Gondwana Research 23 (2013) 1186–1188

Contents lists available at SciVerse ScienceDirect

Gondwana Research

journal homepage: www.elsevier.com/locate/gr

Reply to Comment by C. Gaucher et al. on "Chemostratigraphic constraints on early Ediacaran carbonate ramp dynamics, Río de la Plata craton, Uruguay" by Aubet et al. Gondwana Research (2012), Volume 22, Issues 3-4, November 2012, Pages 1073-1090

Natalie R. Aubet [a,*], Ernesto Pecoits [a], Andrey Bekker [b], Murray K. Gingras [a], Horst Zwingmann [c,d,e], Gerardo Veroslavsky [f], Héctor de Santa Ana [g], Kurt O. Konhauser [a]

[a] Department of Earth and Atmospheric Sciences, University of Alberta, 1-26 Earth Sciences Building, Edmonton, Canada AB T6G 2E3
[b] Department of Geological Sciences, University of Manitoba, 125 Dysart Road (Wallace Building) Winnipeg, Canada MB R3T 2N2
[c] CSIRO, Earth Science and Resource Engineering, Bentley, W.A. 6102, Australia
[d] School of Earth and Environment, The University of Western Australia, Crawley, W.A. 6009, Australia
[e] Department of Applied Geology, Curtin University, Perth, W.A. 6845, Australia
[f] Instituto de Ciencias Geológicas, Universidad de la República, Iguá 4225, Montevideo 11400, Uruguay
[g] Gerente Exploración y Producción, ANCAP, Paysandú y Av. Libertador Brig. Gral. J. A. Lavalleja, Montevideo 11100, Uruguay

1. Introduction

The comment by Gaucher et al. (2012) focuses on three issues: (i) stratigraphy, (ii) age, and (iii) interpretation of the chemostratigraphic data for the Arroyo del Soldado Group (ASG) of Uruguay, as presented by Aubet et al. (2012). In the following, we will demonstrate that their comments are flawed by misconceptions, misinterpretations and use of highly questionable data.

2. Stratigraphy

Gaucher et al. (2012) state that by reading “The group reaches almost 3000 m *in* thickness, and has been subdivided into four formations: the Yerbal, Polanco Limestone, Cerro Espuelitas and Barriga Negra formations (sensu Pecoits et al., 2008; Pecoits, 2010)…” the reader will understand that Pecoits et al. (2008) and Pecoits (2010) were the authors that first separated and mapped the above mentioned formations of the Arroyo del Soldado Group. The stratigraphy of the ASG is controversial as demonstrated by multiple stratigraphic schemes (Gaucher, 2000; Pecoits et al., 2008; Sánchez-Bettucci et al., 2010a,b). It is, therefore, critical to refer an international reader to the stratigraphic scheme adopted in our paper rather than referring to original but outdated contributions. In this regard, geological mapping of key areas, detailed logging of stratigraphic sections and incorporation of structural data led us to conclude that the stratigraphic scheme proposed by Gaucher (2000) is invalid. Furthermore, Pecoits et al. (2008) demonstrated that many lithologies described in various publications by Gaucher and his collaborators are either poorly measured or, more problematically, do not even exist.

Gaucher et al. (2012) also state that we failed to reference Gaucher et al. (2004) when describing some sedimentary structures of the Polanco Limestone Formation, which is an unusual concern considering that we are reporting our own observations. Moreover, Gaucher et al. (2012) assert that our interpretation of the described deposits as representing “a storm-dominated inner ramp setting” is based on his earlier work. However, Aubet et al. (2012) discuss entirely original work about the facies associations and the rationale for the identification of sub-environments. Notably, Gaucher et al. (2004) did not subdivide the Polanco ramp into its various settings, hence they were not referenced.

Gaucher et al. (2012) further claim that Aubet et al. (2012) misleadingly credit Pecoits et al. (2008) and Pecoits (2010) – instead Gaucher et al. (2004) – for interpreting the depositional basin as being redox-stratified during deposition of the lower ASG. This too is incorrect because we emphasize here that Pecoits (2010) reported the first detailed geochemical dataset (REE+Y and redox-sensitive elements) for the ASG, from which was inferred anoxic but non-sulfidic deep-water conditions and well-oxygenated redox state of shallow-water settings. Conversely, Gaucher et al. (2004) suggested sulfidic conditions during deposition of the Yerbal iron formation and the Polanco Limestone Formation. The Gaucher's model not only is entirely different from that proposed by Pecoits (2010), but it also fails to explain deposition of the iron formation since iron is highly insoluble under sulfidic conditions (Poulton et al., 2004; Bekker et al., 2010).

Another point of contention for Gaucher et al. (2012) is that we referenced Bossi (2003) for our map in Figure 1B instead of Mallmann et al. (2007). Figure 1 of Aubet et al. (2012) shows: (A) the location map of Uruguay and tectonostratigraphic subdivision of the crystalline basement, and (B) a schematic geological map of the Nico Pérez terrane showing the distribution of the ASG and location of the sections studied. The tectonostratigraphic subdivision of the crystalline basement of Uruguay into three major blocks, namely, Nico Perez, Piedra Alta and Cuchilla Dionisio terranes, was introduced by Bossi and Campal (1992), Bossi et al. (1993), and Bossi et al. (1998), respectively. The distribution of the Arroyo del Soldado basement (La China and Las Tetas complexes) in the Nico Pérez terrane (shown in Figure 1B of Aubet et al., 2012) corresponds to Hartmann et al. (2001). All these units were synthesized by Bossi (2003); the primary reference that we used in our paper.

* Corresponding author. Tel.: +1 780 492 6532; fax: +1 780 492 2030.
E-mail address: aubet@ualberta.ca (N.R. Aubet).

1342-937X/$ – see front matter
http://dx.doi.org/10.1016/j.gr.2012.09.004

3. Age

The age of the ASG is poorly constrained, but critically, none of the existing geochronologically-determined ages support an uppermost Ediacaran age. According to Gaucher et al. (2008), the maximum depositional age of the ASG is constrained by U–Pb crystallization ages of the Puntas del Santa Lucía pluton and the Mangacha granite dated at 633 ± 8 Ma (Hartmann et al., 2002) and 583 ± 7 Ma (Gaucher et al., 2008), respectively. This is simply incorrect. The only sedimentary unit resting on these plutons is the Arroyo de la Pedrera Group, which has no established relationship with the ASG. The basement to the ASG consists of Archean and Paleoproterozoic high-grade metamorphic rocks with a minimum age of ca. 2.0 Ga (Hartmann et al., 2001; Santos et al., 2003). Minimum age constraints for the ASG are provided by the Guazunambí and Polanco granites, which yield Rb–Sr isochron ages of 532 ± 11 and 548 ± 11 Ma, respectively (Umpierre and Halpern, 1971; Kawashita et al., 1999). If these ages are correct, the ASG is constrained between 2.0 Ga and 548 ± 11 Ma.

Another age constraint used by Dr. Gaucher in various publications (see below) is based on the purported presence of the index fossil *Cloudina*. Indeed, the outcrops where *Cloudina* has been reported are only few square meters in size and the locations are well known, yet our repeated sampling did not yield any unambiguous fossils. Moreover, these fossils have not been made available to us for re-evaluation, which in our opinion is quite disappointing. Therefore, considering that the same few specimens repeatedly illustrated by Gaucher (2000), Gaucher et al. (2003; 2004) and Gaucher and Poiré (2009a) are extremely poorly preserved and not independently verified, the 'presence' of *Cloudina* cannot be taken seriously in discussion about the age of the ASG.

Available K–Ar ages of diagenetic illites from the uppermost Yerbal Formation presented by Pecoits (2010) and Aubet et al. (2012) also do not support the age suggested by Gaucher et al. (2012) and indicate a minimum age of 600–580 Ma for the uppermost Yerbal Formation. Recent SHRIMP U–Pb zircon dating of intrusive granites further constrains the minimum age of the ASG at 585 ± 2 Ma (Oyhantçabal et al., 2012), challenging the presence of 550–540 Ma *Cloudina* (Grotzinger et al., 1995) in the Yerbal and Polanco Limestone formations. Gaucher et al. (2012) further question our Ar diffusion model and the associated ages. In doing so, they clearly miss the point that low temperature thermal history (below 200 °C) does not agree with 2 M1 illite polytype data, which indicate significantly higher temperatures. In short, we refute the suggestion that we have committed a "gross stratigraphic error" by suggesting that the Yerbal and Polanco Limestone formations are pre-Gaskiers (>582 Ma). Conversely, the Barriga Negra and Cerro Espuelitas formations are not intruded by these 585 ± 2 Ma granites and host zircons with the youngest ages of 566 ± 8 Ma (Blanco et al., 2009), clearly suggesting a post-Gaskiers age and significant hiatus between Yerbal-Polanco Limestone and Barriga Negra-Cerro Espuelitas formations.

Interestingly, Gaucher et al. (2011) recently suggested that the Barriga Negra Formation represents the base of the ASG and not its middle part as was thought previously by the same lead author (e.g., Gaucher, 2000). We are fully puzzled by this change of stratigraphy. In fact, how is it possible that a succession previously bracketed between two distinct units, the Polanco Limestone and Cerro Espuelitas formations, with both the upper and lower contacts exposed (Gaucher et al., 1998; Gaucher, 2000; Gaucher et al., 2004, 2008; Blanco et al., 2009; Gaucher and Poiré, 2009b; Blanco et al., 2010; Frei et al., 2011), is now relocated two lithostratigraphic units lower? Furthermore, clasts of the Polanco Limestone Formation have been previously described and illustrated from the Barriga Negra Formation (Preciozzi et al., 1988; Preciozzi and Fay, 1990; Fambrini et al., 2005; Pecoits et al., 2008), as well as in valleys cutting into the Polanco Limestone Formation and filled with the Barriga Negra breccias and conglomerates (Gaucher et al., 2004).

4. Chemostratigraphic data

Gaucher et al. (2012) challenge our interpretation that the negative $\delta^{13}C$ anomaly recorded by the Polanco Limestone Formation in the shallow-water facies is likely a local rather than a basin-wide phenomenon, arguing that the "basinal section (Los Tapes) is the least adequate to pinpoint a negative excursion, because the strong isotopic gradient between shallow and deep water largely masks and smoothes out secular $\delta^{13}C$ variations". We agree that strong isotopic gradients could have existed between shallow- and deep-waters in the late Neoproterozoic oceans, which is the main premise of our paper. We note, however, that the interpretation of the strong isotopic gradient between shallow- and deep-water facies represents a significant difference from that observed in the modern oceans (Kroopnick, 1985) and documented in Archean and Paleoproterozoic oceans influenced by high pCO_2 (e.g., Hotinski et al., 2004). It is proposed herein that this enhanced gradient represents a non-steady state during the period of progressive ocean oxygenation, which we infer to take place during deposition of the Polanco Limestone Formation. More importantly, our detailed sedimentological and chemostratigraphical analyses indicate coupling between negative carbon isotope anomalies in shallow-water sections and enhanced mixing rates in the basin during storm events, thus challenging the global nature of the negative carbon isotope anomaly. Considering that our deep-water facies consistently record negative carbon isotope values, while the shallow-water facies do so only during storm events, it is most parsimonious to infer local rather than global control over the development of the negative carbon isotope anomaly in the shallow-water facies.

Finally, Gaucher et al. (2012) claim that the Isla Patrulla section, as presented by Aubet et al. (2012), is incomplete (250 m) since the whole unit exceeds 900 m and it is, therefore, not clear what its position is within the overall stratigraphic unit. Gaucher et al. (2012) entirely ignore that the stratigraphic position of this section is well supported by the facies association analysis and sequence stratigraphic framework.

5. Final remarks

It is unfortunate that the comments by Gaucher et al. (2012) do not provide any constructive insights, but instead are focused on trying to discredit any other research based on Neoproterozoic geology in Uruguay. In the manuscript by Aubet et al. (2012) we have attempted to present a model coherent with our own, as well as published field observations and geochemical data. It is our opinion that the interpretations we present are in line with that data, but as any reasonable scientist, we are open to the challenges posed by future studies.

References

Aubet, N., Pecoits, E., Bekker, A., Gingras, M.K., Zwingmann, H., Veroslavsky, G., de Santa Ana, H., Konhauser, K.O., 2012. Chemostratigraphic constraints on early Ediacaran carbonate ramp dynamics, Río de la Plata craton, Uruguay. Gondwana Research 22, 1073–1090.

Bekker, A., Slack, J.F., Planavsky, N., Krapež, B., Hofmann, A., Konhauser, K.O., Rouxel, O.J., 2010. Iron formation: the sedimentary product of a complex interplay among mantle, tectonic, oceanic, and biospheric processes. Economic Geology 105, 467–508.

Blanco, G., Rajesh, H.M., Gaucher, C., Germs, G.J.B., Chemale Jr., F., 2009. Provenance of the Arroyo del Soldado Group (Ediacaran to Cambrian, Uruguay): implications for the paleogeographic evolution of southwestern Gondwana. Precambrian Research 171, 57–73.

Blanco, G., Rajesh, H.M., Gaucher, C., Germs, G.J.B., Chemale Jr., F., 2010. Reply to the comment by Sánchez Bettucci et al. on: "Provenance of the Arroyo del Soldado Group (Ediacaran to Cambrian, Uruguay): implications for the paleogeographic evolution of southwestern Gondwana". Precambrian Research 180, 334–342.

Bossi, J., 2003. Estratigrafía del Precámbrico de Uruguay: terrenos tectonoestratigráficos y geocronología. Revista de la Sociedad Uruguaya de Geología. Publicación Especia 1, 1–17.

Bossi, J., Campal, N., 1992. Magmatismo y tectónica transcurrente durante el Paleozoico inferior del Uruguay. In: Gutiérrez, J., Saavedra, J., Rábano, I. (Eds.), Paleozoico Inferior de Ibero-América. Universidad de Extremadura, Alicante, pp. 343–356.

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. Geoeditores, Montevideo.

Bossi, J., Preciozzi, F., Campal, N., 1993. Predevoniano del Uruguay. Parte 1: Terreno Piedra Alta. DINAMIGE, Montevideo. pp. 1–50.

Fambrini, G.L., Fragoso Cesar, A.R.S., Paes De Almeida, R., Riccomini, C., 2005. A Formacão Barriga Negra (Ediacarano do Uruguai): Caracterizacão Estratigráfica e Correlacão com Unidades do Estado Do Rio Grande Do Sul-Brasil. Revista Brasilera de Geociencias 35, 515–524.

Frei, R., Gaucher, C., Døssing, L.N., Sial, A.N., 2011. Chromium isotopes in carbonates — a tracer for climate change and for reconstructing the redox state of ancient seawater. Earth and Planetary Science Letters 312, 114–125.

Gaucher, C., 2000. Sedimentology, palaeontology and stratigraphy of the Arroyo del Soldado Group (Vendian to Cambrian, Uruguay). Beringeria 26, 1–120.

Gaucher, C., Poiré, D., 2009a. Biostratigraphy. Neoproterozoic–Cambrian evolution of the Río de la Plata Palaeocontinent. In: Gaucher, C., Sial, A.N., Halverson, G.P., Frimmel, H.E. (Eds.), Neoproterozoic–Cambrian tectonics, global change and evolution: a focus on southwestern Gondwana. Developments in Precambrian Geology, 16. Elsevier, pp. 103–114.

Gaucher, C., Poiré, D., 2009b. Palaeoclimatic events. Neoproterozoic-Cambrian evolution of the Río de la Plata Palaeocontinent. In: Gaucher, C., Sial, A.N., Halverson, G.P., Frimmel, H.E. (Eds.), Developments in Precambrian Geology, 16. Elsevier, pp. 123–130.

Gaucher, C., Sprechmann, P., Montaña, J., Martínez, S., 1998. Litoestratigrafia, sedimentologia y paleogeografia del Grupo Arroyo del Soldado (Vendiano-Cambrico, Uruguay). Actas II Congreso Uruguayo de Geologia, Punta del Este, pp. 24–31.

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. Precambrian Research 120, 241–278.

Gaucher, C., Sial, A.N., Blanco, G., Sprechmann, P., 2004. Chemostratigraphy of the lower Arroyo del Soldado Group (Vendian, Uruguay) and palaeoclimatic implications. Gondwana Research 7, 715–730.

Gaucher, C., Finney, S.C., Poiré, D.G., Valencia, V.A., Grove, M., Blanco, G., Pamoukaghlián, K., Gómez Peral, L., 2008. Detrital zircon ages of Neoproterozoic sedimentary successions in Uruguay and Argentina: insights into the geological evolution of the Río de la Plata Craton. Precambrian Research 167, 150–170.

Gaucher, C., Frei, R., Sial, A.N., Cabrera, J., 2011. Contrasting Sr isotope composition of Paleo- and Neoproterozoic high-Sr limestone successions from the Nico Pérez Terrane, Uruguay. Gondwana 14, 165 (Abstracts, Búzios).

Gaucher, C., Sial, A.N., Frei, R., Sprechmann, P., Bossi, J., Poiré, D.G., Blanco, G., Sánchez Bettucci, L., 2012. Comment on: chemostratigraphic constraints on early Ediacaran carbonate ramp dynamics, Río de la Plata craton, Uruguay by Aubet et al. Gondwana Research http://dx.doi.org/10.1016/j.gr.2012.03.011.

Grotzinger, J.P., Bowring, S.A., Saylor, B.Z., Kaufman, A.J., 1995. Biostratigraphic and geochronologic constraints on early animal evolution. Science 270, 598–604.

Hartmann, L.A., Campal, N., Santos, J.O.S., McNaughton, N.J., Bossi, J., Schipilov, A., Lafon, J.-M., 2001. Archean crust in the Rio de la Plata Craton, Uruguay-SHRIMP U–Pb zircon reconnaissance geochronology. Journal of South American Earth Sciences 14, 557–570.

Hartmann, L.A., Santos, J.O.S., Bossi, J., Campal, N., Schipilov, A., MacNaughton, 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 15, 229–236.

Hotinski, R.M., Kump, L.R., Arthur, M.A., 2004. The effectiveness of the Paleoproterozoic biological pump: a $\delta^{13}C$ gradient from platform carbonates of the Pethei Group (Great Slave Lake Supergroup, NWT). Geological Society of America Bulletin 116, 539–554.

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 (Abstract Volume), pp. 399–402.

Kroopnick, P.M., 1985. The distribution of ^{13}C of $\sum CO_2$ in the world oceans. Deep Sea Research 32, 57–84.

Mallmann, G., Chemale, F., Avila, J.N., Kawashita, K., Armstrong, R.A., 2007. Isotope geochemistry and geochronology of the Nico Pérez Terrane, Río de la Plata Craton, Uruguay. Gondwana Research 12, 489–508.

Oyhantçabal, P., Wagner-Eimer, M., Wemmer, K., Schulz, B., Frei, R., Siegesmund, S., 2012. Paleo- and Neoproterozoic magmatic and tectonometamorphic evolution of the Isla Cristalina de Rivera (Nico Pérez Terrane, Uruguay). International Journal of Earth Sciences (Geol Rundsch) http://dx.doi.org/10.1007/s00531-012-0757-4.

Pecoits, E., 2010. Ediacaran iron formations and carbonates of Uruguay: palaeoceanographic, palaeoclimatic and palaeobiologic implications. Ph.D. Thesis, University of Alberta.

Pecoits, E., Gingras, M., Aubet, N., Konhauser, K., 2008. Ediacaran in Uruguay: palaeoclimatic and palaeobiological implications. Sedimentology 55, 689–719.

Poulton, S.W., Fralick, P.W., Canfield, D.E., 2004. The transition to a sulphidic ocean ~1.84 billion years ago. Nature 431, 173–177.

Preciozzi, F. Fay, A., 1990. Carta geológica del Uruguay, Hoja F-23 Pirarajá, Escala 1:100/000. Memoria explicativa. DINAMIGE-UdelaR, Montevideo, 15 pp.

Preciozzi, F., Spoturno, J., Heinzen, W. Rossi, P., 1988. Carta geológica del Uruguay a escala 1:500/000. Memoria explicativa. DINAMIGE, Montevideo, 90 pp.

Sánchez-Bettucci, L., Peel, E., Masquelin, H., 2010a. Neoproterozoic tectonic synthesis of Uruguay. International Geology Review 52, 51–78.

Sánchez-Bettucci, L., Masquelin, E., Peel, E., Oyhantçabal, P., Muzio, R., Ledesma, J.J., Preciozzi, F., 2010b. Comment on "Provenance of the Arroyo del Soldado Group (Ediacaran to Cambrian, Uruguay): implications for the palaeogeographic evolution of southwestern Gondwana" by Blanco et al. [Precambrian Research 171 (2009) 57–73]. Precambrian Research 180, 328–333.

Santos, J.O.S., Hartmann, L.A., Bossi, J., Campal, N., Schipilov, A., Piñeyro, D., McNaughton, N.J., 2003. Duration of the Trans-Amazonian Cycle and its correlation within South America based on U-Pb SHRIMP geochronology of the La Plata Craton, Uruguay. International Geology Review 45, 27–48.

Umpierre, M., Halpern, M., 1971. Edades estroncio-rubidio en rocas cristalinas del sur de la República Oriental del Uruguay. Revista de la Asociación Geológica Argentina 25, 138–151.