

**- SHORT NOTE -**  
**GLACIAL DEPOSITS IN THE RIO DEL PEÑÓN FORMATION**  
**(LATE CARBONIFEROUS), RIO BLANCO BASIN,**  
**NORTHWESTERN ARGENTINA**

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### INTRODUCTION

The Río del Peñón Formation (Borrello, 1955 nom. subst. González y Bossi, 1986) forms the upper part of the late Paleozoic outcropping in the Río Blanco anticline (northwest Precordillera, La Rioja Province). This unit is predominantly composed of a thick (1270 m.) sandstone and mudstone sequence including thin levels of coal and scarce conglomerates (Scalabrini Ortiz, 1972; Scalabrini Ortiz and Arrondo, 1973; González and Bossi, 1986). These deposits represent a complex interfingering of shallow marine and fluvial deposits recording relative sea-level fluctuations during the Late Carboniferous-Early Permian. The Río del Peñón Formation overlies andesites and volcanic breccias of the Punta del Agua Formation (Fig. 1 and 2a).

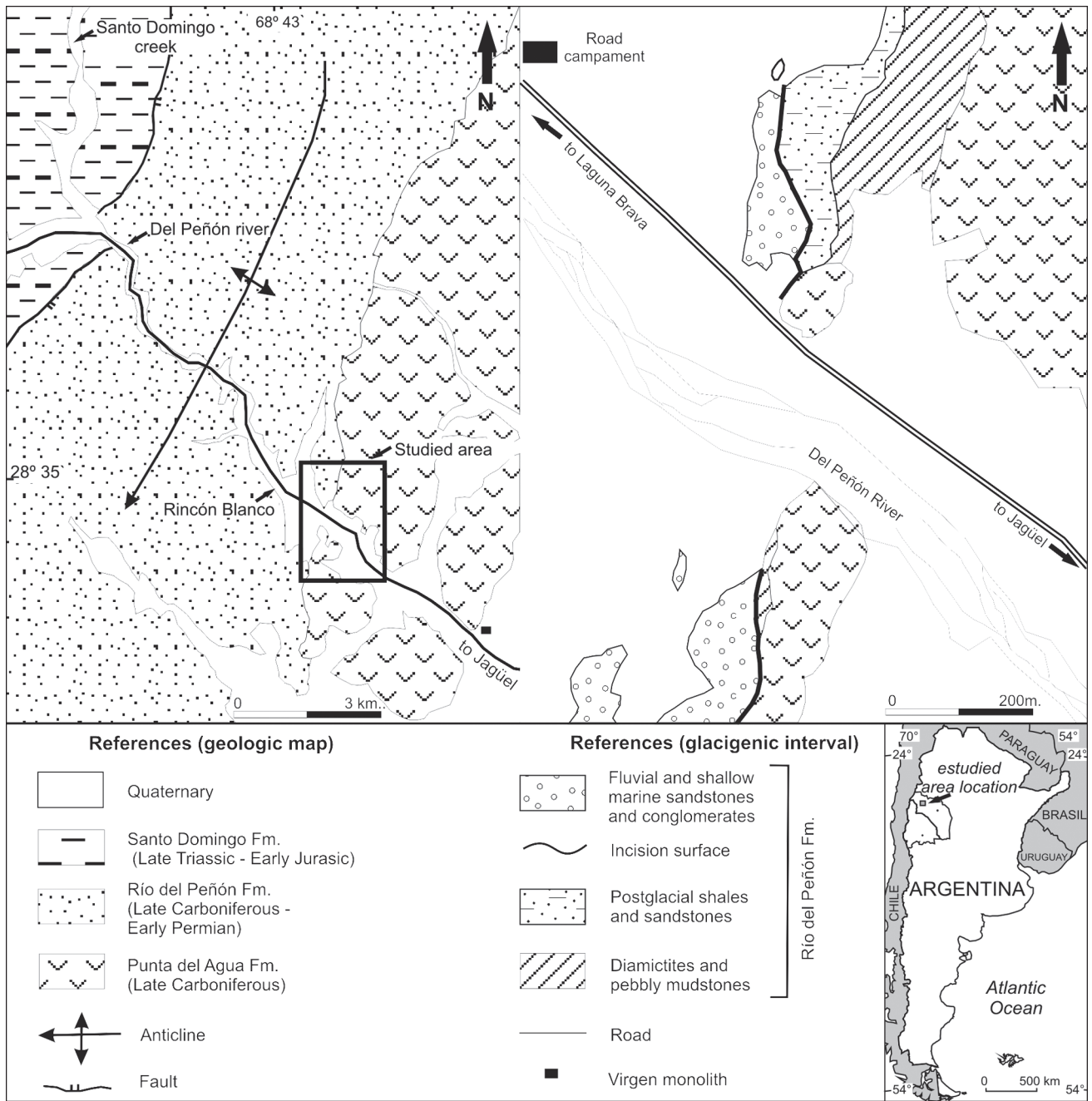
Despite well known Late Carboniferous glacial deposits from different localities within the Precordillera (López Gamundí, 1987, 1997; López Gamundí and Martínez, 2000; Marenssi *et al.*, 2004; Limarino and Spalletti, 2006; Henry *et al.*, in press), glaciogenic deposits have not been reported from the Río del Peñón Formation. This documentation of glacial-related sediments in this succession serves to further constrain our knowledge of the temporal and paleogeographic distribution of Gondwanan glacial deposits.

### THE GLACIGENIC DEPOSITIS

Previous studies have interpreted the Río del Peñón succession as deposited in fluvial, transitional and ma-

rine environments (Scalabrini Ortiz and Arrondo, 1973, González and Bossi, 1986; Limarino *et al.*, 1996). This association of facies appropriately characterizes most of the formation and, indeed, describes the whole of the sequence to the South of the del Peñón River. However, to the North, the basal part of the Río del Peñón succession is composed of diamictites and shales (Fig. 1). These basal units compose the glacial interval described in this paper and they were likely overlooked previously because diamictites are lacking or poorly exposed to the South of the del Peñón River. The glacial interval is well exposed to the North of the study area but progressively thins towards the South where a high-relief erosive surface separates the diamictitic interval below from shallow marine and fluvial sediments above (Fig. 1). In this way, to the North of the del Peñón River, the glacial interval reaches a maximum thickness of 80 m but it thins progressively to the South due to truncation. The erosive surface eroding the glacial interval (Fig. 2b) cuts stratigraphically downward to the South where it is developed on fine-grained shallow marine sandstones overlain by medium and coarse-grained fluvial sandstones.

The glacial and early post-glacial deposits can be informally divided into four major components: (1) various diamictite types, (2) pebbly mudstones, (3) laminated shales, and (4) interbedded mudstones and sandstones. Overall, the glacial interval was deposited in a marine environment as indicated by the presence of marine invertebrates, thick levels of laminated shales and wave-cross laminated sandstones.



**Figure 1.** Geologic map showing the distribution of the glacial interval.  
**Figura 1.** Mapa geológico mostrando la distribución del intervalo glacigénico.

**Diamictites:** The basal deposits of the Río del Peñón Formation are composed of massive matrix-supported diamictites, stratified matrix-supported diamictites, stratified clast-supported diamictites and laminated pebbly mudstones. Massive matrix-supported diamictites are the more abundant lithology forming irregular, occasionally amalgamated beds up to 2 m thick. Clasts to matrix (clay and silt) ratio ranges from 0.25 to

0.40 including locally derived (andesitic) boulders up to 1.5 m in length (Fig. 2c). Smaller, granite, sandstone and low-grade metamorphic clasts were also recognized but are less common (Fig. 2d). Although striated clasts are rare, the presence of faceted and/or polygonal clasts is commonly observed. Characteristically, stratification features are lacking in this type of diamictite.

Stratified matrix-supported diamictites occur as tab-

ular isolated beds up to 0.5 m thick showing smaller clast-size diameters (up to 20 cm) and higher clast to matrix ratio (from 0.30 to 0.70). Another feature of this type of diamictite is a tendency to a more diverse clast composition. Indeed, clasts of sandstone, volcanic and lower-grade metamorphic rocks occur in subordinate quantities together with minor proportions of granitic and quartzose clasts. Despite a predominance of subrounded to rounded clast textures, faceted polygonal clasts are also common. Beds exhibit two main types of stratification, first, normally graded layers and second, poorly defined horizontal (or low-angle) stratification that consist of alternating matrix-rich and clast-rich laminae.

Stratified clast-supported diamictites are less common, they define irregular or lenticular beds (up to 40 cm thick) composed of up to 20 cm maximum-diameter clasts immersed in a fine-grained sandy to silty matrix. Matrix to clast ratio is higher than 0.70 and the clast composition is similar to the previously described matrix-supported stratified diamictites. These deposits exhibit diffuse horizontal stratification and normally graded layers.

Diamictites can be roughly grouped into two different genetic types. Genetic type-1, deposited directly by ice action without measurable reworking of clasts, consists of the massive matrix-supported diamictites. Massive diamictites can form by a number of different processes in glacial settings. These include subglacially (where they are often sheared and the clast are preferentially oriented parallel to flow), from abundant (ice proximal) rainout (combination of settling from meltwater plumes and ice berg rafting), abundant icerafting, debris flow, and iceberg or sea ice keel turbation. However, at least part of the massive matrix-supported diamictites recorded at the Río del Peñón can be interpreted to be tillites deposited in a subaqueous environment. The second group consists of stratified matrix- and clast-supported diamictites. Stratified diamictites can also form from a number of different processes in glacial settings. These include rain out (combination of settling from meltwater plumes and ice berg rafting), ice rafting (ice berg and sea ice), debris flow, and from a combination of ice rafting and bottom currents. The stratification features indicate subaqueous reworking by currents and/or gravity processes as recorded by horizontal (or low-angle) stratification, graded layers, increase in the clast/matrix ratio, and the overall coarser grain-size of the matrix fraction (very fine sand to silt).

**Pebbly mudstones:** laminated pebbly mudstones occur as repeated stratigraphic intervals intercalated with the various diamictite types. This facies forms tabular and occasionally deformed beds ranging in thickness from 10 cm to 100 cm. The deposits consist of laminated mudstones with isolated large clasts of up to 10 cm in diameter (dropstones) that deform or interrupt the lamination (Fig. 2e,f). Clast proportion varies from 2 to 15%, and pass gradationally into the aforementioned stratified matrix-supported diamictites. This gradation might suggest that these two are related possibly due an increase in rain out for the stratified diamictites (closer to the ice front) vs. laminated mudstones occurring either farther from the front or in areas protected from icebergs.

These pebbly mudstones are interpreted to have been formed by two different processes. Subtle changes in the rate of settling of fine particles in a low energy environment formed laminated layers. Sporadic input of large clasts from icebergs or sea-ice impacted the bottom deforming or interrupting the horizontal lamination.

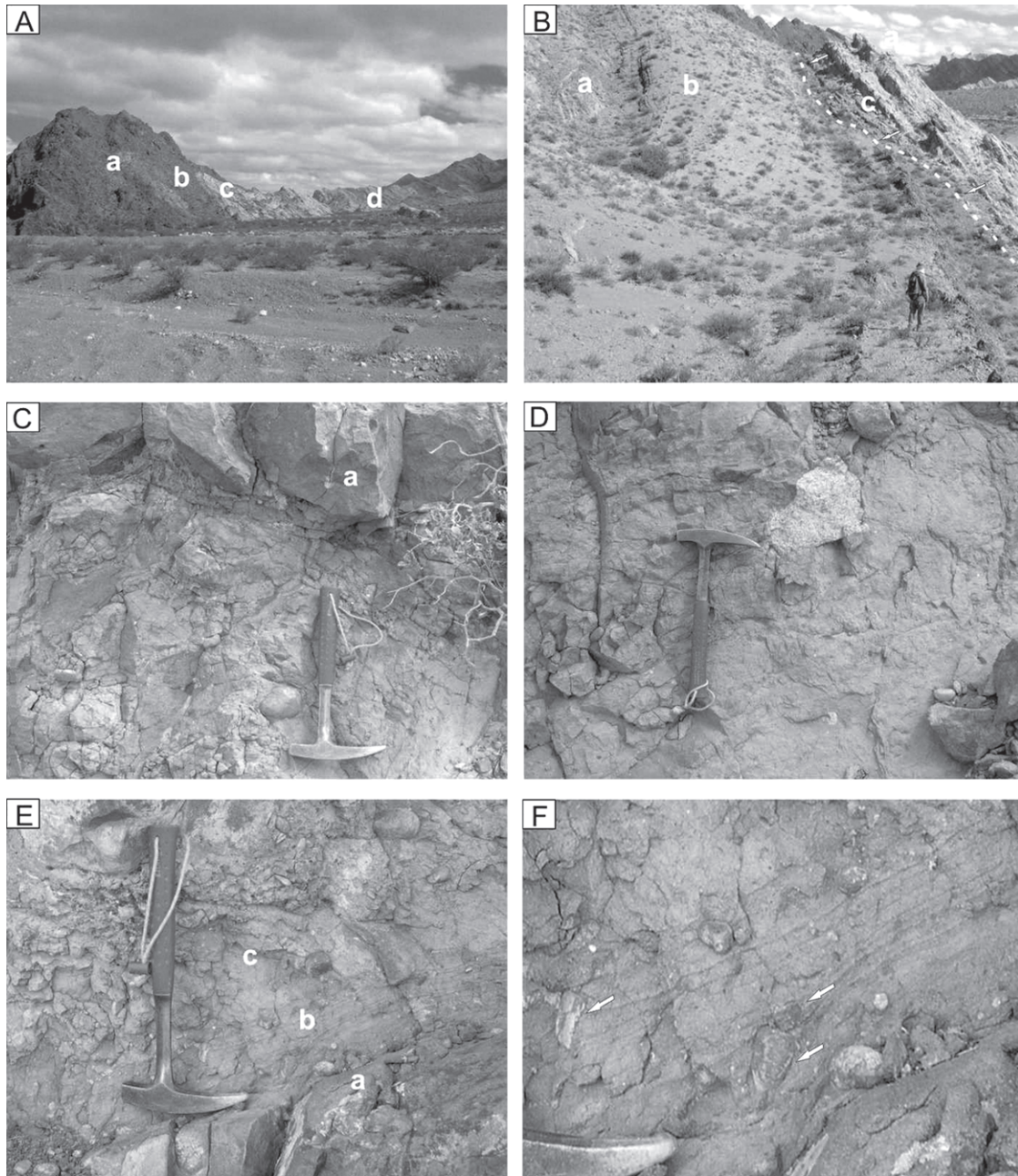
**Laminated shales:** Fine-grained laminated sediments without dropstones overlie various diamictite types and pebbly mudstones. Laminated shales are composed of homogeneous fine-grained deposits reaching a maximum thickness of 30 meters. Within this interval, thin (< 5 cm thick) tabular beds of very fine-grained laminated or massive sandstones and massive marls are sporadically intercalated.

**Interbedded sandstones and mudstones:** The number and thickness of individual fine-grained sandstones and laminated shales increases progressively upward into the overlying coarsening-upward succession of interbedded sandstones and mudstones. The coarsening-upward successions, up to 50 m thick, consist of massive, wave cross-laminated or rarely cross-bedded, fine to medium-grained sandstones stratified in tabular beds up to 15 cm thick. Poorly preserved plant remains occur rarely in sandy beds. Bioturbated sandstone deposits occur in the upper part of the succession.

Mudstones form both massive and laminated beds ranging in thickness from few centimeters up to 40 cm. Marine invertebrates and palynomorph assemblages have been recovered from these rocks.

The rhythmic alternation of sandstones and mudstones beds, the coarsening-upward pattern of these





**Figure 2.** a) General view of the Punta del Agua section at the south of the del Peñón river (references, (a) Punta del Agua Formation, (b) conglomerates and shales, (c) fluvial sediments covering the incision surface described in the text and (d) transgressive marine deposits. b) View at the north of the del Peñón river of the glacial interval (a), succeeded by shales and interbedded sandstones and mudstones (b) exhibiting erosion by the incision surface (arrows). Note shallow marine and fluvial sandstones covering the erosive surface (c). c) Large andesitic clasts (a, up to 1.5 m), of the underlying Punta del Agua Formation, within chaotic diamictitic levels d) Massive matrix-supported diamictites showing granitic clasts. e) Two levels of massive matrix-supported diamictites (a and c) separated by a thin interval of laminated pebbly mudstones bearing dropstones (b). f) Detail of the outcrop shown in E exhibiting dropstones interrupting and deforming laminae (arrows).

**Figura 2.** a) Vista general del perfil de Punta del Agua al sur del río del Peñón (referencias, (a) Formación Punta del Agua, (b) conglomerados y pelitas, (c) sedimentitas fluviales cubriendo la superficie de incisión descrita en el texto, y (d) depósitos marinos transgresivos. b) Vista del intervalo glacial hacia el norte del río del Peñón (a), seguido por pelitas e interestratificación de areniscas y pelitas (b) mostrando erosión producida por la superficie de incisión (flechas) (c). c) Clasto de andesita de 1.5 m (a en la foto) proveniente de la infrayacente Formación Punta del Agua dentro de niveles diamictíticos caóticos. d) Diamictitas masivas, matriz soportadas incluyendo clastos graníticos. e) Niveles (a y c) de diamictitas masivas, matriz soportadas separadas por un delgado intervalo de fangolitas guijarrosas con cadilitos (b). f) Detalle del afloramiento mostrado en E donde se observan cadilitos interrumpiendo y deformando la laminación (flechas).

deposits and the existence of marine invertebrates together with poorly preserved (reworked) plant remains, suggest deposition during a progradational depositional phase. Sandy beds may represent distal mouth bar deposits generated by subaqueous currents coming from landward while mudstones were likely deposited from suspension or by highly diluted low-energy currents.

## DISCUSSION

Glacial deposits described in this paper were very probably deposited in a proximal glacial environment including both true tillites (part of the massive matrix-supported diamictites) and resedimented diamictites. The latter are characterized by the existence of stratification features such as horizontal lamination and graded layers, which are common in stratified and graded matrix-supported diamictites as well as in stratified clast-supported ones. The existence of faceted, pentagonal and occasional striated clasts supports the proposed glacial or inherited glacial origin. On the other hand, laminated mudstones bearing dropstones (Fig. 2f) are characteristic of glaciomarine deposits suggesting periods of ice-front retreat (calving). Interestingly, the glacial deposits described in this paper are different from others described in the basin where only a unique basal level of diamictites has been found. In the del Peñón river area at least four levels of diamictites occur intercalated with repeated intervals of pebbly mudstones bearing dropstones (Fig. 2e). This could indicate different episodes of glacial advance and retreat as has been described in the Guandacol Formation from the adjacent Los Pozuelos creek region (Marenssi *et al.*, 2004).

The laminated shale interval (Fig. 1) is characteristic of many Late Paleozoic glacial sequences described in the Precordillera and Sierras Pampeanas. These levels may mark the Namurian post-glacial maximum flooding interval registered throughout the major part of the western basins of Argentina (Limarino *et al.*, 2002). Lastly, the interbedded sandstones-mudstones sequence probably reflects high-sea level conditions and high sediment input that favored the progradation of shoreline deposits.

It is also interesting to speculate on the origin of the incision surface that cross-cuts the glacial deposits across the paleo-landscape. This erosive event could be related to the Westphalian regression recognized in most of the Late Paleozoic basins of western and northwestern Argentina (Limarino *et al.*, 2006).

Another important aspect of results presented here lies in the stratigraphic distribution of the diamictites and their age. Recently, Gutierrez and Limarino (2006) reported palynological assemblages from deposits that immediately (?) overlie the incision surface in the basal part of the studied succession at the South of the del Peñón river study area (level "A" of Gutierrez and Limarino, 2006). The palynomorphs, that appear above the incision surface and therefore in higher stratigraphic levels than the glacial interval, belong to the *Raistrickia densa-Convolutispora muriornata* of Late Mississippian-Pennsylvanian age (Césari and Gutierrez, 2001). Moreover, radiometric ages obtained from the underlying Punta del Agua Formation (Aceñolaza *et al.*, 1971, Fauqué *et al.*, 1999; Coughlin, 2000), though of low precision, suggest that Punta del Agua volcanic rocks are not younger than Mississippian age. This argues strongly for a Namurian to early Westphalian age for the glacial interval reported here, an age similar to those previously reported for the glacial event in this part of Gondwana.

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