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Reply to the Discussion by Duarte and Hartmann on "Volcanic stratigraphy of intermediate to acidic rocks in southern Paraná Magmatic Province, Brazil" by Polo and Janasi (2014), *Geologia USP. Série Científica*, 14(2), 83-100

Réplica da Discussão de Duarte e Hartmann sobre "Vulcano-estratigrafia das rochas intermediárias a ácidas ao sul da Província Magmática Paraná, Brasil" de Polo e Janasi (2014), Geologia USP. Série Científica, 14(2), 83-100

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DISCUSSION

Duarte and Hartmann (in this issue) raise some important questions on the origin and stratigraphic significance of sediments that occur associated with the acidic lava flows in the Gramado Xavier (RS, BR) region (Polo and Janasi, 2014), questioning whether they could correspond to injectites and/or to post-volcanic sediments correlative to the Tupanciretã Formation.

The presence of sedimentary deposits during most of the evolution of the three acidic volcanic sequences that were recognized during our mapping studies is central to our evolutive model, and thus the evidences for alternative origins must be carefully considered. We are therefore grateful to the authors for sharing with us their experience on these alternative possibilities and thus giving us the opportunity to develop further our arguments for a depositional origin for most of the sediments that are reported in our work, and also to share with the readers some specific doubts whose resolution may be important for future research.

In the context of the Paraná Magmatic Province, the volume of sedimentary material associated with the lavas is surprisingly large in the Gramado Xavier region, and we take the opportunity to acknowledge that Dr. Jorge K. Yamamoto first drove our attention to this fact. Back in 2005 he invited one of us (Janasi) to visit some key outcrops of these sediments, which, together with the exceptionally good exposures of volcanic structures stimulated our subsequent research in the region. In particular, our decision to carry out a "classical" geological mapping in a semi-detail (1:50,000) scale aroused from our evaluation that in order to correctly identify the stratigraphic relations of such remarkably diverse set of volcanic and sedimentary deposits we should not rely only on individual outcrops or road profiles. Indeed, the fact that we have pursued the continuity and lateral variation of some deposits was crucial to bring in arguments about their origin. In addition, we must point out that some good outcrops with sedimentary deposits (see location in Table 1) do exist in the region, even though not normally of the same exceptional quality as many of the exposures of volcanic rocks.

Sandstone deposits with thicknesses between 0.2 and 3.0 m appear associated with all three mapped acidic sequences, but are remarkably absent in both the beginning (lower part of the Caxias do Sul sequence) and in the end (upper Santa Maria sequence) of the acidic magmatism. Even if usually discontinuous, some of these deposits may persist laterally for over 1 km, and show typical sedimentary structures such as plane-parallel layering; when thicker, they frequently show cross-bedding (e.g., outcrops RS-73 and GX-117 – Table 1 and Figure 1), reminiscent of structures typical of aeolian sediments of the Botucatu Formation, which is recognized to overlap in time with the Paraná lava flows (e.g., Waichel et al., 2007, 2008).

Table 1. UTM coordinates (zone 22J) of selected outcrops of sedimentary and volcanic rocks near Barros Cassal, Rio Grande do Sul, Brazil.

Outcrop	Latitude	Longitude	Elevation (m)		Unit/feature
RS-73	340350	6763229	423	CSS/BCS/SMS	Glassy acidic rocks from the 3 volcanic sequences with intercalated sandstone layers
GX-18	344738	6778201	557	Pre-SMS	Sedimentary breccia
GX-19	344958	6779143	550	Pre-SMS	Reddish sandstone with volcanic interaction
GX-21	344743	6780511	606	SMS	Autobreccia – rhyolitic lava flows
GX-24	341445	6767706	486	SMS	Peperite
GX-101	346498	6768052	550	CSS	Reddish sandstone and dacitic lava flows
GX-113	348200	6777230	440	BCS	Reddish sandstone and andesitic lava flows
GX-117	349308	6777279	448	BCS	Andesitic flows with sandstone layers
GX-38	346515	6772019	568	Tupanciretã?	Sandstone with conglomerate facies
GX-139	343766	6776022	578	Tupanciretã?	Sandstone with conglomerate and breccia facies

CSS: Caxias do Sul Sequence; BCS: Barros Cassal Sequence; SMS: Santa Maria Sequence

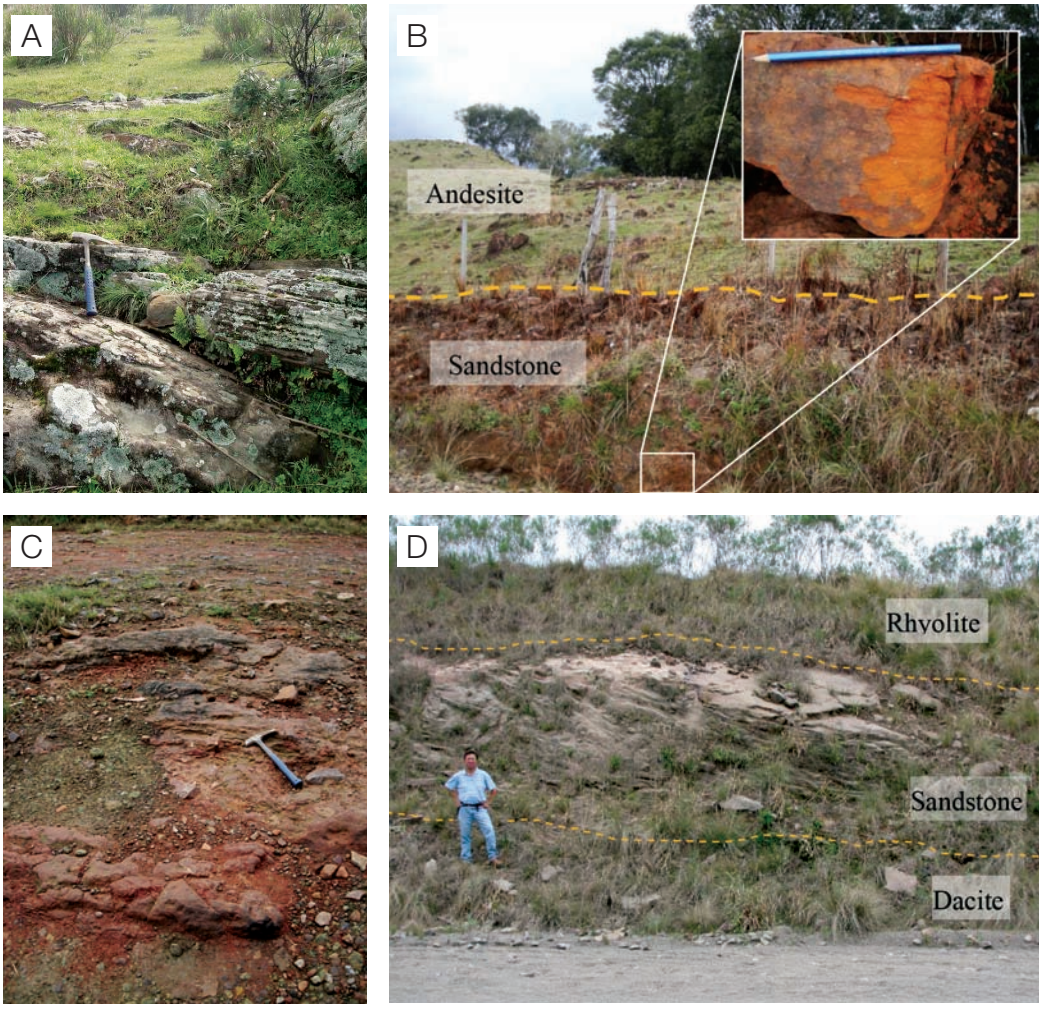

Figure 1. Sandstone deposits with structures typical of eolian sediments, intercalated with lava flows. (A) cross-bedding in a sandstone deposit covering lavas of Barros Cassal Sequence (BCS); (B) andesitic BCS flow covering reddish sandstone with plane-parallel layering; contact is highlighted by yellow line (GX-117); (C) sandstone with plane-parallel layering sandwiched between andesitic (base) and dacitic flows (top) of BCS (GX-113); (D) sandstone layer with cross-bedding between two volcanic sequences (highlighted by yellow line): dacite of BCS (base) and rhyolite of Santa Maria sequence (top) (RS-73).

It is also very common to find fractures at the upper portion of lava flows that are filled from above by sand. The presence of unmistakable sedimentary (S_0) layering (Figure 2; point RS-73) does not leave doubt that in these cases they do not correspond to injectites. It must be stressed that we do not deny that sand injectites may be present in the region, and by no means we cast doubt on the importance of such deposits in the Paraná Magmatic Province, as properly described in several areas by Hartmann et al. (2012a, 2012b).

Moreover, we refer the readers to our work on the Ourinhos dacites in the north Paraná Province (the only occurrences of acidic volcanics that were directly deposited over the Botucatu sandstones), where we describe a series of "sand dikes" injecting from below some of the lower acidic flows (Janasi et al., 2007).

Regarding the breccias (e.g., GX18; Figure 3), we found several relatively thick deposits, mostly concentrated in an area at the south of Barros Cassal, which immediately attracted our attention. We were alerted by some colleagues about the possibility that they correspond to post-volcanic sediments correlative to the Tupanciretã Formation cited by Menegotto et al. (1968). Even though we recognized some similarities with those sediments, and we believe some outcrops in the region might well be remnants of that unit, we argue that the outcrops described below are most probably syn-volcanic based on the following evidences:

(1) These deposits have lateral gradation to sandstones (GX-19) and occur a few meters away from rhyolitic lavas of the base of Santa Maria sequence (e.g., GX-21; Table 1);
(2) Between the sandstone and lava flow outcrops cited above (GX-19 and GX-21), which are < 200 m apart, we identified peperite-type structures (e.g., outcrop GX-24) that resulted from lava-sediment interaction. The peperites feature angular fragments of glassy rhyolite dispersed in a hardened reddish fine sandstone (Figure 4) which is sometimes vesiculated. The jigsaw puzzle arrangement among the volcanic fragments reveals that the lava was fragmented *in situ* and was not reworked;
(3) At the contact between the lava flow front and the sediment occurs a network of macro and micro fractures infiltrated by sand, generated within the volcanic rock, probably in response to thermal contraction.

The origin of these syn-volcanic breccias is unclear, and its investigation would demand more extensive and systematic field studies.

Notwithstanding genetic considerations, we reemphasize our view that the sedimentary deposits cited here are important stratigraphic markers, and are often present at the contacts between chemically distinct magma-types, which suggests the existence of temporal gaps between different volcanic events.

On other hand, we acknowledge that some post-volcanic sedimentary deposits may occur in the region, such

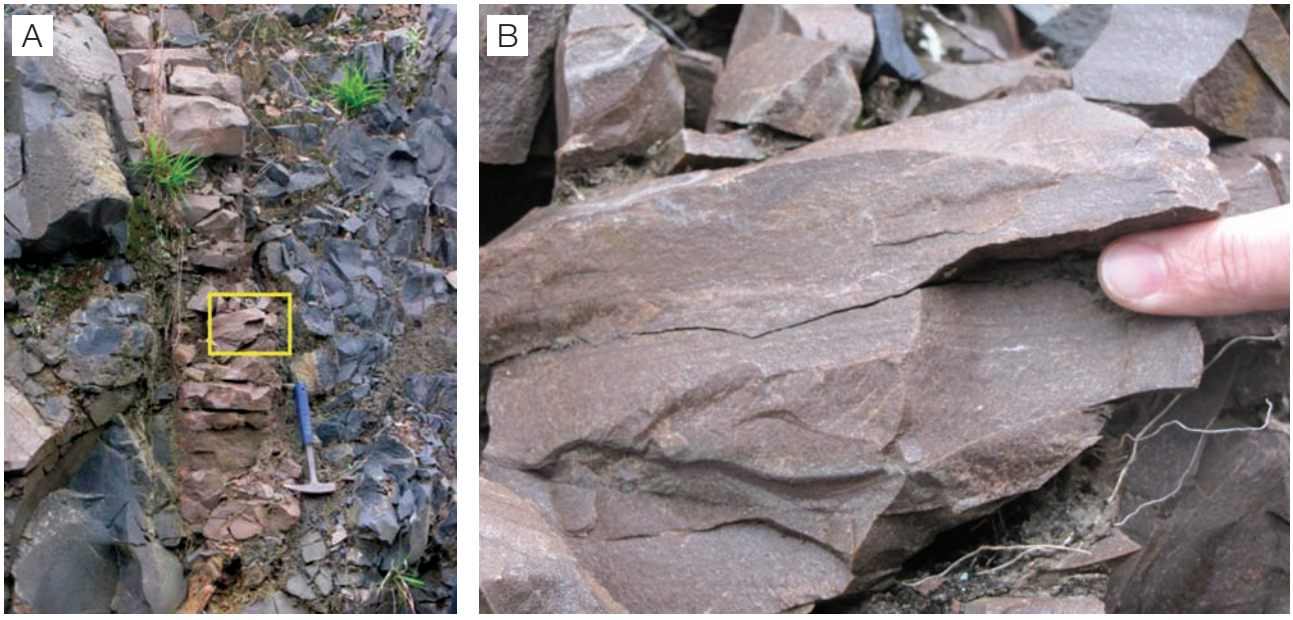

Figure 2. (A) Fracture at the upper portion of an obsidian lava flow filled from above by sand; (B) detail of (A): the presence of primary sedimentary layering (S_0) does not leave doubt that in these cases they do not correspond to injectites. Outcrop RS-73.

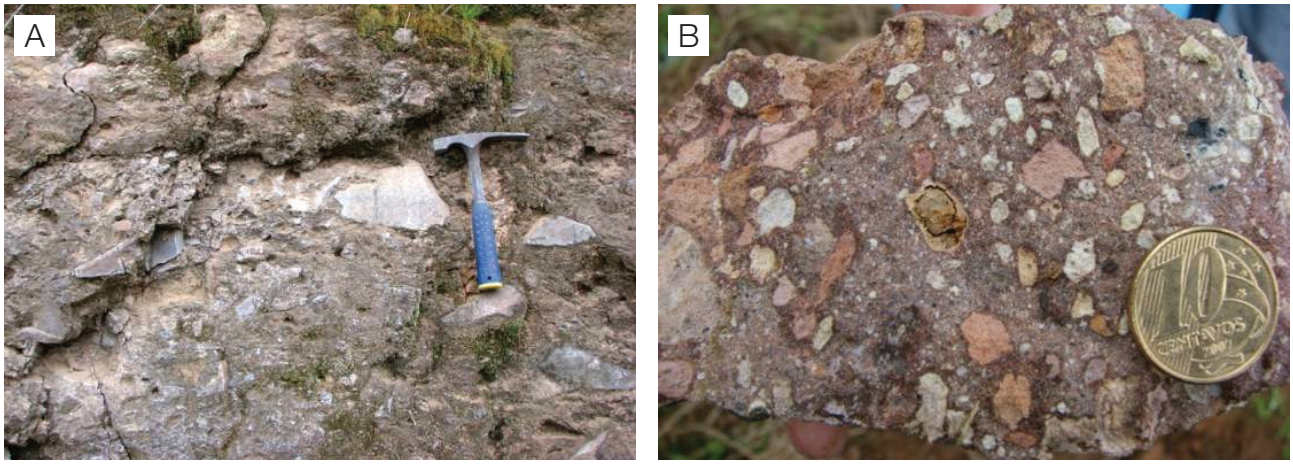

Figure 3. (A) Outcrop of volcanic breccia (GX-18); (B) detail of breccias, with irregular fragments of volcanic rocks set in a fine matrix.

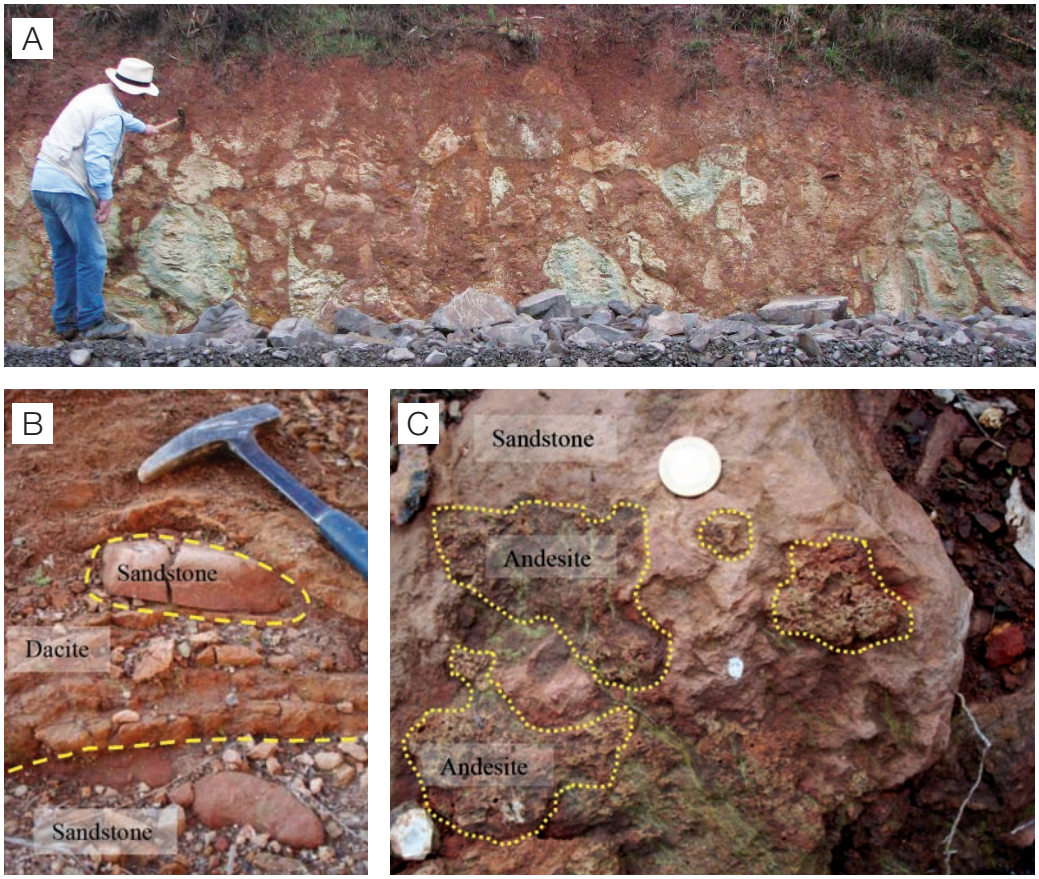

Figure 4. Structures generated by interaction of sediment with volcanic rocks. (A) peperite resulting from interaction of rhyolitic lava flows (Santa Maria Sequence) with wet and unconsolidated sediments (outcrop GX-24). Although the deposits are largely altered the color contrast between the fragments of glassy materials (usually white to light pink) and the red sand allows an easy recognition of the structures; (B) sandstone fragment within the dacitic lava flow; note that lava accommodated around the fragment. The yellow line marks the contact of dacitic lava over sediment substrate; (C) irregular fragments of volcanic rock (andesite) within a sediment layer that occurs between two BCS lava flows.

as sandstones and conglomerates cropping out to the east of the mapped area (e.g., GX-38) which do not have clear relationships with lava flows, and also a thick sedimentary package with conglomeratic facies that appears at the south of Barros Cassal (GX139). Their possible correlation the Tupanciretã Formation deserves further investigation.

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