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Report

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UNDERSTANDING THE DRIVERS OF PATAGONIAN ICE SHEET DEGLACIATION: INSIGHTS FROM ITS NORTHEASTERN-CENTRAL SECTOR

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Background and Rationale

A key unresolved question is the timing, rate, and forcings of Patagonian Ice Sheet (38° - 56°S; Figure 1A) deglaciation following the end of the global Last Glacial Maximum. Current chronological evidence implies that ice recession was regionally asynchronous (Davies *et al.*, 2020), sometimes exhibiting millennial-scale differences in the onset of retreat and stabilisation. Latitudinal asynchronies are regularly attributed to poleward and equatorward shifts in the precipitation-bearing Southern Hemisphere westerly wind belt (SWW; Figure 1B), a key regional and interhemispheric climate driver (Garreaud *et al.*, 2013; Denton *et al.*, 2021). Yet, if climate forcing mechanisms are responsible for this variability, why were neighbouring Patagonian outlet glaciers sometimes out of phase (e.g., Lira *et al.*, 2023)? Given marked altitudinal and topographic differences between the northern, central, and southernmost sectors of the former ice sheet, it is likely that glacier response to climate was more complex.

We posit that these regional asynchronies are a product of (de)glaciation style, driven by both climatic and non-climatic factors, and their changing impact on glaciology. To address this topic, we looked to the northeastern-central sector of the former ice sheet, focusing on the Río Cisnes valley (~45°S). Whilst most eastern outlet glaciers formed large ice-contact palaeolakes during recession, lakes in this region have now drained (Figure 1C), offering a more complete landform record than those located south. The aim of this work, and a second field campaign, was to understand the spatial and temporal evolution of sediment-landform associations across the study area.

Glacial Geomorphology and Sedimentology

For the purpose of this short summary, we focus on some key characteristics of the Río Cisnes valley. Ice-marginal landform associations include low-relief, discontinuous (~10-50 m), arcuate, and closely spaced ridges deposited on reverse-bed slopes at the easternmost ends of the outlet valleys. Based on their geometry, these landforms are interpreted as push moraines forming during minor re-advances or stillstands (e.g., Evans, 2003). Flat-topped ridges with a more subdued relief, inset from these ridges, resemble the typical morphology of overridden moraines.

There is a distinctive change in the size, scale, and form of ridges moving west, once ice had receded down a reverse-bed slope and began calving into a proglacial lake dammed in an over-deepening. These stratigraphically younger, steep (c. 200 m relief), and arcuate ridges (Figure 2A,B) are mostly composed of massive, well-consolidated, and blocky diamictons, interdigitated with gravelly and diamictic clinoforms (Figure 2B). These landforms are interpreted as latero-frontal moraine ridges, characterised by intermittent exposures of subglacial traction till (cf. Evans *et al.*, 2006) and sub-aqueous debris flow deposits.

Subglacial associations include large expanses of smooth and streamlined bedrock, usually oriented in the direction of local ice flow (west-east), and interspersed with areas of diamicton. These features are interpreted as glacially scoured bedrock plastered with areas of subglacial traction till.

A glacial over-deepening (e.g., Figure 2C) comprises a large sector of the outlet valley, which restricted proglacial drainage. The over-deepening is covered with exposures of finely laminated sands, silts and clays. These sediments sometimes exhibit soft sediment deformation in the form of flame structures, convolute bedding, or ball-and-pillow structures (e.g., Figure 2D) and always contain dispersed outsized clasts. In most cases, laminated fines cap the top of individual sediment exposures. Fine laminations reflect the extent and evolution of an ice-contact palaeolake (cf. Ashley, 2002), which has experienced intermittent periods of quiescent conditions (ice cover) allowing for rhythmic sedimentation.

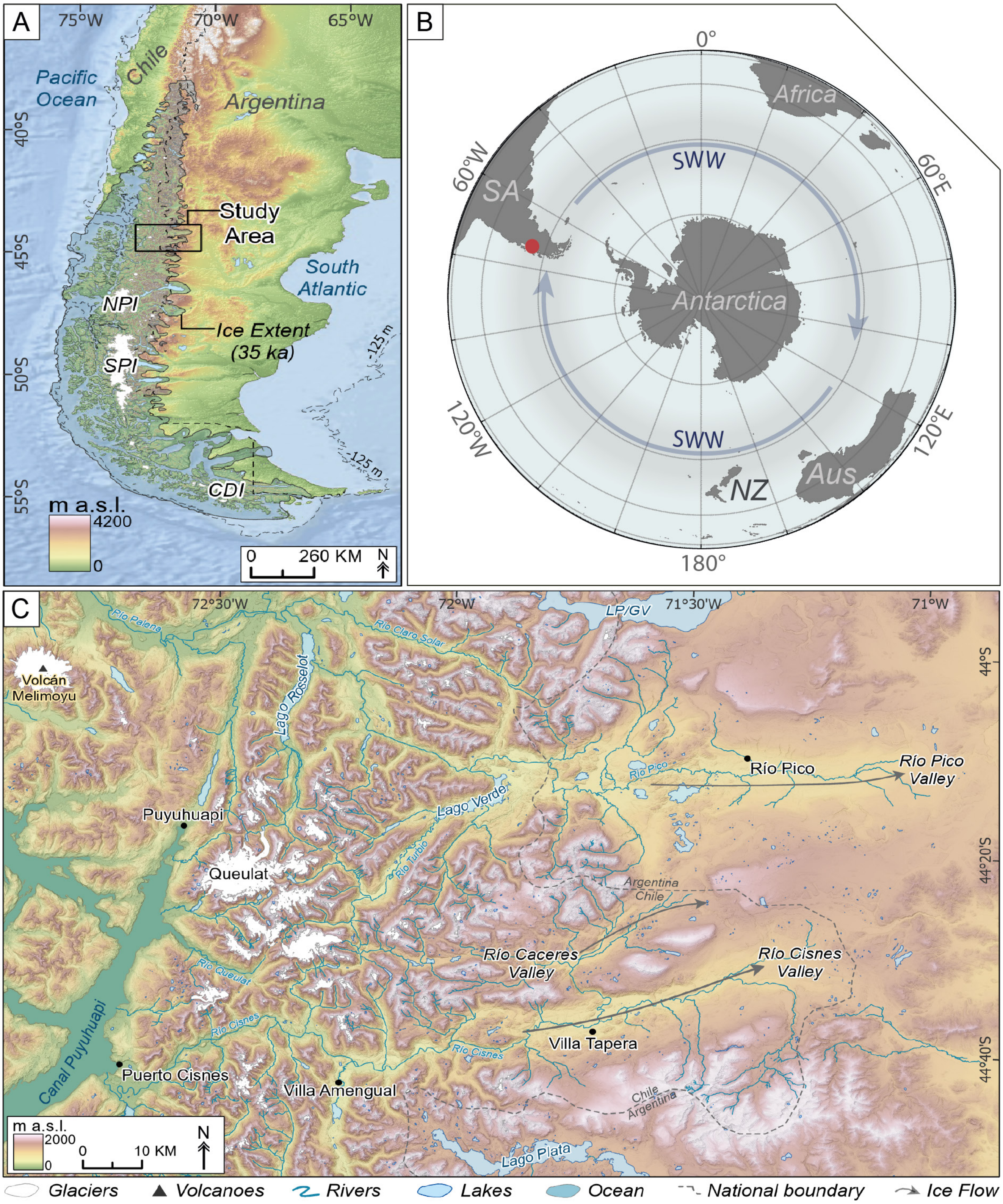

Figure 1. Location of the study area within a Patagonian and Southern Hemisphere context. [A] Patagonia, including reconstructed ice extent at 35 ka (Davies *et al*., 2020). NPI: Northern Patagonian icefield, SPI: Southern Patagonian icefield, and CDI: Cordillera Darwin icefield. DEM: 30 arc-second DEM of South America. Bathymetry: General Bathymetric Chart of the Oceans. Approximate sea level extent at the global Last Glacial Maximum is signified by a -125 m contour. [B] Location of the study area (red dot) in the Southern Hemisphere. SWW: Southern Hemisphere westerly wind belt, approximate modern core location. [C] Location of the study area, including the Río Cisnes valley. Ice moved in a west-east direction towards the Argentine foothills. LP/GV: Lago Palena/General Vintter.

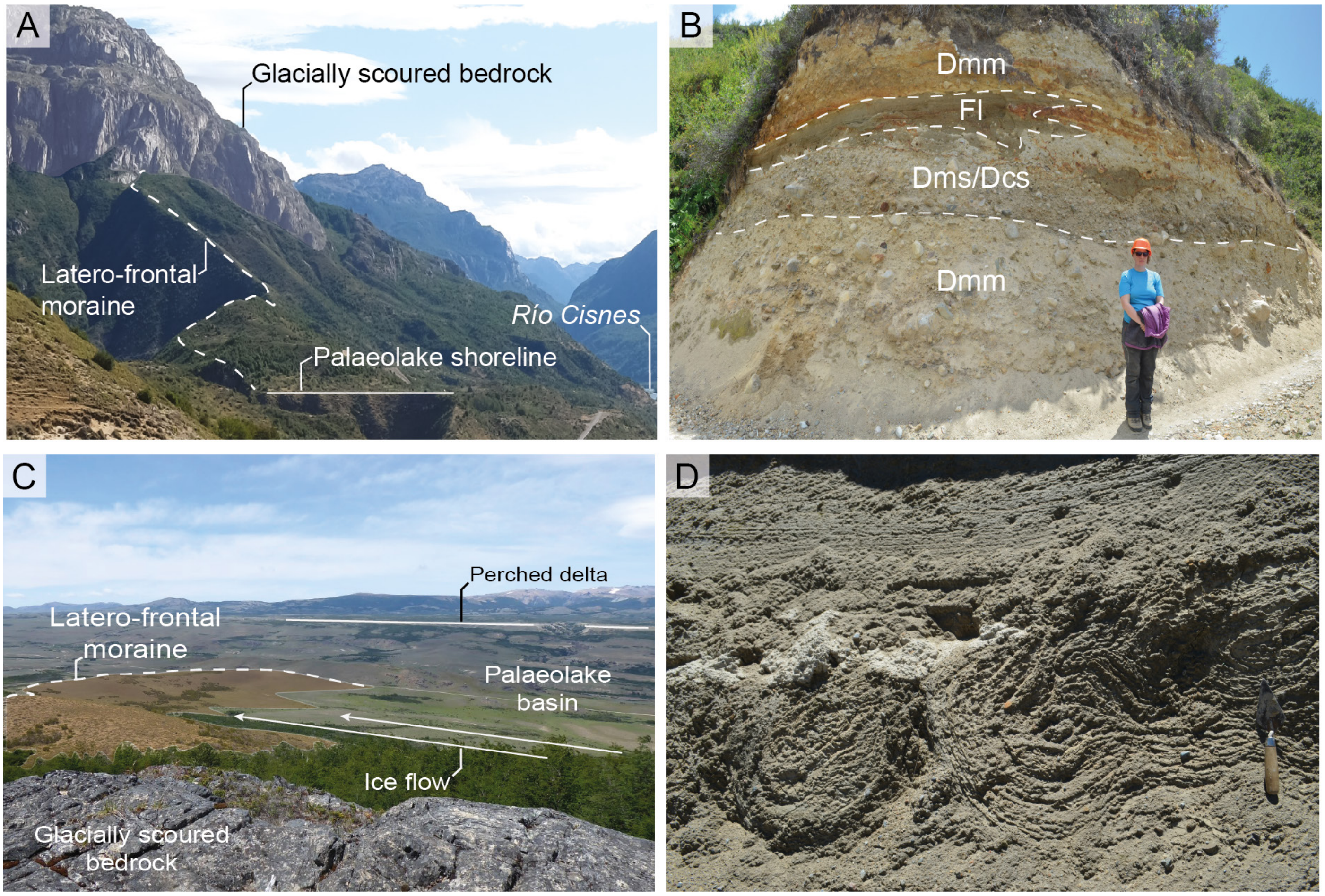

Figure 2. Landforms and sediments of the Río Cisnes valley. [A-B] Latero-frontal moraine ridge that formed during deglaciation and example of sediments therein. [C] View from area of glacially scoured bedrock looking into over-deepening. A perched deltas marks former lake levels. [D] An example of laminated fines deformed by deposition of a coarser sand bed.

Glaciofluvial associations include flat-topped expanses of sorted sands, and gravels, adjacent to ice margins and imprinted with sinuous to braided channels. These landforms are interpreted as proglacial outwash plains. These plains are only found preserved at the easternmost ends of the outlet valleys and mark the former configuration of less restricted drainage networks towards the South Atlantic. Within these plains, and adjacent to ice margin positions, steep and rounded hollows are interpreted as kettle holes.

Significance

These results are a small selection of sites described during our second Patagonian field season, but evidence clearly points to the presence of an active temperate glacial landsystem (e.g., push moraines; overridden moraines; proglacial outwash plains etc.). This is not unexpected; however, the exciting characteristic of this area relates to spatial and temporal changes in sediment-landform associations, which reflect an evolving topographic setting. As ice retreated down a reverse-bed slope and into a glacial over-deepening, proglacial drainage became more restricted. Landforms and sediments reflect this east-west trend of increasing topographic constraint and increasing restriction of proglacial drainage. Such changes will have implications for the timing of moraine formation, and the relative roles of climatic versus glacio-dynamics controls on ice recession in this sector of Patagonia.

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