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Push moraines in the upper valley of Santa Cruz river, southwest Argentina. Structural analysis and relationship with Late Pleistocene paleoclimate

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ABSTRACT

The upper cliff of the Santa Cruz River was used to assess the proglacial environments of the Argentino Glacier outlet of Late Pleistocene age. These cliffs show glaciolacustrine, fluvioglacial and till deposits, where only the first one are deformed. Glacial landforms in the area and these structures suggest that the ice mass advanced, topographically controlled, towards the east from the Patagonian Ice Sheet pushing up the proglacial sediments.

The spatial arrangement of thrusts and overturned folds, the drumlins-flutes moraine directions and the end moraines shape, allow inferring the dynamic and the Argentino glacier profile. Detailed analyses of the glaciotectonic structures indicate that these have two origins: load in the north with stress transfer to the southeast, and push from the west. Through the analysis of deformed sediments, their thickness and their sedimentary and structural features, three zones of deformations were recognized. Each of these zones was associated to glacial advances because of changes of the regional climate conditions.

1. Introduction

During Late Pliocene-Pleistocene times, the Patagonian Ice Sheet had extended along the southern Andes from ca. 36°S to ca. 56°S (Glasser et al., 2008). The Patagonian Ice Sheet flowed along the fluvial valleys, oblique to the Andean Range, as outlet glaciers. Throughout the Patagonia, well-preserved glacial sediments and landforms record the advances and retreats of these ice margins.

Darwin (1842) was the first to describe erratic blocks in the southern Patagonia, while Nordenskjöld (1898) mentioned the presence of frontal moraines at high levels. Caldenius (1932), who first mapped moraine systems, distinguished four separate moraine belts and other glacial landforms associated to them. He concluded from their state of preservation that the three inner moraine systems were relatively young and named the three moraine limits (from inner to outer) the "Finiglacial", the "Gotiglacial", and the "Daniglacial". Caldenius' scheme was only slightly modified by subsequent authors (Feruglio, 1944, 1950; Mercer, 1976; Strelin, 1995; Strelin and Malagnino, 1996; Wenzens, 1999a-b, 2005; Schellmann, 1999; Schellmann et al., 2000; Rabassa and Coronato, 2002) who correlated the Finiglacial moraines to the Last Glacial Maximum and the Daniglacial and the Gotiglacial moraines systems to the mid-Pleistocene glaciations.

The authors mentioned described moraines and fluvioglacial deposits in the Santa Cruz river area (Fig. 1), but only Caldenius (1932), Feruglio (1944), Strelin (1995) and Strelin and Malagnino (1996) mentioned the deformed glaciolacustrine deposits placed beneath them.

A detailed geomorphological map and a glacial stratigraphy description of the Santa Cruz river valley were presented by Strelin (1995) and Strelin and Malagnino (1996). They recognized six glaciations from Pliocene to late Pleistocene times and reconstruct the glacial history of the valley. These authors assign those glacial

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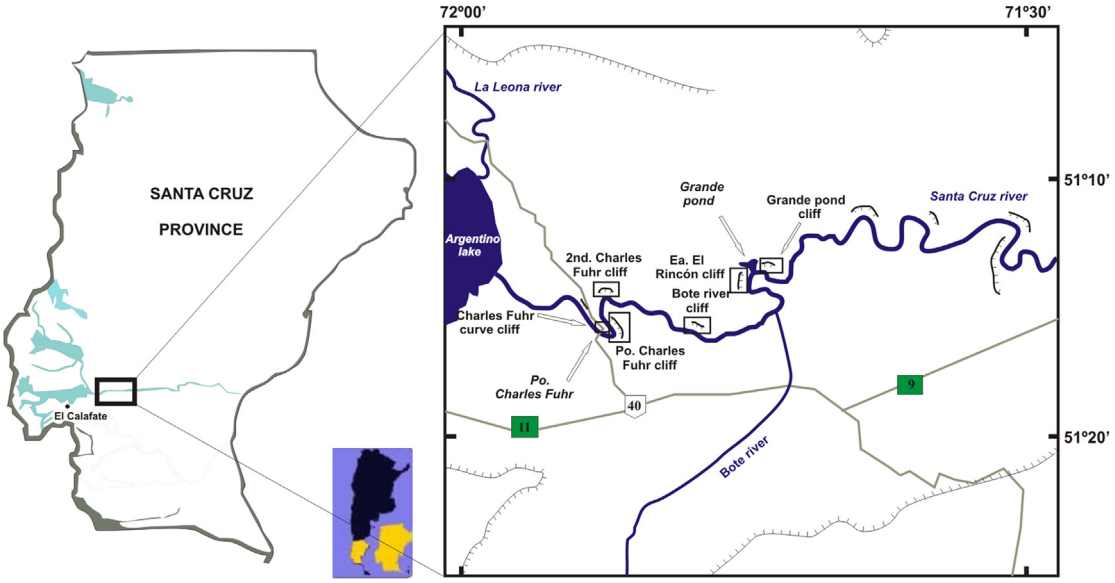

Fig. 1. Map of studied area in the Valley of Santa Cruz River and the location of the six outcrops analysed.

deposits and landforms to a huge glacial lobe named "Argentino glacier". Besides paleolacustrine landforms (raised beaches, bars, spits, lagoons and deltas) in the upper Santa Cruz River basin indicates that multiple Pleistocene glacial lakes existed upon this southern Patagonian landscape (Austin and Strelin, 2011). They named these lakes as "Argentino paleolake".

This work is a comprehensive study of glacial deposits, landforms and structural evidences left by the Argentino outlet glacier advances, which flowed in the Valley of Santa Cruz River (Fig. 1). The excellent exposure on the cliff provides a unique opportunity to study spatial and temporally patterns due to glaciotectonic deformation. These patterns were used to infer past glacier dynamics, fields of local stresses, and its possible relationship with paleoclimate settings. The relevance of this papers is according with Harts and Rose (2001), who mentioned that investigation of glacier bed conditions and subglacial processes is an obligatory requirement for the modelling and understanding of contemporary glacier behaviour, past glacier behaviour, glacier response to both spatial and temporal variations in bed material, and glacier response to external forcing factors such as climate change.

1.1. Regional setting

The Santa Cruz River Valley is one of many oblique valleys in Patagonia, which extends from the eastern margin of Argentino lake to the Atlantic Ocean. This valley is bounded on both sides by steep slopes of the sub-Andean Pliocene plateaus.

The underlying formations of the Quaternary glacigenic deposits are marine to fluvial sedimentary beds that represent marine ingressions-regressions during Mesozoic–Cenozoic times in the Austral Basin (Feruglio, 1944; Casadio et al., 2000; Arbe, 2002; Nullo and Combina, 2002; Nullo and Haller, 2002; Zilli et al., 2002). These formations crop out on both sides of the valley below the plateaus.

The area presents a wide range of glacial landforms evidencing the presence and movement of the Argentino glacier (Caldenius, 1932; Feruglio, 1944; Strelin, 1995; Strelin and Malagnino, 1996). The presence of a moraine belts to the east, 41 km from El Calafate, records the maximum extent of the glacier down the river valley (Fig. 2-a). The moraine belt are composed by a set of eight ridges (Fig. 2-b) where each ridge is between 10 and 12 km long, 10–15 m high, 80–110 m wide and are concave upstream. The moraine belt has lateral continuity over both sides of the valley, where in the north side it is at 300 m of altitude, while at the south, the moraine belt is at the bottom of the valley. It is evidencing the asymmetrical profile of the ice with the highest thickness of the glacier located in the north (Strelin and Malagnino, 1996). Rabassa et al. (2005) argue that this moraine corresponds with the Last Glacial Maximum occurred between 25,000 and 16,000 cal yr ago (Late Pleistocene).

Behind of the terminal moraine there are a wide zone with drumlins and fluted moraines (Strelin, 1995; Strelin and Malagnino, 1996). These are very low landforms, with less than 20 m in local relief over the surrounding topography, corresponding to the spindle-shaped drumlin type (Fig. 2-c and d). They show a clear turn in the main axes direction from south-southeast (south of the river) to east-southeast (north of the river). Besides, the elongation of these streamlined forms tends to increase towards the east, from 500 m to 1000 m (Goyanes, 2010). The surface and sides of drumlins are covered by scattered erratic blocks from Andean Range lithologies.

Marginal meltwater channels seem to have been common features along the lateral margins of the Argentino glacier (Strelin, 1995; Strelin and Malagnino, 1996) as is evidenced in satellite image by old river courses. They seem to have joined with Santa Cruz River downstream. In front of the end moraines there is a fluvioglacial plain that in the satellite images was differentiated due to its smooth surface.

Glacigenic sediment exposures in the area are scarce, but the river bank sections on Santa Cruz river show glaciolacustrine and fluvioglacial beds folded and thrusted.

Overall, six outcrops were identified along the river margins, which named from west to east are: Charles Fuhr curve, Paso Charles Fuhr cliff, 2nd Charles Fuhr cliff, Bote river cliff, El Rincon cliff and Grande pond cliff (Figs. 3–7).

2. Methods

The studied area was divided into six sections. The thickness and lateral extent of each section was measured with GPS. The stratigraphic relationships between the different sedimentological units exposed on the cliff were examined, and their contacts were traced along the cliff in order to assess the geometry of each unit. A general sedimentological logging, emphasising and characterizing the