also known how they fit in the overall Neoproterozoic to early Paleozoic geotectonic framework of southwestern Gondwana. The Haribes Member of the Nababis Formation forms part of the Fish River Subgroup, which represents the youngest subgroup of the Nama Group (Germs, 1983). The Nama Group was deposited in a foreland basin and is subdivided from old to young into the Kuibis, Schwarzrand and Fish River Subgroups (e.g. Germs, 1983). The detrital sediments of the Kuibis Subgroup are generally white and quartzitic, those of the Schwarzrand Subgroup greenish and less quartzitic and those of the Fish River Subgroup reddish and at many places feldspathic. Each of the subgroups can be subdivided into formations and members. The sediments below the unconformity at the base of the Nomtsas Formation (uppermost Schwarzrand Subgroup) are Neoproterozoic in age and those above the base of the Nomtsas Formation early Cambrian in age (Germs, 1983). The black sands of the early Paleozoic Haribes Member generally accumulated in a braided fluvial environment. Although they occur in the large-scale trough cross-bedded facies, they occur predominantly in the overlying flat-bedded facies (upper flow regime) of this member. The sediments of the Haribes Member were transported from the north, i.e. from a provenance area occurring in the rising orogen (the Khomas Orogenic Belt), which formed by the collision of the Kalahari and Congo cratons (Germs, 1983, 1995). The framework mineral assemblage is heterogeneous in the layers that host the black sands. The minerals occurring in the black sands are well sorted. Quartz (rarely undulose) is generally the most abundant mineral and is generally well-rounded. The feldspar content varies from 5 to 30%. More plagioclase (anorthite content <20) than K-feldspar occurs. In some layers microcline and anorthoclase predominantly occur, whereas other layers are dominated by sanidine. Albite is rare. Both feldspar types, plagioclase and K-feldspar are altered, interestingly the K-feldspar in some layers more than the plagioclase. The grain size of plagioclase is generally smaller than that of quartz and K-feldspar. Rock fragments are abundant (< 30%) and mainly of sedimentary or metamorphic origin. Sedimentary fragments are small-grained

(siltstones). Metamorphic clasts can be divided into two groups: polycrystalline quartz-rich grains and gneisses. Biotite is very rare, whereas detrital muscovite is quite abundant and large (< 3 mm) in size. Some layers show a new growth of small mica minerals. Zircon and different Fe-oxides are accessory minerals. In some cases calcite occurs. The percentage of the matrix is generally lower 5 %, but some rocks show a pseudo-matrix caused by the alteration and decayment of lithoclasts.

The black sands are mainly deposited in small layers of 0.5 to 1.5 cm, in some samples they can be 5 cm thick. However, an overgrowth of hematite in thin layers over an so far unidentified minerals causes mainly the black colour. Furthermore, altered magnetite grains to martite are observable, where the alteration can be determined as pre-depositional. Hematite-ilmenite segregation is abundant in thin layers, as well as goethite-hematite paragenesis.

The main aim of our heavy minerals study of the Haribes black sands is to determine the mineral composition of the source area (the Khomas Orogenic Belt), which supplied the detrital material. Preliminary results show that zircon occurs relatively abundantly and that staurolite and sillimanite (derived from metamorphic rocks) also occur. Rutile and turmaline are abundant, as expected. Further analyses for identification of the heavy minerals are in progress.

The results of this study will allow testing of the existing paleotectonic models for the Khomas Orogenic Belt and also serve as a test to find out if there is a possibility to combine heavy mineral data with a modern quantitative provenance analysis including geochemical and isotope geochemical studies.

References

- Germis, G.J.B., 1983. Implications of a sedimentary facies and depositional environmental analysis of the Nama Group in South West Africa/Namibia. *Geol.Soc.S.Afr. Spec.Publ.*, v. 11, p. 89-114.
- Germis, G.J.B., 1995. The Neoproterozoic of southwestern Africa, with emphasis on platform stratigraphy and paleontology. *Precambrian Research*, v. 73, p. 137-151.
- Morton, A.C. 1985. Heavy minerals in provenance studies, *in*: Zuffa, G.G. (ed.), *Provenance of Arenites*, p. 49-277.
- Morton, A.C. 1991. Geochemical studies of detrital heavy minerals and their application to provenance research, *in*: Todd, A.C. & Haughton, P.D.W. (eds.), *Developments in Sedimentary Provenance Studies*, Geological Society Special Publication, v. 57, p. 31-45.
- Pettijohn, F.J., Potter, P.E. & Siever, R., 1973. *Sand and sandstone*, Springer Verlag, New York-Heidelberg-Berlin, 618pp.

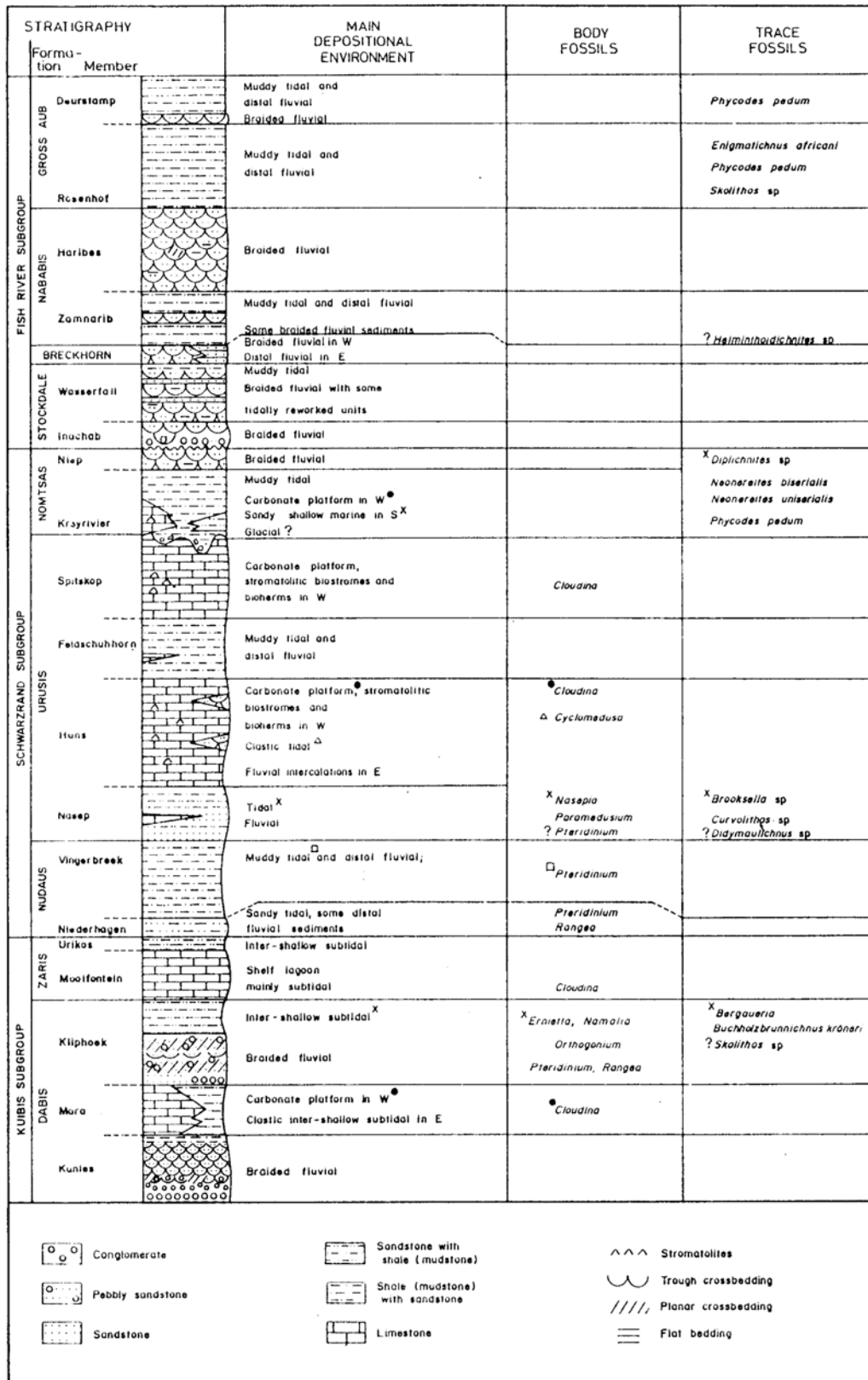


Fig. 1. Stratigraphic column of the Nama Group in the southern part of Namibia (not to scale), together with a summary of the depositional environments and associated trace and body fossils. Poorly defined beach deposits may occur within the various stratigraphic units (Germs, 1983). Please note the occurrence of black sands in the Haribes Member.