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Reply to the comments on: “From source-to-sink: The Late Permian SW gondwana paleogeography and sedimentary dispersion unraveled by a multi-proxy analysis” [journal of South American earth sciences 70 (2016) 368–382] by Vesely & Schemiko

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ABSTRACT

The publication of the comments by Vesely & Schemiko (Comment on “From source-to-sink: The Late Permian SW Gondwana paleogeography and sedimentary dispersion unraveled by a multi-proxy analysis” by L. Alessandretti, R. Machado, L.V. Warren, M.L. Assine and C. Lana [Journal of South American Earth Sciences 70 (2016) 368–382], Journal of South American Earth Sciences, this issue) on our paper entitled “From source-to-sink: The Late Permian SW Gondwana paleogeography and sedimentary dispersion unraveled by a multi-proxy analysis” (L. Alessandretti, R. Machado, L.V. Warren, M.L. Assine and C. Lana (Journal of South American Earth Sciences 70 (2016) 368–382) provides a worthy opportunity to further clarify our observations and interpretations regarding the provenance of the Late Permian Rio do Rasto Formation and its implications on SW Gondwana paleogeography and sedimentary dispersion.

> “*Thus, it is truly tectonics which governs stratigraphy, and the two branches of the geological sciences are inseparable. A structural geologist who is not a stratigrapher is only a geometer, not a geologist; for he reasons about abstract surfaces and volumes, emptied of their history; and a stratigrapher who never concerned himself with tectonics would produce only a dead stratigraphy.*” (*Gignoux, 1950, p. 3*)

1. Introduction

The authors thank Fernando F. Vesely and Danielle C. B. Schemiko for their interest and fruitful discussion of our recent paper, and to give us the opportunity to reinforce our data and interpretations on the Late Paleozoic stratigraphic record of the Paraná Basin and implications to SW Gondwana paleogeography and sediment dispersion.

The paleogeography of the SW Gondwana has been intensely debated for over a century, since the precursor works of Keidel (1913, 1916) and Du Toit (1927, 1937). More recently, significant contributions provided a range of new data on the tectonic evolution of the southwestern sector of Gondwana, shedding light on some key questions on this issue (Newton et al., 2006; Tankard et al., 2009; Ramos et al., 2013; Linol et al., 2015; Pángaro et al., 2015; Andersen et al., 2016; Alessandretti et al., 2016; Canile et al., 2016; Uriz et al., 2016). Ramos et al. (2013) reported a detailed provenance study of the Paleozoic Ventania System of central-eastern Argentina, reinforcing the proposition of the Late Paleozoic collision of Patagonia terrane against the southern Gondwana continental margin. According to these authors, substantial volcanic and plutonic zircons were carried from the

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Gondwanides Orogen (which currently crop out in the northern Patagonia) and the Ventania Foldbelt to the Claromecó Foreland Basin. Andersen et al. (2016) reported a conspicuous Permian age peak coupled with a main fluvial sediment transport towards north during deposition of the straightforward correlated Karoo Supergroup in the Main Karoo Basin, southern Africa. They argue that these deposits are dominated by recycled material derived from older sedimentary units and that the Late Paleozoic age zircons come from the Gondwanides Orogen. In the Paraná Basin, Canile et al. (2016) showed that the Siderópolis Member of the Rio Bonito Formation is the Permian unit that shows an impressive change in the source of sediments in the Paraná Basin. According to these authors, the U-Pb and Lu-Hf isotopic signatures show the presence of these Permian age peaks in this unit, which reveals distant Argentinian sources from the North Patagonian Massif and Choiyoi Igneous Province. For the Late Permian to Early Triassic deposits (Sanga do Cabral Supersequence) in the Rio Grande do Sul State (Brazil), Zerfass et al. (2003, 2004) described wide alluvial systems flowing from the Gondwanides Orogen towards the intraplate setting. In the offshore of the Pennsylvanian to Lower Triassic Hespérides Basin of Argentina, Pángaro et al. (2015) described a large (hundreds of kilometers) submarine lobe complex that progradated to the NE direction. In this way, our recent published paper (Alessandretti et al., 2016) is in complete consonance with the paleogeographic reconstructions proposed by recent works as Pángaro et al. (2015) for the Hespérides Basin, Andersen et al. (2016) for the Karoo Basin, and Zerfass et al. (2003, 2004) and Canile et al. (2016) for the Paraná Basin.

Vesely and Schemiko (2016, this issue) criticize the sedimentologic data and provenance interpretation presented by us (Alessandretti et al., 2016), putting in question our interpretations of the sedimentary sources and sedimentary dispersal pattern during the Permian of the Paraná Basin. In this reply we show how the comments are not well grounded on robust sedimentological information and a careful examination of key previous studies. Among other serious problems identified in the model proposed by Vesely & Schemiko, we cite the acquisition of paleocurrents in architectural elements propitious to generate dispersion in measures (see Warren et al., 2008). Besides, they propose to discuss the paleogeographic scenario of the Permian in the Paraná Basin only based on local sedimentologic information of the Morro Pelado Member, the upper unit of the Rio do Rasto Formation. In sum, we show in this reply how a paleogeographic model based in a very restrict local observations and just one analytic method can be completely flaw. We organize our response to the specific issues following the order of the Vesely & Schemiko comments on our work.

2. The issues

2.1. Stratigraphic framework

The formation of the Gondwanides Orogen (Keidel, 1916) in southern Gondwana reordered the whole arrangement of the Late Paleozoic drainage system, catchment areas and, consequently, altered the sediment dispersion pattern. These remarkable paleogeographic modifications resulted in changes in the stratigraphic architecture of the southwestern Gondwana basins during the Late Permian to Early Triassic (Andreis and Cladera, 1992; López-Gamundí et al., 1995, Zerfass et al., 2004; Limarino et al., 2013; Ramos et al., 2013; Alessandretti et al., 2016). As mentioned by Vesely & Schemiko (this issue), the sedimentary succession of the Rio do Rasto Formation is chronocorrelated and contiguous to the Gai-As Formation in northern Namibia (Stollhofen et al., 2000). The bivalve *Leinzia similis*, which is typical of the basal portion of the Serrinha Member, is likewise found in the African unit (Stollhofen et al., 2000) suggesting that the Serrinha depositional site exceed the actual eastern margin of the basin (Stollhofen et al., 2000; Holz et al., 2010; Vesely & Schemiko this issue). Nonetheless, it is important to note that the fluvial, eolian and minor lacustrine deposits of the upper Morro Pelado Member are time-equivalent to several another non-marine clastic successions of the southwestern Gondwana basins (not addressed by Vesely & Schemiko, this issue) as we will demonstrate below.

In the Claromecó Foreland Basin, central-eastern Argentina, the Late Permian Tunas Formation registers significant changes in compositional, structural and textural signatures in comparison with the underlying formations (Reinoso, 1968; Andreis and Cladera, 1992; López-Gamundí et al., 1995; 2013, Alessandretti et al., 2013; Ramos et al., 2013). The mainly northward fluvial sedimentary transport (Reinoso, 1968; Andreis and Cladera, 1992; López-Gamundí et al., 1995), moderate to low content of quartz, abundant volcanic and metasedimentary clasts (López-Gamundí et al., 1995; Alessandretti et al., 2013) and U-Pb ages from detrital zircons (Ramos et al., 2013), indicate that the source areas corresponds to a poorly dissected relief (i.e. Gondwanides Orogen) and the uplifted orthoquartzites of the Ventania Foldbelt. Pángaro et al. (2015) described a wide sedimentary wedge extending more than 1000 km from the Gondwanides Orogen core towards north, reaching south and offshore of Uruguay. They linked the Hespérides Basin (Argentina) with the Chacoparaná Basin to the west, the Paraná Basin to the north and the Karoo and Kalahari basins to the east. According to Zerfass et al. (2004) the Late Permian to Early Triassic continental sedimentation in southern Brazil is straightly related to the Gondwanides Orogen. The aforementioned authors interpreted the Early Triassic Sanga do Cabral Supersequence (Rio Grande do Sul State, Brazil) as corresponding to poorly channelized braided rivers. Their paleocurrent data indicates a northward to east-north-eastward trend of fluvial transport with source areas in the Gondwanides units and uplifted sedimentary terranes to the south and southwest (e.g. peripheral bulge of the Ventania Foldbelt). Our proposed paleogeographic scenario based on sedimentological features, paleocurrent data and detrital zircon isotopic signatures (Alessandretti et al., 2016) is analogous to the model presented by Zerfass et al. (2004) for the Late Permian to Early Triassic.

2.2. Facies interpretation

Vesely and Schemiko (2016, this issue) state that "*Eolian facies of the uppermost Rio do Rasto Formation were misinterpreted as fluvial or deltaic, putting into question the paleocurrent database*". This statement is merely speculative and obviously cannot be considered as a scientific argument. Our columnar section and table with sedimentary facies and depositional interpretations (Alessandretti et al., 2016) of the upper Morro Pelado Member is mainly composed by sandstones with through cross stratification formed as product of migration of eolian dunes, but interbedded with alluvial facies and representing a good example of interaction of fluvial and eolian processes.

The presence of paleosoil and mud cracks pointed by Vesely and Schemiko (2016, this issue) cannot be considered as a conclusive evidence of eolian deposition. Several outcrops of the upper portion of the Morro Pelado Member in Lages (Santa Catarina State) show calcrete horizons developed in pelite beds deposited as deltaic interdistributary bays and overbank fines in fluvial plains (Warren et al., 2008). Moreover, the presence of mud cracks in the Rio do Rasto Formation is quite controversial (Lavina, 1991). Many samples of mud cracks in the entire succession of Rio do Rasto Formation exhibit characteristics of classic seismites or dewatering mud cracks (*sensu* Tanner, 1998), such as upward bifurcation, upward injection features intersecting more than one bed and association with synsedimentary faults and clastic dykes (Fig. 1a and b) (see Warren, 2006; Alessandretti et al., 2016 for further explanations). The absence of evidences presented by Vesely and Schemiko (2016, this issue) to refute the fluvio-deltaic origin for the upper portion of the Morro Pelado Member, are also considered flaw. Moreover, it is always good to remember that claim for absence of evidence is not a trustable scientific procedure.

The presence of tabular beds of very fine sandstones with climbing ripples (contrary to what was stated by Vesely and Schemiko, 2016; this issue) can also result from flow desaceleration in a diversity of situations like in distal inundites and mouth bars (Fig. 1c and d). The occurrence of meter-thick beds of red laminated siltstones interbedded with these deposits in the Rio do Rasto Formation can be also product of deposition in stable water bodies (permanently flooded), and not necessarily in shallow interdunes that are periodically exposed to subaerial conditions. In addition, the apparent absence of fining-upward facies can be an effect of absolute lack of grain size contrast in the very fine sandstones of the Morro Pelado Member.

A careful analysis of the bibliography reveal that the presence of deltaic/lacustrine/fluvial deposits interbedded with eolian facies was reported by several authors in the upper portion of the Rio do Rasto Formation (Lavina, 1991; Rohn, 1994; Warren, 2006; Warren et al., 2008). This assumption is particularly applicable to the Serra do Espigão and Rio do Rasto sections, where proximal deltaic facies occur together with eolian dunes deposits characterized by large-scale cross-stratification and wind ripple lamination (Warren et al., 2006; Vesely and Schemiko, 2016; this issue).

Thus, based in solid data we sustain the hypothesis of the deltaic influence in the upper portion of the Morro Pelado Member. Considering the above evidence, we reinforce what was emphasized in the Alessandretti et al. (2016) article that all paleocurrents measurements were acquired in very fine sandstones with trough cross-bedding and current ripples deposited in fluvio-deltaic setting, more specifically in a deltaic plain associated with eolian deposits.

2.3. Fluvial paleocurrents

Vesely and Schemiko (2016, this issue) claim that the northward paleocurrent pattern presented by Alessandretti et al. (2016) is based on a small amount of data when compared with the dataset of Schemiko et al. (2014). Despite this large dataset, the paleocurrent stations presented by Schemiko et al. (2014) are distributed solely along 150 km in the eastern border of the Paraná Basin of the Santa Catarina and Paraná states. Our paleocurrent stations cover a distance of approximately 750 km along the eastern border of the Paraná Basin (Paraná, Santa Catarina and Rio Grande do Sul states), showing a consistent northward sediment-routing system. Rohn (2007) already highlighted that recent studies indicated that the cross stratifications and laminations of the Morro Pelado Member (except the eolian sandstones) usually indicate a mean sediment transport northwards and not in centripetal orientations.

A remarkable problem in the work of Schemiko et al. (2014) is the way that their paleocurrent data were organized and interpreted into single rose diagrams for the described lithofacies. For example, the authors group different lithofacies (St, Sr and Fhr) from the same architectural element (MB, sensu Miall, 1985) in a single rose diagram, producing a clearly dispersion. The lack of subdivision/hierarchy in the way to process the data produces this interpretive anomaly. Another problem is that the main paleocurrent direction to southeast, east and northeast presented by Schemiko et al. (2014) were also derived from measures made on crevasse splay lobes, mouth bars and lateral accretion point bars. Such data show similar dispersion (but contrary directions) to those presented by Warren (2006) and Warren et al. (2008) measured in subaquatic wave ripples with main transport direction to the northwest, and secondarily, to the west.

Moreover, is noteworthy that Schemiko et al. (2014) and Vesely and Schemiko (2016, this issue) do not present any sedimentological and/or paleocurrent data from the basal Serrinha Member to

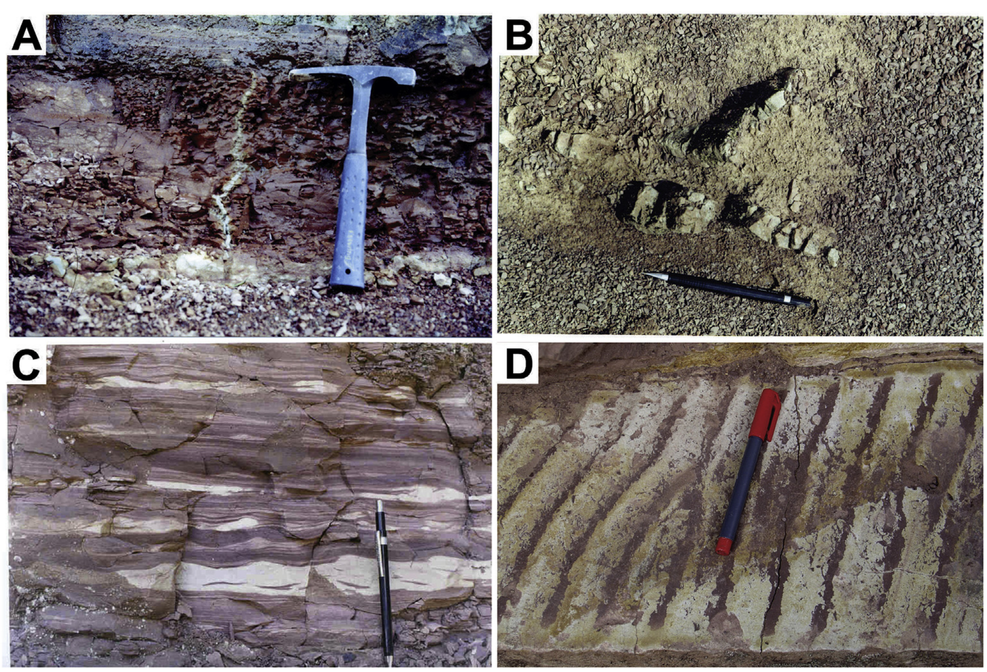

Fig. 1. Sedimentary facies and synsedimentary deformation features of the Morro Pelado Member in the Serra do Espigão locality. A – Detail of a clastic dyke within massive siltstone facies. B – Plan view of a clastic dyke showing lateral bifurcation. In this perspective, these structures are easily confused with diseccation cracks (see Tanner, 1998; Warren, 2006 for further explanation) C – Detail of current ripples in the base of a mouth bar deposit. D – Plan view of a mouth bar deposit showing very good examples of ripple marks. The hammer in A is 27.9 cm long and the pen in B, C and D is 17 cm.

support the proposed paleogeographic scenario for the Rio do Rasto Formation. They also argue that *"the main depositional zone"* of the Paraná Basin *"was filled by sediment from several sources and in a centripetal fashion, a typical characteristic of continental interior basins"*. However, to sustain the hypothesis of a centripetally filled basin, it is necessary a radial pattern of paleocurrents (see Fig. 5 of Vesely & Schemiko et al. this issue). Nevertheless, the main SE and E paleocurrent directions present by Schemiko et al. (2014) and Vesely & Schemiko et al. (this issue) do not support this hypothesis.

Corroborating with our observations in the Rio do Rasto Formation, several Late Permian-Early Triassic units from the southwestern Gondwana basins shows a main northward pattern of fluvial sediment transport. A drastic change of 180° in the paleocurrent directions (south to north) is recorded in the Late Paleozoic deposits of the Claromecó Foreland Basin (central-eastern Argentina). The fluvial paleocurrents to northeastern and northwestern, geochemical fingerprints and detrital zircon ages of the sandstones from the Tunas Formation indicate provenance from this immature magmatic juvenile arc (Ramos et al., 2013; Alessandretti et al., 2016) situated south from the depositional area. Pángaro et al. (2015) based on correlation of exploratory wells and 2D seismic lines, proposed an inter-continental straightforward connection between the Chaco-Paraná, Hespérides, Kalahari and Karoo basins during the Late Paleozoic-Triassic interval. According to these authors, this link implies in a huge sedimentary wedge extending from more than 1000 km from the Gondwanides Orogen to areas further north. The straightforward correlated Upper Ecca and Beaufort groups of the Karoo Basin in southern Africa were deposited with paleocurrents mainly to the N, NE and NW from the rising Cape Foldbelt, ca. 245–278 Ma (Cole, 1992; Veevers et al., 1994; Newton et al., 2006; Tankard et al., 2009; Andersen et al., 2016). Based on paleocurrents records coupled with detrital zircon geochronology, Andersen et al. (2016) suggested that the Gondwanides Orogen was the source for the Permian zircons; while the Late Mesoproterozoic and Neoproterozoic zircons were derived from sedimentary recycling of the Cape Supergroup, Natal Group and Msikaba Formation of the Cape Foldbelt in South Africa. The Late Permian-Early Triassic Sanga do Cabral Supersequence (this unit overlies the Rio do Rasto Formation) of the Paraná Basin in southern Brazil was interpreted by Zerfass et al. (2003) as representing deposits of poorly channelized braided rivers flowing towards the intraplate setting (to the north). The paleocurrent data indicate a northward to east-north-eastward trend of fluvial transport with the Gondwanides acting as source area (Zerfass et al., 2003, 2004). Finally, our interpreted northward sediment-routing system for the Rio do Rasto Formation is in consonance with paleocurrent measures of coeval Late Permian to Early Triassic units of southwest Gondwana.

2.4. Detrital provenance, U-Pb ages and Hf zircon composition

The increasing number of studies combining paleocurrents and U-Pb-Hf data from detrital zircons has significantly improve our understanding of the Paleozoic paleogeographical scenario of the Paraná Basin and adjacent areas of southwestern Gondwana (see Ramos et al., 2013; Alessandretti et al., 2016; Andersen et al., 2016; Canile, 2016; Canile et al., 2016; Uriz et al., 2016). Here, again, we will scrutinize the paleogeographic configuration of the southwestern Gondwana and emphasize the problematic involving the sources of the sediments during the end of Permian.

The sedimentological data presented by Schemiko et al. (2014) and Vesely and Schemiko (2016, this issue), led us to don't agree with the sentence "*The interpreted sources for detrital zircon are biased by the paleocurrent results and exclude several other areas that expose igneous rocks with same ages than those of the zircon crystals*". First, as explained above, all of our paleocurrent data were measured on fluvio-deltaic lithofacies and show a consistent transport direction to northwest and north. Vesely and Schemiko (2016, this issue) also stated that: "*The most suitable paleogeographical setting for the Rio do Rasto Formation and equivalent units includes a main depocenter between the eastern Paraná Basin and western Namibia that was centripetally filled by sediment sourced from different elevated areas flanking the basin*". By assuming main paleocurrent patterns to southeast for the Rio do Rasto Formation (as claimed by Vesely and Schemiko, 2016; this issue), how to explain the massive presence of Ordovician to Permian age detrital zircons derived solely from elevated areas flanking the basin? The only sector of southwestern Gondwana that records Ordovician and Devonian plutonic and volcanic rocks is the Sierras Pampeanas, Argentina (Ramos et al., 2010). This region was located to the west and southwest of the Paraná Basin during the Late Permian. Thus, the fluvial paleocurrents to the southeast reported by Schemiko et al. (2014) and Vesely and Schemiko (2016, this issue) do not explain the Ordovician to Devonian zircons grains found in the Rio do Rasto Formation. The most plausible hypothesis for the sedimentary source is the recycling of the Ordovician to Devonian zircons-bearing old sedimentary successions of the Ventania Foldbelt, North Patagonian Massif and Paraná Basin. Furthermore, the only sectors along southwestern Gondwana with Permo-Carboniferous magmatic units are the Patagonian Massif and the Choiyoi Igneous Province. All sediments and, consequently, detrital zircons coming from northwestern regions were hampered by the Asunción Arch, which acted as a topographic barrier during Late Permian times preventing the eastward transport of detritus from Sierras Pampeanas and the Choiyoi Igneous Province. Thus, a plausible alternative is to consider a remote source area and a long-distance transport travel from the southernmost Gondwana sectors. In this way, as highlighted by Alessandretti et al. (2016) and Canile et al. (2016), the Permian age detrital zircons found in the Permian units of the Paraná Basin came from the North Patagonian Massif and were subjected to a long journey to the continental inner portion.

Vesely and Schemiko (2016, this issue) stated of ambiguous way that *"Precambrian rocks now exposed east of the Paraná Basin border (Ribeira, Dom Feliciano and part of the Damara belt) were not exposed during the late Permian and, by consequence, do not operated as sediment-source areas for the Rio do Rasto Formation and equivalent units."* and then *"Other possible sources for Neoproterozoic to Early Paleozoic detrital zircon may include granitic rocks from the Assunción arc and the Sierras Pampeanas to the west, the Paraguay belt and the Goiás magmatic arc to the north and the Ribeira, Dom Feliciano and Kaoko belts to the east and southeast"*. Canile et al. (2016) reported four main detrital-age groups (Neoarchean, mid-Paleoproterozoic, Grenvillian and Brasiliano-Pan African) in the Permian units of the Paraná Basin, showing the importance of Precambrian basement (i.e. Dom Feliciano, Kaoko and Namaqua-Natal belts) bordering the east side of the basin during this period. A provenance and paleogeographic study of the Durazno Group of the Paraná Basin carried by Uriz et al. (2016) showed that the Dom Feliciano Belt acted as source area during the Devonian, reinforcing the idea that this mobile belt was a topographic high at least since this period. The globally renowned paleotopographic and paleotectonic map presented by Ziegler et al. (1997) shown that parts of the Namaqua-Natal and Damara belts in southern Africa and the Río de La Plata Craton in southern South America, were also elevated areas during the Permian-Triassic transition.

For the chronocorrelated Karoo Supergroup of the Karoo Basin (southern Africa), Andersen et al. (2016) demonstrated that the Late Mesoproterozoic (940–1120 Ma) and Neoproterozoic (470–720 Ma) detrital zircons reflect recycling of older cover sequences, whereas the Permian age (240–280 Ma) grains has a direct provenance from the Gondwanides Belt. They concluded that the "sink" of one sedimentary cycle will act as the "source" in subsequent cycles and that detrital zircon in this context can provide important information on sedimentary process rather than on provenance itself. In our paper (Alessandretti et al., 2016) we proposed an analog sedimentary process to explain the provenance patterns found in entire the Rio do Rasto succession. Thus, we suggest that direct provenance from Precambrian and Early Paleozoic mobile belts coupled with recycling of old sedimentary successions from the southwestern Gondwana were the main processes responsible for providing detrital sediments for the Paraná Basin during Late Permian times. Paleoproterozoic, Mesoproterozoic, Neoproterozoic and Ordovician to Devonian detrital zircons have also come from orthoquartzites from the uplifted Paleozoic Ventania Foldbelt, immature sandstones from the Claromecó Foreland Basin in central-eastern Argentina and the Silurian-Devonian successions of the southern Paraná Basin (central-northern Uruguay) and North Patagonian Massif. Based in geochemical evidences and U-Pb and Lu-Hf isotopic signatures we also demonstrate that the Permian plutonic zircons (rather than volcanic crystals, Alessandretti et al., 2016) come from the Gondwanides Orogen, more specifically from the North Patagonian Massif (Fig. 2).

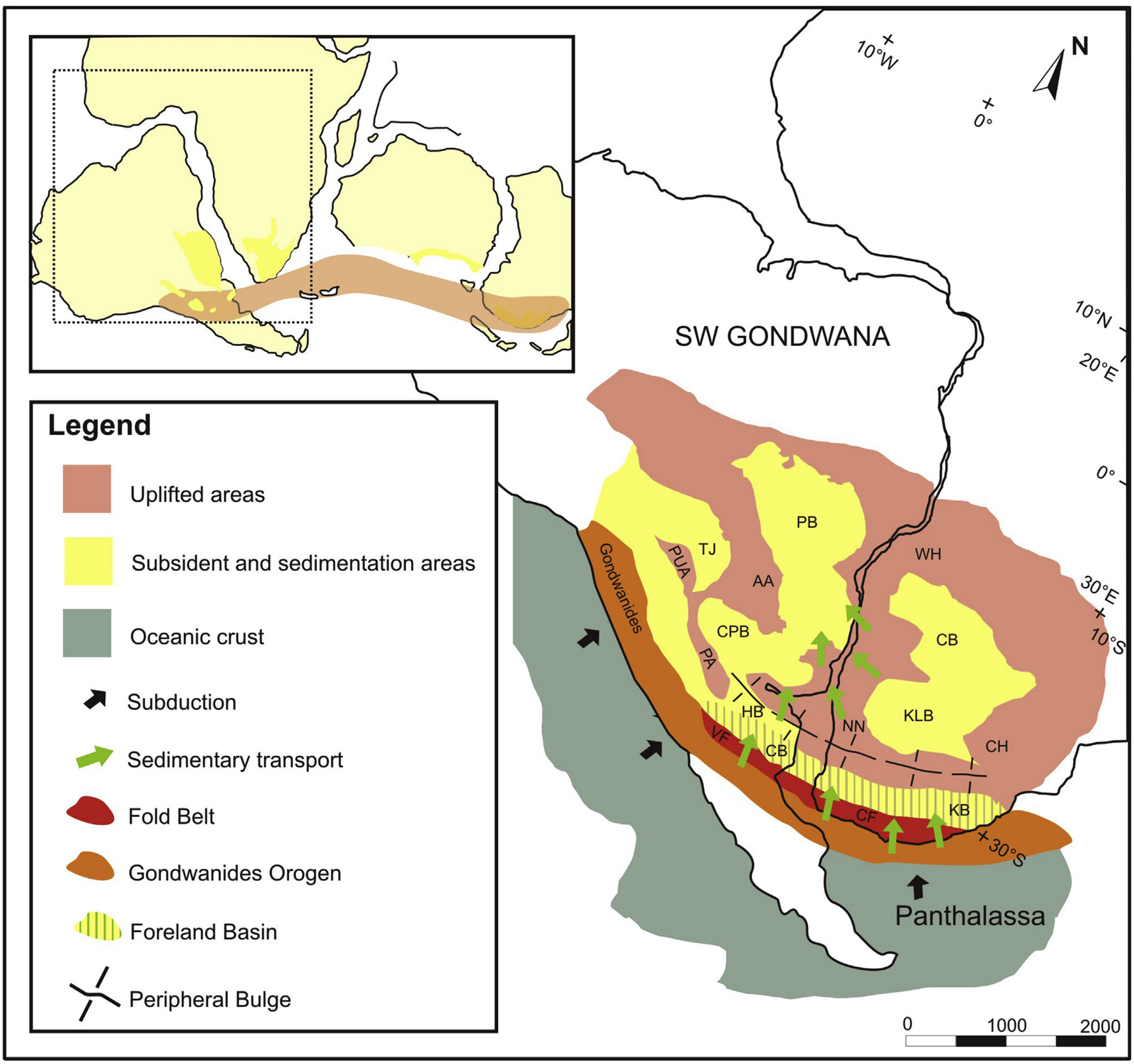

Fig. 2. Reconstruction of the Permian-Triassic paleogeography of the SW Gondwana showing the surrounding uplifted areas and the main depositional sites in the Paraná, Karoo and Kalahari basins. Note that the sources of sediment correspond to elevated areas located in the south and the peripheral bulge associated with the Ecca Foreland basin. All data from Cole (1992), Veevers et al. (1994), Milani (1997), Warren (2006), Zerfass et al. (2004), López-Gamundi (2006), Newton et al. (2006), Milani and De Wit (2008) Tankard et al. (2009), Ramos et al. (2013), Linol et al. (2015), Alessandretti et al. (2016). AA – Asunción Arch; CB – Claromecó Basin; CB – Congo Basin; CPB – Chaco-Paraná Basin; HB – Hesperides Basin; KB – Karoo Basin; KLB – Kalahari Basin; PB – Paraná Basin; TJ – Tarija Basin; VF – Ventania Foldbelt; CF – Cape Foldbelt; AA – Assunción Arch; PA – Pampean Arch; PUA – Puna Arch; WH – Windhoek Highlands; CH – Cargonian Highlands; NN – Namaqua-Natal Belt.

3. Paleogeographic scenario of SW gondwana

Vesely and Schemiko (2016, this issue) argue that the Paraná Basin was centripetally filled with sediments from different areas that flanked the depositional site during the Late Permian. This assertive is partially correct, if we consider the exhumed areas of the Archean-Paleoproterozoic basement and Neoproterozoic to Early Paleozoic Damara (Namibia) and Ribeira (Uruguay and southern Brazil) mobile belts. However, the southwestern continental margin of Gondwana experienced a complex geological history during the Paleozoic, involving an active convergent setting between its cratonic block and the oceanic lithosphere of Panthalassa (Coira et al., 1982). The successive amalgamation of allochthonous terranes along the southwestern Gondwana (see Ramos et al., 1986) margin during the Paleozoic orogenies certainly resulted in the formation of a high altitude cordillera (Lavina, 1991; Soares, 1992; Milani and Ramos, 1998). The paleotopographic reconstitution of the Permo-Triassic limit proposed by Ziegler et al. (1997) suggests that the Gondwanides Orogen reached a maximum elevation of about 1000–2000 m above the Panthalassa sea level at the Permo-Triassic limit. Additionally, an inter-continental connection between the Hespérides Basin (an Argentinian offshore basin) with the Chacoparaná basin to west, the Paraná Basin to the north and the Kalahari and Karoo basins to the east was established by Pángaro et al. (2015, 2015) and Alessandretti et al. (2016) also showed that strong denudation process removed large amounts of detritus from the Ventania Foldbelt (and surrounding areas) and the Tandilia System located in southern Buenos Aires province. This paleogeographic scenario implies in a sedimentary wedge extending from more than 1000 km from the Gondwanides Orogen core to areas further north, including the Paraná Basin (Zerfass et al., 2004; Pángaro et al., 2015; Alessandretti et al., 2016). Reinforcing the tendency to the sedimentary dispersion to the north, a depositional dip to northeast is revealed by the isopach map of the Gondwana I Supersequence provided by Milani and Ramos (1998).

It is important to note that, the paleogeographic scenario of the SW Gondwana must have be substantially the same during the interval between the upper Permian and Lower Triassic (Lavina, 1991; Zerfass et al., 2003, 2004). In the beginning of the Mesozoic, the sedimentation in the Paraná Basin is represented by the Sanga do Cabral Supersequence, a fluvial unit that show sedimentary transport direction to the north and northeast (Zerfass et al., 2003). Another units, as Santa Maria Formation (Paraná Basin, southern Brazil) and Talampaya and Tarjado sequences were deposited in analogous context and also present alluvial units with same paleocurrent direction (Zerfass et al., 2003).

Following all the evidence cited above and based on the northward paleocurrent pattern and U-Pb-Hf isotopes data from detrital zircons of the Rio do Rasto Formation reported by Alessandretti et al. (2016), it can be stated that a transcontinental sediment-routing system from the Gondwanides Orogen coupled to proximal fluvial systems were responsible for the sedimentary input to the Paraná Basin during the Late Permian. Long-distance sedimentary transport is a worldwide recognized phenomenon from both modern and ancient basins. Evidence of transcontinental sedimentary transport was reported by Van Lente (2004), who observed detrital zircons that were transported from the North Patagonian Massif, to the Permian Tanqua and Laingsburg depocenters (~1500 km) in the Karoo Basin. Dickinson and Gehrels (2003) inferred that transcontinental Permian and Jurassic river systems of Appalachian provenance transported sediments westward across the depressed surface of the Laurentian Craton, North America. Evidence of sediment transport on a continental-scale was also reported by Rösel et al. (2013), who obtained U-Pb ages from detrital rutile and zircon from Ordovician sediments of the North Gondwana passive margin (Saxo-Thuringia, Germany). The authors argue that the ca. 950 Ma zircons have no recognizable African sources, and proposed that these crystals are derived from the Rayner Complex-Eastern Ghats regions of Antarctica and India, indicating continental-scale sedimentary transport from central Gondwana to its margins or multiple cycles of sediment reworking and deposition.

4. Final remarks

The conclusions of Schemiko et al. (2014) and Vesely and Schemiko (2016, this issue) fail to explain the paleogeographic scenario of the Late Permian Rio do Rasto Formation, probably due to the limited paleocurrent sampling area or even the wrong decision of the authors to measure and combine paleocurrents of architectural elements that produce considerable dispersion on paleocurrent data. The fact that the authors do not present additional information of the basal Serrinha Member is another key point for the flaw model. Even more, the proposed southeastward fluvial sediment-routing system by Vesely and Schemiko (2016, this issue) contradicts all geological evidence that clearly revealed the importance of long-distance (transcontinental) sedimentary transport from southern elevated areas to the Paraná Basin and other straightforward correlated basins. As shown here, in the last years several sedimentological and geochronological studies have demonstrated a main northward sedimentary transport direction in the Late Permian deposits of the southwestern sector of Gondwana (Ramos et al., 2013; Pángaro et al., 2015; Alessandretti et al., 2016; Andersen et al., 2016; Canile et al., 2016). Moreover, our data and interpretations are in consonance with the Permian-Triassic paleogeography of southern South America and Africa proposed by Lavina (1991), Soares (1992), Milani and Ramos (1998), Zerfass et al. (2003, 2004), Warren et al. (2008), Pángaro et al. (2015) and Andersen et al. (2016).

We concluded that Vesely and Schemiko (2016, this issue) do not provide any conclusive geological arguments to support their proposed paleogeographic scenario for the Rio do Rasto Formation.

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References

Alessandretti, L., Machado, R., Warren, L.V., Assine, M.L., Lana, C., 2016. From source-to-sink: the Late Permian SW Gondwana paleogeography and sedimentary dispersion unraveled by a multi-proxy analysis. J. S. Am. Earth Sci. 70, 368–382.

Andersen, T., Kristoffersen, M., Elburg, M., 2016. How far can we trust provenance and crustal evolution information from detrital zircons? A south African study. Gondwana Res. 34, 129–148.

Andreis, R.R., Cladera, G., 1992. Las epiclastitas pérmicas de la cuenca Sauce Grande (Sierras Australes, Buenos Aires, Argentina). Parte I: composición y procedencia de detritos. 4° Reunión Argentina de Sedimentología (La Plata). Actas 127–134.

Canile, F.M., 2016. Geocronologia de zircões detríticos (U-Pb, O e Hf) e em rocha total (Sm-Nd, Pb-Pb) das unidades aflorantes ao longo da seção tipo de White: implicações na proveniência sedimentar e evolução geológica da Bacia do Paraná. PhD Thesis. Instituto de Geociências, USP, São Paulo.

Canile, F.M., Babinski, M., Rocha-Campos, A.C., 2016. Evolution of the Carboniferous-Early Cretaceous units of Paraná Basin from provenance studies based on U–Pb, Hf and O isotopes from detrital zircons. Gondwana Res. 40, 142–169.

Coira, B., Davidson, J., Mpodozis, C., Ramos, V., 1982. Tectonic and magmatic evolution of the Andes Northern Argentina and Chile. Earth Sci. Rev. 18, 303–332.

Cole, D.I., 1992. Evolution and development of the Karoo basin. In: de Wit, M.J., Ransome, I. (Eds.), Inversion Tectonics of the Cape Fold Belt Karoo and Cretaceous Basins of Southern Africa. A.A. Balkema, Rotterdam, pp. 87–99.

Dickinson, W.R., Gehrels, G.E., 2003. U–Pb ages of detrital zircons from Permian and Jurassic eolian sandstones of the Colorado Plateau, USA: paleogeographic implications. Sediment. Geol. 163, 29–66.

Du Toit, A.L., 1927. A Geological Comparison of South America with South Africa, vol. 381. Publications Carnegie Institute, pp. 1–157.

Du Toit, A.L., 1937. Our Wandering Continents. Oliver and Boyd, London, p. 366.
Gignoux, M., 1950. Stratigraphic Geology. English translation from the Fourth French Edition (1950) by Gwendolyn G. Woodford. WH. Freeman and Co., San Francisco, p. 682.
Holz, M., França, A.B., Souza, P.A., Iannuzzi, R., Rohn, R., 2010. A stratigraphic chart of the late carboniferous/permian succession of the eastern border of the Paraná Basin, Brazil, South America. J. S. Am. Earth Sci. 29, 381–399.
Keidel, J., 1913. Über das Alter, die Verbreitung und die gegenseitigen Beziehungen der verschiedenen tektonischen strukturen in den argentinischen Gebirgen. XII° Session du Congrés Géologique International, Compte Rendu (Toronto), pp. 671–687.
Keidel, J., 1916. La geología de las Sierras de la Provincia de Buenos Aires y sus relacionescon las montañas de Sudáfrica y Los Andes. In: Ministerio de Agricultura de la Nación, Sección Geología, Mineralogía y Minería, Anales, 11. Servicio Geológico Nacional, Buenos Aires, pp. 1–78.
Lavina, E.L., 1991. Geologia sedimentar e paleogeografia do Neopermiano e Eotriássico (intervalo Kazaniano - Citiano) da Bacia do Paraná. PhD Thesis, vol. 2. Universidade Federal do Rio Grande do Sul.
Limarino, C.O., Césari, S.N., Spalletti, L.A., Taboada, A.C., Isbell, J.L., Geuna, S., Gulbranson, E.L., 2013. A paleoclimatic review of southern South America during the late Paleozoic: a record from icehouse to extreme greenhouse conditions. Gondwana Res. 25, 1396–1421.
Linol, B., de Wit, M.J., Milani, E.J., Guillocheau, F., Scherer, C., 2015. Chapter 13: new regional correlations between the Congo, Paraná and cape-karoo basins of southwest gondwana. In: de Wit, M.J., Guillocheau, F., de Wit, M.J.C. (Eds.), The Geology and Resource Potential of the Congo Basin, Regional Geology Reviews. Springer-Verlag, Berlin Heidelberg, pp. 246–268. http://dx.doi.org/10.1007/978-3-642-29482-2_13.
López Gamundi, O.R., Conaghan, P., Rossello, E.A., Cobbold, P.R., 1995. The Tunas Formation (permian) in the Sierras australes foldbelt, east-central Argentina: evidence of syntectonic sedimentation in a varisican Foreland Basin. J. S. Am. Earth Sci. 8 (2), 129–142.
López Gamundí, O., Fildani, A., Weislogel, A., Rossello, E.A., 2013. The age of the Tunas Formation in the Sauce Grande basin-Ventana foldbelt (Argentina): implications for the Permian evolution of the southwestern margin of Gondwana. J. S. Am. Earth Sci. 45, 250–258.
López-Gamundi, O., 2006. Permian plate margin volcanism and tuffs in adjacent basins of west gondwana: age constraints and common characteristics. J. S. Am. Earth Sci. 22, 227–238.
Miall, A.D., 1985. Architectural-element analysis: a new method of facies analysis applied to fluvial deposits. Earth Sci. Rev. 22, 261–308.
Milani, E.J., 1997. Evolução tectono-estratigráfica da Bacia do Paraná e seu relacionamento com a geodinâmica Fanerozóica do Gondwana sul-ocidental. Phd thesis, Instituto de Geociências. Universidade Federal do Rio Grande do Sul, Porto Alegre, 2v.
Milani, E.J., Ramos, V.A., 1998. Orogenias Paleozóicas no domínio sul-ocidental do Gondwana e os ciclos de subsidência da Bacia do Paraná. Rev. Bras. Geociências 28 (4), 473–484.
Milani, E.J., DeWitt, M.J., 2008. Correlations between the classic Paraná and Cape - Karoo sequences of South America and southern Africa and their basin infills flanking the Gondwanides: du Toit revisited. In: Pankhurst, R.J., Trouw, R.A.J., Brito Neves, B.B., De Wit, M.J. (Eds.), West Gondwana: Pre-Cenozoic Correlations Across the South Atlantic Region, 294. Geological Society, Special Publications, pp. 319–342.
Newton, A.R., Shone, R.W., Booth, P.W.K., 2006. The cape fold belt. In: Johnson, M.R., Anhaeusser, C.R., Thomas, R.J. (Eds.), The Geology of South Africa. Council for Geoscience, Pretoria, South Africa, pp. 521–530.
Pángaro, F., Ramos, V.A., Pazos, P.J., 2015. The Hesperides Basin: a continental-scale upper palaeozoic to triassic basin in southern Gondwana. Basin Res. 27 (2), 1–27.
Ramos, V.A., Jordan, T., Allmendinger, R., Mpodozis, C., Kay, S., Cortez, J., Palma, M., 1986. Paleozoic terranes of the central Argentina-Chilean Andes. Tectonics 5, 855–880.
Ramos, V.A., Vujovich, G., Martino, R., Otamendi, J., 2010. Pampia: a large cratonic block missing in the Rodinia supercontinent. J. Geodyn. 50, 243–255.
Ramos, V.A., Chemale, F., Naipauer, M., Pazos, P.J., 2013. A provenance study of the Paleozoic Ventania System (Argentina): transient complex sources from western and eastern Gondwana. Gondwana Res. 26 (2), 719–740.
Reinoso, M., 1968. Paleocorrientes en la Formación Providencia. Devónico, Sierras Australes de la provincia de Buenos Aires. Revista de la Asociación Geológica Argentina, 23, 287–296.
Rohn, R., 2007. Evolução ambiental da Bacia do Paraná durante o Neopermiano no leste de Santa Catarina e do Paraná. PhD Thesis, vol. 2. Universidade de São Paulo, São Paulo.
Rösel, D., Boger, S.D., Möller, A., Gaitzsch, B., Barth, M., Oalmann, J., Zack, T., 2013. Indo-Artarctic derived detritus on the northern margin of Gondwana: evidence for continental-scale sediment transport. Terra Nova. 26, 64–71.
Schemiko, D.C.B., Vesely, F.F., Fernandes, L.A., Sowek, G.A., 2014. Distinção dos elementos deposicionais fluviais, eólicos e lacustres do Membro Morro Pelado, Permiano Superior da Bacia do Paraná. Geol. Usp. Série Científica 14, 29–46.
Soares, P.C., 1992. Tectônica sin-sedimentar cíclica na Bacia do Paraná: controles. Tese de professor titular. Departamento de Geologia, Universidade Federal do Paraná, Curitiba, p. 148.
Stollhofen, H., Stanistreet, I.G., Rohn, R., 2000. The gai-as lake system, northern Namibia and Brazil. In: Gierlowski-Kordesch, E.H., Kelts, K.R. (Eds.), Lake basins through Space and Time: AAPG Studies in Geology, vol. 46, pp. 87–108.
Tankard, A., Welsink, H., Aukes, P., Newton, R., Stettler, E., 2009. Tectonic evolution of the cape and Karoo basins of South Africa. Mar. Pet. Geol. 26 (8), 1379–1412.
Tanner, P.W.G., 1998. Interstratal dewatering origin for polygonal patterns of sand filled cracks: a case study from late Proterozoic metasediments of Islay, Scotland. Sedimentology 45, 71–89.
Uriz, N.J., Cingolani, C.A., Basei, M.A.S., Blanco, G., Abre, P., Portillo, N.S., Siccardi, A., 2016. Provenance and paleogeography of the devonian Durazno group, southern parana Basin in Uruguay. J. S. Am. Earth Sci. 66, 248–267.
Van Lente, B., 2004. Chemostratigraphic Trends and Provenances of the Permian Tanqua and Laingsburg Depocentre, Southwest Karoo Basin, South Africa. Ph.D. thesis. University of Stellenbosch, South Africa.
Veevers, J.J., Cole, D.I., Cowan, E.J., 1994. Southern Africa: Karoo basin and Cape Fold belt. In: Veevers, J.J., Powell, C.McA. (Eds.), Permian–triassic Pangean Basins and Foldbelts along the Panthalassan Margin of Gondwanaland. Geological Society of America Memoir, vol. 184, pp. 223–280.
Vesely, F.F., Schemiko, D.C.B., 2016. Comment on "From source-to-sink: the Late Permian SW Gondwana paleogeography and sedimentary dispersion unraveled by a multi-proxy analysis". J. S. Am. Earth Sci. 2016.
Warren, L.V., 2006. Evolução sedimentar da Formação Rio do Rasto na região centro-sul do Estado de Santa Catarina. Master dissertation. Universidade de São Paulo, p. 174.
Warren, L.V., Almeida, R.P., Hachiro, J., Machado, R., Roldan, L.F., Steiner, S.S., Chamani, M.A.C., 2008. Evolução sedimentar da Formação Rio do Rasto (Permo-Triássico da Bacia do Paraná) na porção centro sul do estado de Santa Catarina. Bras. Rev. Bras. Geociências 38, 213–227.
Zerfass, H., Lavina, E.L., Schultz, C.L., Garcia, A.J.V., Faccini, U.F., Chemale Jr., F., 2003. Sequence-stratigraphy of continental strata of Southernmost Brazil: a contribution to Southwestern Gondwana palaeogeography and palaeoclimate. Sediment. Geol. 161, 85–105.
Zerfass, H., Lavina, E.L., Schultz, C.L., Garcia, A.J.V., Faccini, U.F., Chemale Jr., F., 2004. Sequence-stratigraphy of continental strata of Southernmost Brazil: a contribution to Southwestern Gondwana palaeogeography and palaeoclimate. Sediment. Geol. 161, 85–105.
Ziegler, A.M., Hulver, M.L., Rowley, D.B., 1997. Permian world topography and climate. In: Martini, I.P. (Ed.), Late Glacial and Postglacial Environmental Changes: Quaternary, Carboniferous–Permian and Proterozoic. Oxford University Press, Oxford, pp. 111–146.