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- SHORT NOTE - FINDINGS OF INTRAFORMATIONAL STRIATED PAVEMENTS IN THE LATE CARBONIFEROUS GLACIAL DEPOSITS OF THE ANDEAN PRECORDILLERA, ARGENTINA

Pablo J. ALONSO MURUAGA [1-5], Carlos O. LIMARINO [1-5], Luis A. SPALLETTI [2-5], Ferrán COLOMBO PIÑOL [3], Pablo JUÁREZ [4]

[1] Dto. de Geología, Facultad de Ciencias Exactas y Naturales (Universidad de Buenos Aires), Pabellón 2, Ciudad Universitaria,1428 Buenos Aires, Argentina.
[2] Centro de Investigaciones Geológicas, calle 1 # 644, La Plata, Argentina.
[3] Departamento Estratigrafia, Paleontología i Geociencies Marines, Facultat Geologia, Unversitat de Barcelona, C/Martí i Franqués s/n, E-08028, Barcelona, España.
[4] Facultad de Ciencias Naturales e Instituto Miguel Lillo, Universidad Nacional de Tucumán, 4000 San Miguel de Tucumán, Argentina.
[5] CONICET.

INTRODUCTION

One of the most important glacial events in the history of the Earth took place during the Late Paleozoic when large areas of the Gondwana Supercontinent were covered by ice-masses (Crowell, 1978; Hambrey and Harland, 1981; Isbell *et al*., 2003a,b; Rocha Campos *et al*., 2008; Fielding *et al*., 2008; López Gamundí, 2010). Though this glacial event was initially considered a large and unique episode spanning a great part of the Carboniferous and Permian in Gondwana, new geological evidence suggests that the glacial period was not continuous, but rather punctuated by several interglacial events. In this way, López Gamundí (1997) and later Isbell *et al*. (2003b) divided the Late Paleozoic Ice Age (LPIA) into four major glacial intervals corresponding to the Early Carboniferous (LPIA 1), Late Carboniferous-Early Permian (LPIA 2), Early Permian (LPIA 3) and Late Permian (LPIA 4). This division adequately describes the record of the glacial deposits in Gondwana and allows for the proposal of a general stratigraphy for the glacial deposits demonstrating the existence of low-frequency climatic changes.

In this paper we describe two subglacial basal contact surfaces found in the lower part of the Guandacol Formation (Frenguelli, 1944; Cuerda, 1965) in the Central Precordillera (northwestern Argentina). The Guandacol Formation is well known for containing glacial deposits, including diamictites and resedimented diamictites at the lower third of the unit (Limarino *et al*., 2006; Marenssi *et al*., 2002; Marenssi *et al*., 2005). According to paleontological (palynological) information, and some radiometric dating, the age of the glacial deposits is Late Visean-Early Bashkirian and therefore fits into the LPIA 2 interval of Isbell *et al*. (2003b).

The presence of intraformational glacial pavements in the Guandacol Formation allows for a more precise history of the LPIA 2 glacial interval suggesting that interglacial periods not only separated low-frequency climatic changes (LPIA intervals) but also were likely present within individual LPIA periods (high-frequency climatic changes). In addition, palynological data and radiometric evidence is discussed in order to be more precise about the age of the intraformational pavements.

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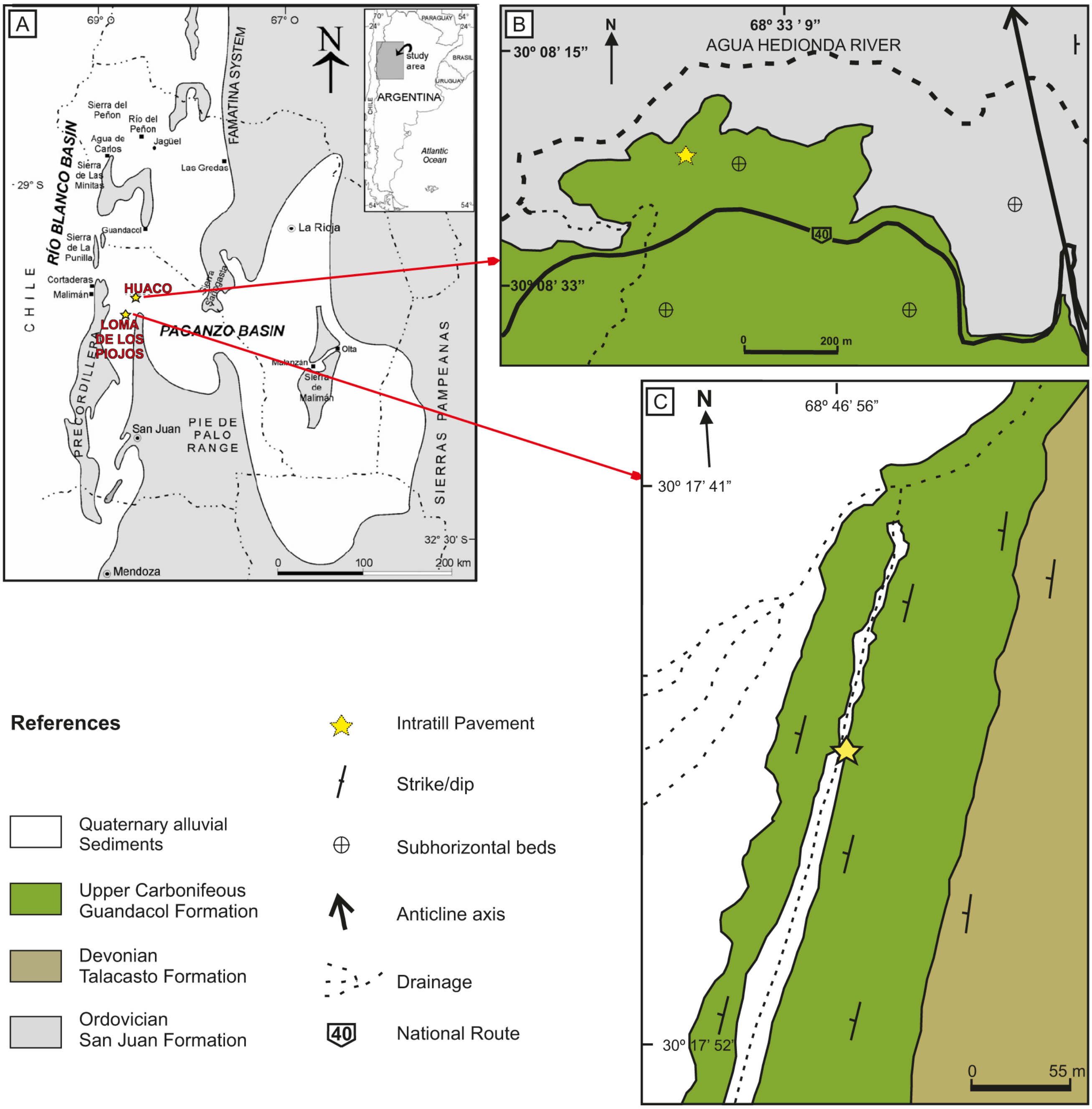

Figure 1: a) Late Paleozoic paleogeography of the Paganzo Basin showing the location of the Huaco and Loma de Los Piojos areas (modified after Salfity and Gorustovich, 1983). b) Geologic map of the Huaco Anticline area. c) Geologic map of Loma de Los Piojos area. Stars show the location of intraformational striated pavements.

PAVEMENT DISTRIBUTION AND DESCRIPTION

Intraformational pavements of the Guandacol Formation were recorded in two localities in the Central Precordillera of Argentina (Fig. 1a): Huaco anticline and Loma de Los Piojos areas.

Huaco Anticline Area

In this area, Carboniferous rocks rest uncoformably on Ordovician limestones of the San Juan Formation and all the Paleozoic deposits are folded into a N-S oriented anticline (Fig. 1b). The best exposures of the Guandacol Formation follow both limbs of the anticline, and are also near the axis of the fold where the beds rest subhorizontally over Ordovician limestones. Following Limarino *et al.* (2002) the Guandacol Formation can be subdivided in two sections. The lower section (Fig. 2) comprises

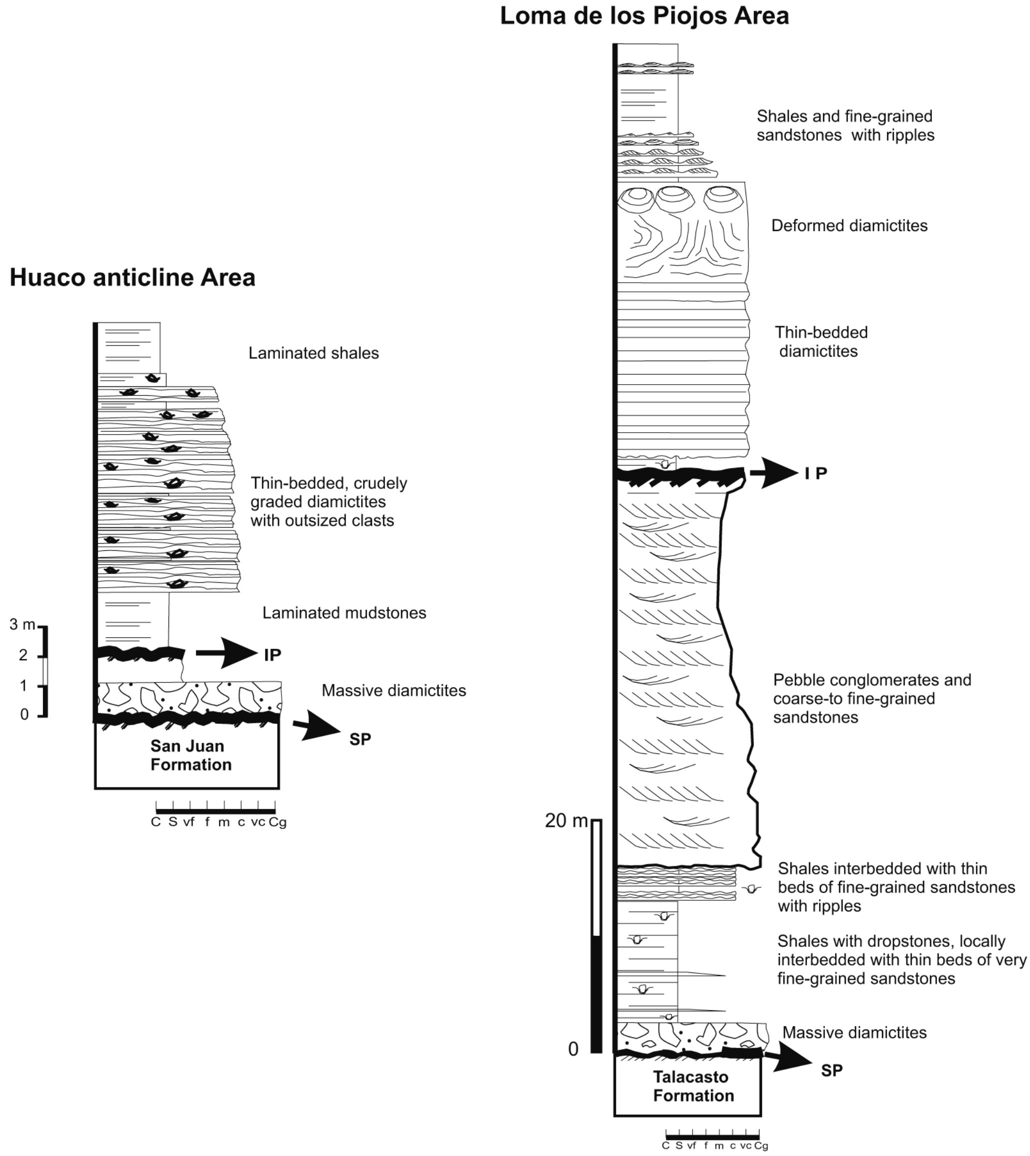

Figure 2: Glacial sections of Loma de Los Piojos and Huaco Anticline area showing the location of the intraformational striated pavements (**IP**) and the basal striated pavements (**SP**).

mudstones, sandstones, scarce conglomerates and several beds of diamictites located near the base of the unit (Limarino *et al*., 2002). Moreover, striated pavements (Fig. 2) carved into Ordovician limestones (San Juan Formation) were described by López Gamundí and Martínez (2000) and Marenssi *et al*. (2005). This section has been interpreted as being deposited within glacial and fjord environments (Pazos, 2000; López Gamundí and Martínez, 2000; Marenssi *et al*., 2005).

The upper section of the Guandacol Formation is mainly composed of fine-grained sandstones, shales and mudstones deposited during a postglacial marine transgression that flooded glacial valleys forming fjord environments (Limarino *et al*., 2002).

Intraformational Striated Pavement. The pavement identified in the Huaco area consists of a striated surface of about 6 m^2 exposed subhorizontally in the outcrops between Agua Hedionda river and National Road 40 (the exact location is S 30° 8' 23.4"; W 68° 33' 14.2"). The pavement is developed over a massive bed of pebbly muddy sandstone (Fig. 2) that laterally grades into siltstones with isolated clasts of coarse-grained sandstones. The striated surface is overlain by massive siltstones and claystones, which contain clasts of pebble, cobble, and boulder sizes. The surface is undulated resembling the whaleback landform with ridges and grooves parallel to the axis of undulation (Fig. 3a). Ridges and furrows are continuous, approximately 1.5 m long, locally

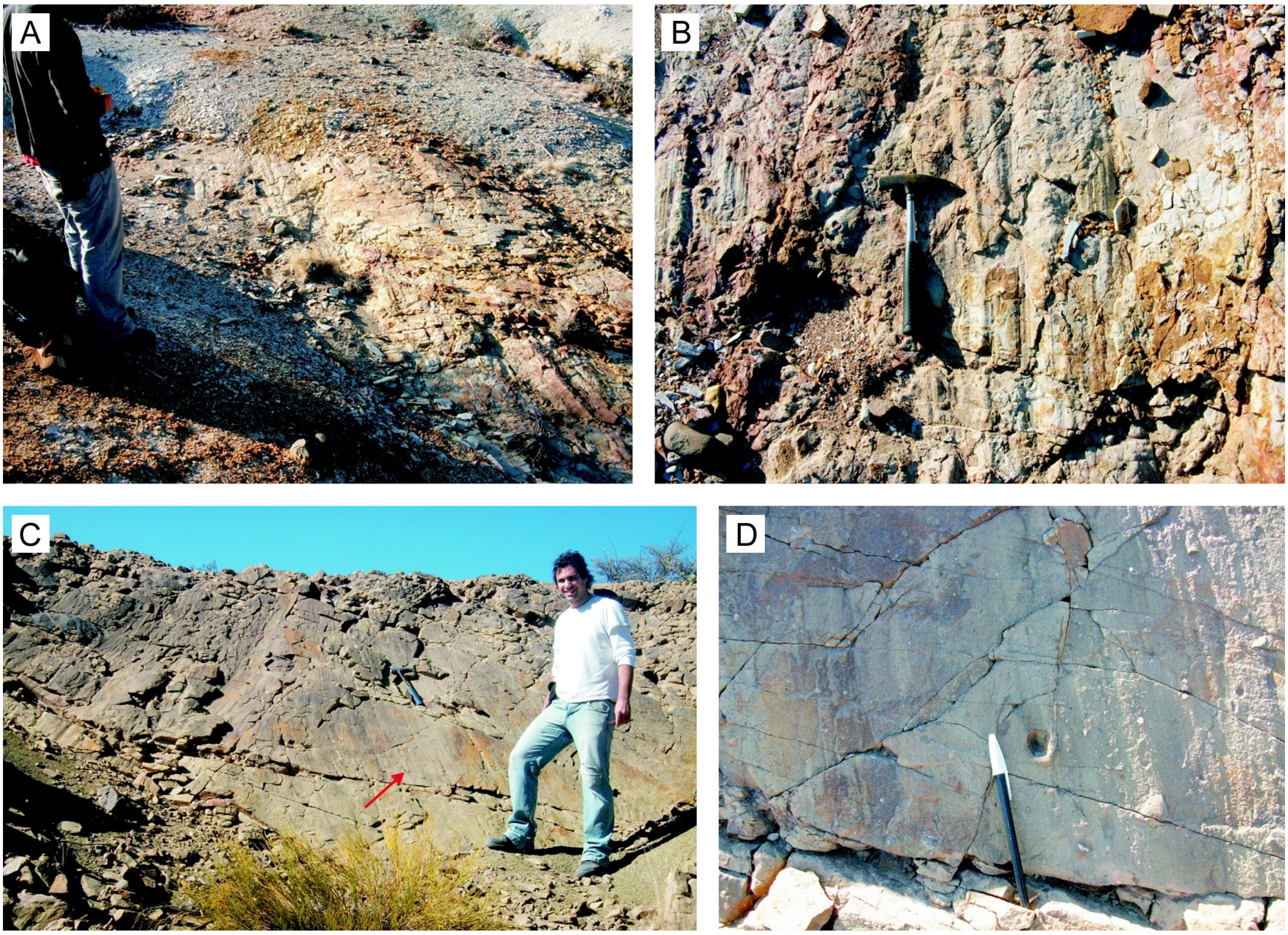

Figure 3: a) Cuesta de Huaco intraformational striated pavement (note the whaleback morphology). b) Detail of the linear structures in the surface. c) Loma de Los Piojos intraformational striated pavement (red arrow points to slipped clast mould). d) Detail of the slipped clast mould.

associated with parallel to subparallel millimetric striations (Fig. 3b). The striations show a mean azimuth of 305º-125º but no clear evidence of sense of ice flow was indentified.

Loma de los Piojos Area

In the Loma de Los Piojos area, the Guandacol Formatión lies in sharp contact over Devonian sandstones and mudstones of the Talacasto Formation (Fig. 1c). The strike of the outcrops is almost north–south, dipping to the west at 15º-25º. The Guandacol Formation in this area (Fig. 2) is mainly composed of mudstones, diamictitic lenses, thin-bedded diamictites, thin beds of fine-grained sandstones, clast- to matrix-supported pebble conglomerates and poorly sorted, coarse-grained sandstones. The beds locally show abundant soft-sediment deformation. Dropstones, in shale beds, are also present. A basal striated pavement was carved into Devonian sandstones (Talacasto Formation) and covered by the basal deposits of the Guandacol Formation (López Gamundí and Martínez, 2000).

Intraformational Striated Pavement. The intraformational striated pavement was developed over a medium- to coarse-grained sandstone oriented N 16º E and dipping 50º NW. It consists of isolated striated surfaces, some of which reach a maximum area of 9 m² (Fig. 3c). They are all part of a single pavement that can be followed along the strike for at least 70 meters. Some surfaces show very low amplitude undulations, with striations oriented oblique and subparallel to the axis of the main undulations. Paleoice flow direction data was obtained, from the orientations of each of the striae from the inclined bed. The restored striations indicate an azimuth of 290º-110º. Although no clear indicators of ice flow

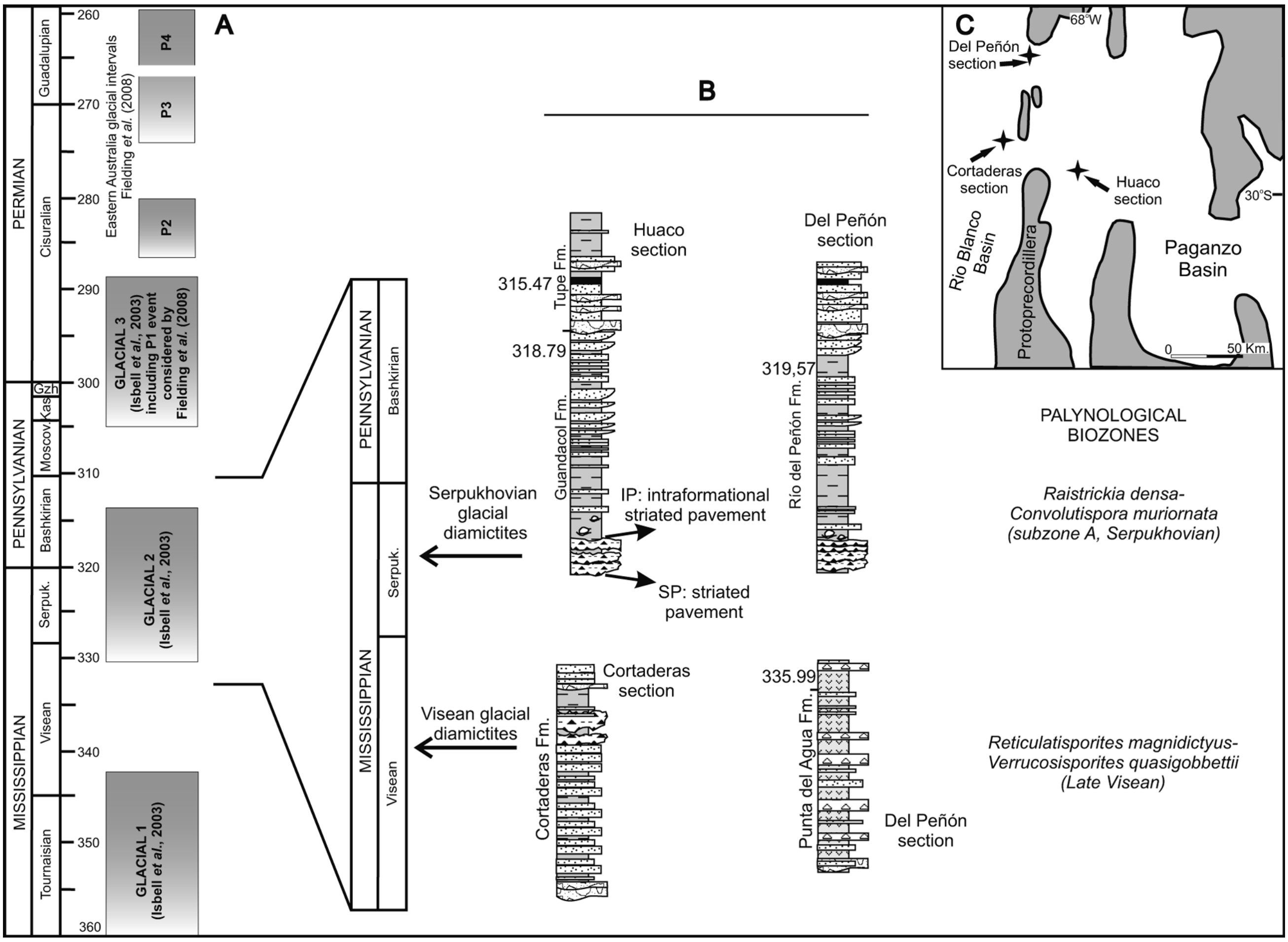

Figure 4: Stratigraphic position and age of the intraformational striated pavement identified in the Guandacol Formation. Note that these glacial deposits are younger than those of the Cortaderas Formation. a) Glacial intervals proposed by Isbell *et al.* (2003a) and Fielding *et al.* (2008). b) Schematic stratigraphic sections of Huaco and Del Peñón showing radiometric ages and palynological biozones. c) Location of the localities mentioned in the text.

direction could be inferred, a slipped clast mould (Fig. 3d) present in the striated surface suggests paleoice flow towards the west.

AGE OF THE GLACIAL EVENT

The glacial event that affected the whole of Gondwana during the Late Paleozoic is probably the most extended glacial era recorded during the Phanerozoic. Initially, the glacial event was described as a long-lived ice age of several tens of millions of years (60 m.y.-80 m.y.) punctuated by brief interglacial periods. However, the growing up knowledge of the Late Paleozoic glaciation evidenced a much more complex history of the glacial era (Isbell *et al.* 2003a,b; Limarino *et al.*, 2006; Fielding *et al.*, 2008). Isbell *et al.* (2003a) recognized three major glacial episodes during the latest Devonian-early Mississippian, Late Mississippian-Early Pennsylvanian and latest Pennsylvanian-early Cisuralian. A later work by Fielding *et al.* (2008) added three glacial periods during the middle Cisuralian and Guadalupian, but they show lesser areal extent along Gondwana and are mainly recorded in Australia.

Following the model proposed by Isbell *et al.* (2003a) and Fielding *et al.* (2008) the glacial diamictites considered in this paper correspond to the glacial stage 2 which encompasses from the Late Mississippian to the Early Pennsylvanian. This age is suggested by both paleontological and chronostratigraphic studies. In this regard, the interval of the Guandacol Formation including the intraformational striated pavements yields abundant palynological assemblages in the Cuesta de Huaco area (Césari and Vázquez Nístico, 1988; Pérez Loinaze, 2007; Pérez Loinaze *et al.*, 2010).

The palynofloras were obtained from different stratigraphic levels all which overlie the basal striated pavement and are disposed under and above the intraformational striated pavement (Fig. 2). According to Pérez Loinaze *et al.* (2010) the palynological assemblages belong to the Subzone A of the *Raistrickia densa-Convolutuispora muriornata* Biozone which suggests a Serpukhovian age for the glacial diamictites (Fig. 4).

This age is consistent with new radiometric information obtained by Gulbranson *et al.* (2010) in the Punta del Agua and Guandacol Formations (Fig. 4). There, a $^{206}Pb/^{238}U$ 335.99 ± 0.06 Ma age was obtained for andesites unconformably covered by glacial diamictites, suggesting that glacial deposits of the Guandacol Formation are not older than the mid-late Visean (Césari *et al.*, 2011). In the Huaco area, the Guandacol Formation yielded an age of $^{206}Pb/^{238}U$ 318.79 ± 0.10 Ma (Fig. 4) from tuff levels intercalated in postglacial shales free of dropstones and lacking any evidence of glacial processes. This age indicates that during the middle Bashkirian glacial conditions ceased in the studied region. In short, palynological and radiometric ages are consistent and suggest that glacial deposits, including the intraformational pavement considered here, correspond to the glacial stage 2 of Isbell *et al.* (2003a).

It is interesting to note that glacial deposits considered in this paper are younger than those found in the Cortaderas Formation in the neighboring Río Blanco Basin, which are characterized by palynological assemblages belonging to the *Reticulatisporites magnidictyus-Verrucosisporites quasigobbettii* Biozone of late Visean age (Pérez Loinaze *et al.*, 2010, Fig. 4). These glacial diamictites may correspond to the onset of the glacial stage 2 in western Gondwana separated by an interglacial period from the above considered diamictites of the Guandacol Formation (Fig. 4).

CONCLUSIONS

The following conclusions can be drawn from the data presented in this paper:

1. The presence of intraformational striated pavements is for the first time stablished in the Guandacol Formation in Cuesta de Huaco and Loma de Los Piojos localities.

2. According to radiometric data, the striated pavements are not older than middle late Visean and not younger than middle Bashkirian. Moreover, palynological remains, obtained in the glacial sequence, are consistent with radiometric information and suggest a late Serpukhovian age for the studied horizons. Therefore the striated pavements belong to the LPIA 2 glacial event.

3. These striated pavements strongly suggest episodes of advance and retreat of ice during the glacial event in the Paganzo Basin, which was previously suggested by López Gamundí and Martínez (2000) and Marenssi *et al*. (2002, 2005).

4. The age of the striated pavements identified in the Guandacol Formation is similar to the intraformational striated pavement reported by González (1981) from the Hoyada Verde Formation (Calingasta-Uspallata Basin). Whether or not these surfaces mark a major retreat-advance glacial episode in the region should be considered as a possibility. However the exact correlation among Huaco, Loma de Los Piojos and Barreal (Hoyada Verde Formation) based on the identification of subglacial basal contact surfaces will have to be confirmed in the future when more paleontological and radiometric data become available.

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REFERENCES

Césari, S.N. and **B. Vázquez-Nístico**, 1988. Palinología de la Formación Guandacol (Carbonífero), provincia de San Juan, República Argentina. *Revista Española de Micropaleontología* 20:39-58.

Césari, S.N., **C.O. Limarino** and **E.L. Gulbranson**, 2011. An Upper Paleozoic biochronostratigraphic scheme for the western margin of Gondwana. *Earth-Science Reviews* 106:149-160.

Crowell, J.C., 1978. Gondwanan glaciation, cyclothems, continental positioning and climate change. *American Journal of Science* 278:1345-1372.

Cuerda, A., 1965. Estratigrafía de los depósitos neopaleozoicos de la Sierra de Maz, Provincia de la Rioja. *II Jornadas Geológicas Argentinas*, Acta III:79-84.

Fielding, C.R., **T.D. Frank** and **J.L. Isbell**, 2008. *Resolving the Late Paleozoic Ice Age in Time and Space*. Geological Society of America, Special Paper 441, 354 pp.

Frenguelli, J., 1944. Apuntes acerca del Paleozoico Superior en el noroeste argentino. *Revista Museo de La Plata*, Sección Geología II:213-265.

González, C.R., 1981. Pavimento glaciario en el Carbónico de la Precordillera. *Revista de la Asociación Geológica Argentina* 36: 262-266.

Gulbranson, E.L., **I.P. Montañez**, **M.D. Schmitz**, **C.O. Limarino**, **J.L. Isbell**, **S.A. Marenssi** and **J.L. Crowley**, 2010. High-precision U-Pb calibration of Carboniferous glaciation and climate history, Paganzo Group, NW Argentina. *Geological Society of America Bulletin* 122:1480-1498.

Hambrey, M. and **W. Harland**, 1981. *Earth's Pre-Pleistocene Glacial Record*. Cambridge University Press, Cambridge, 1044 pp.

Isbell, J.L., **P.A. Lenaker**, **R.A. Askin**, **M.F. Miller** and **L.E. Babcock**, 2003a. Reevaluation of the timing and extent of late Paleozoic glaciation in Gondwana: Role of Transantarctic Mountains. *Geology* 31:977-980.

Isbell, J.L., **M.F. Miller**, **K.L. Wolfe** and **P.A. Lenaker**, 2003b. Timing of late Paleozoic glaciation in Gondwana: Was glaciation responsible for the development of northern hemisphere cyclothems? In Chan, M.A. and A.A. Archer (Eds.), *Extreme Depositional Environments: Mega End Members in Geologic Time*. Geological Society of America, Special Paper 370:5-24.

Limarino, C.O., **S.N. Césari**, **L.I. Net**, **S.A. Marenssi**, **P.R. Gutiérrez** and **A. Tripaldi**, 2002. The Upper Carboniferous postglacial transgression in the Paganzo and Río Blanco Basins (northwestern Argentina): facies and stratigraphic significance. *Journal of South American Earth Sciences* 15:445-460.

Limarino, C.O., **A. Tripaldi**, **S.A. Marenssi** and **L. Fauqué**, 2006, Tectonic, sealevel, and climatic controls on Late Paleozoic sedimentation in the western basins of Argentina: *Journal of South American Earth Sciences* 22: 205-226.

López Gamundí, O.R., 1997. Glacial-postglacial transition in the Late Paleozoic basins of southern South America. In Martini, I.P. (Ed.), *Late Glacial and Postglacial Environmental Changes-Quaternary, Carboniferous–Permian, and Proterozoic*. Oxford University Press, New York, 147-168.

López Gamundí, O.R., 2010. *Transgressions related to the demise of the Late Paleozoic Ice Age: Their sequence stratigraphic context*. Geological Society of America, Special Paper 468:1-35.

López-Gamundí, O.R. and **M. Martínez**, 2000. Evidence of glacial abrasion in the Calingasta-Uspallata and western Paganzo basins, mid-Carboniferous of western Argentina. *Palaeogeography, Palaeoclimatology, Palaeoecology* 159:145-165.

Marenssi, S.A., **A. Tripaldi**, **A.T. Caselli** and **C.O. Limarino**, 2002. Hallazgo de tillitas sobre el flanco occidental del anticlinal de Agua Hedionda (Provincia de San Juan): evidencias de avances y retrocesos del hielo durante la glaciación gondwánica en la Cuenca Paganzo. *Revista de la Asociación Geológica Argentina* 54:349-352.

Marenssi, S.A., **A. Tripaldi**, **C.O. Limarino** and **A.T. Caselli**, 2005. Facies and architecture of a Carboniferous grounding-line system from the Guandacol Formation, Paganzo Basin, Northwestern Argentina. *Gondwana Research* 8:187-202.

Pazos, PJ., 2000. Trace fossils axid facies in glacial to postglacial deposits from the Paganzo Basin, (late Carboniferous), central Precordillera, Argentina. *Ameghiniana* 37:23-38.

Pérez Loinaze, V.S., 2007. *Análisis bioestratigráfico sobre la base de estudios palinológicos de la transición Mississippiano - Pennsylvaniano en secuencias de las provincias de San Juan y La Rioja.* Ph.D. Thesis. Universidad de Buenos Aires, Facultad de Ciencias Exactas y Naturales, 550 pp.

Pérez Loinaze, V.S., **C.O. Limarino** and **S.N. Césari**, 2010. Glacial events in Carboniferous sequences from Paganzo and Río Blanco Basins (Northwest Argentina): Palynology and depositional setting. *Geologica Acta* 8:399-418.

Rocha Campos, A.C., **P.R. dos Santos** and **J.R. Canuto**, 2008. Late Paleozoic glacial deposits of Brazil: Paraná Basin. In Fielding, C.R., T.D. Frank and J.L. Isbell (Eds.), *Resolving the Late Paleozoic Ice Age in Time and Space*. Geological Society of America Special Paper 441:97-11.

Salfity, J.A. and **S.A. Gorustovich,** 1983. Paleogeografía de la Cuenca del Grupo Paganzo (Paleozoico Superior). *Revista de la Asociación Geológica Argentina* 38:437-453.