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Timing and rates of foreland sedimentation: New detrital zircon U/Pb geochronology of the Cerro Dorotea, Río Turbio, and Río Guillermo formations, Magallanes basin

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Abstract. We report new detrital zircon U/Pb geochronology from the Cenozoic Magallanes foreland basin (near 51 °S) in both Argentina and Chile, that sheds light on sedimentary provenance and improved timing of sedimentation for the Cerro Dorotea, Río Turbio, and Río Guillermo formations. Using youngest detrital age populations to constrain maximum depositional age (MDA), we provide the first radiometric age confirmation of Paleocene deposits in the Cerro Dorotea Formation at this latitude. Lower Eocene (47-46 Ma) MDA constrains the overlying unit, the Lower member of the Río Turbio Formation, which shares sedimentological, paleontological, and provenance affinity with the northern Man Aike Formation. Revised timing of sedimentation indicates that deposition of the Upper member of the Río Turbio Formation occurred during the Eocene-Oligocene transition ca. 33-34 Ma and continued until ca. ≤ 26 Ma. Revised Miocene depositional ages for the Río Guillermo Formation indicate the onset of fluvial sedimentation after 23.5 Ma. Changes in detrital provenance signatures reveal upsection increase in Late Cretaceous zircon sources, persistence of mid-Cretaceous zircons (~90-110 Ma), and reduction in Late Jurassic and Paleozoic igneous sources. These signatures suggest changes in the orogenic upland paleogeographic configuration during advancement of thrust sheets and recycling of the Cretaceous depocenter.

Keywords: Magallanes Basin, Detrital Geochronology, Cenozoic, Patagonian fold-thrust belt

1 Introduction

Tectonics, climate, and global eustasy in dynamic plate systems control fluctuations between marine and terrestrial conditions along continental margins, changes in surface and rock uplift, rates of erosion and sedimentation, and biogeography. With the emergence of a new paradigm in the last two decades recognizing the dynamic interactions and feedbacks among these processes (e.g., Marshall et al., 1982; Beaumont et al., 1992; Browning et al., 2006), it has become all the more essential to differentiate among the signals (timing, tempo, magnitude) of tectonics, climate, and eustasy in the stratigraphic record. For instance, enhanced tectonism in foreland basin settings can cause crustal load-driven subsidence and basin deepening. Globally, the growth and ablation of continental ice sheets regulates sea level and global climate, and precipitation and temperature gradients influence erosion rates, vegetation cover, and the distribution of deformation. Advances in radiometric dating and detrital provenance techniques expand our ability to evaluate these signals.

This study centers on improved understanding of the timing and controls of basin subsidence, marine transgressions, and continental sediment dispersal patterns in the Magallanes-Austral region of South America during middle Cenozoic time. In Patagonia and Tierra del Fuego, several middle Cenozoic transgressions have been linked to global sea level rise due to climate (Malumián and Náñez, 2011), but it is as of yet undetermined to what extent these phases were driven by tectonic subsidence and changes in upland sediment supply or eustasy alone. In this contribution, we report new detrital zircon U/Pb geochronology data that track changes in orogenic paleogeography of upland sources during deposition and improve estimates of timing of sedimentation through youngest detrital age component.

2 Analytical Methods

Nine sandstone samples for detrital geochronology were collected from the outcrop belt exposed between Cerro Castillo area, Chile and Ruta 40 and Estancia Cancha Carrera, Argentina. Zircon extractions were carried out using standard crushing and sizing procedures following the methods in Fosdick and others (2015). Final zircon concentrates were inspected under a microscope, mounted on tape in epoxy resin, and polished to expose the grain interiors. U/Pb detrital zircon geochronology was conducted by Laser Ablation-Inductively Coupled Plasma Mass Spectrometry (LA-ICP-MS) at the Arizona LaserChron Center at the University of Arizona, USA. Detrital zircons were randomly analyzed from a linear

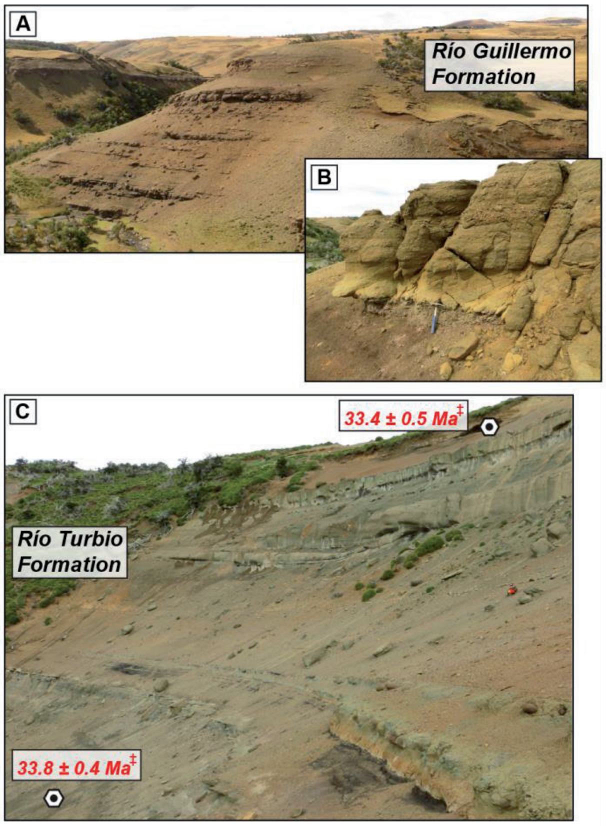

Figure 1. Stratigraphy and geochronology of middle Cenozoic foreland basinfill exposed at Cancha Carrera. A) Fluvial sandstone and conglomerate of the Río Guillermo Fm., B) Erosive unconformity between Río Turbio and Río Guillermo formations, C) Interbedded glauconitic sandstone, siltstone, and coal seams of the Upper Río Turbio Formation.

swath of grains across the epoxy mount. Interpreted U/Pb ages use the ^{204}Pb corrected $^{206}Pb/^{238}U$ ratio for <1.0 Ga grains and the ^{204}Pb corrected $^{206}Pb/^{207}Pb$ ratio for >1.0 Ga grains. Analyses that were >20% normally discordant or >5% reverse discordant were excluded. For MDA calculations, ages were determined on youngest age peaks defined by 2 or more overlapping zircon ages (within 2σ and <5% discordance).

3 Results and Interpretations

Cerro Dorotea Formation: Detrital zircon geochronology from three stratigraphic horizons (225 grains) within the mapped Cerro Dorotea Fm. near Cerro Castillo reveals an upward decreasing youngest age peaks, major age populations between 60-66 Ma, 74-115 Ma, 123-160 Ma, 473-630 Ma, 960-1130 Ma, and lesser numbers of Proterozoic and lower Paleozoic ages (Fig. 2). Youngest detrital age populations yield MDA estimates of 61.9 ± 0.3 Ma (n = 4) and 60.5 ± 0.8 (n = 3) for the uppermost samples, collected from thick-bedded, trough cross-bedded tan-yellow sandstone and orange brown sandstone with interbedded siltstone and coal-bearing mudstone, respectively.

Lower member of the Río Turbio Formation: Two samples (214 grains) collected from the overlying greenish gray glauconitic and brown sandstone units: with abundant marine invertebrate fossils, plant debris, and tropical leaf fossils yield similar ages and a pronounced 45-48 Ma age peak. Estimation of MDAs from the youngest zircon population indicates sedimentation occurred ≤ 47.1 ± 2.7 Ma (n = 2) at the base of the green glauconitic sandstone and ≤ 46.3 ± 1.3 Ma (n = 2) Ma at the top of the brown deltaic sandstone unit.

Upper member of the Río Turbio Formation: Three detrital zircon U/Pb geochronology samples (314 grains) near the Estancia Cancha Carrera (Fig. 2) yield an upsection decrease in youngest zircon U/Pb age peaks, robust age populations between 29-45 Ma, 63-109, 113-137 Ma, 218-288 Ma, and lesser numbers of Late Jurassic grains. Proterozoic grains are noticeably lacking compared to underlying detrital signatures. Estimation of the maximum depositional age from zircon data indicate that the fossiliferous and highly bioturbated fully marine grey to greenish sandstones were deposited ≤ 33.4 Ma (Fig. 1), and the top of the sequence, composed by fine grained sandstones and mudstones, with fossil woods fragments and organics near the contact with the Río Guillermo Formation, occurred at ≤ 26.6 ± 0.2 Ma (Fig. 2).

Río Guillermo Formation: One sample (95 grains) collected from the base of the Río Guillermo Fm. yields a broad Mid to Late Cretaceous zircons and major age peaks between 23-26 Ma, 33-36 Ma, 72-109 Ma, 113-128 Ma, 149-154 Ma, 275-304 Ma, and lesser numbers of Proterozoic grains. The youngest zircon age population indicates a maximum depositional age of ≤ 23.5 ± 0.3 Ma (n = 5) for initiation of fluvial sedimentation at this latitude in the basin (Fig. 2).

4 Discussion and Conclusions

Detrital geochronologic data from collected sandstone samples suggest significantly younger depositional ages than previously thought for the Upper member of the Río Turbio and the Río Guillermo formations, motivating the need for rethinking of their depositional connections to changes in Cenozoic climate and/or phases of deformation in the active Andean orogenic belt. A younger age (Selandian) is also proposed for the upper sections the Cerro Dorotea Formation, classically assigned to the Danian based on the foraminiferal content (Malumián and Náñez, 2011). This report is also the first formal confirmation on the occurrence of this classic Paleocene unit in Chile. We also investigated key stratigraphic areas and documented changes in provenance, depositional facies, and fossil assemblages. In the present understanding, there are four major Atlantic transgressions in the Magallanes basin of Patagonia and Tierra del Fuego: Maastrichtian-Danian, Late Middle Eocene, Late Oligocene ("*Julian*" transgression) and Early Miocene

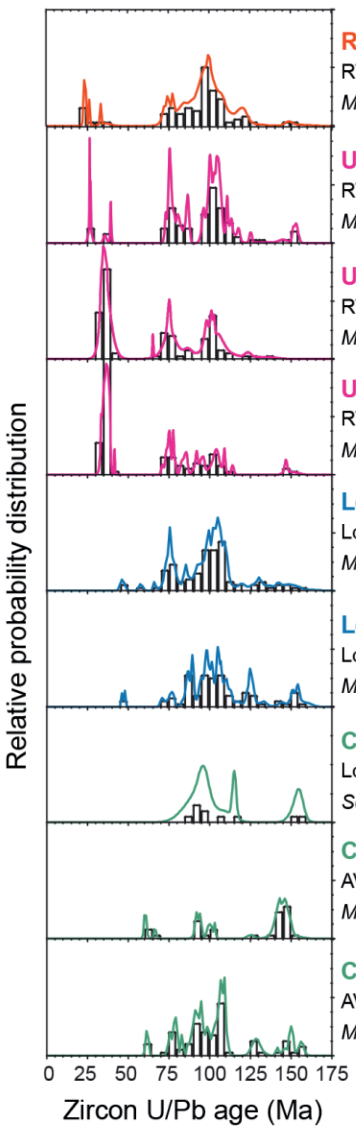

Figure 2. Detrital zircon U/Pb geochronology data from the Cerro Castillo and Cancha Carrera sections. Age distributions reveal upsection variations in proportions of igneous sources. These data reveal maximum depositional ages (MDA) younger than reported biostratigraphic age. N denotes total number zircons analyzed; n denotes number of grains that define MDA.

("*Patagonian*" transgression), the two youngest one probably representing integrated eustatic cycles. Based on biostratigraphic age assignments, two of these marine incursions are tied to global climatic optima, the Late Middle Eocene, and the Early Miocene (Malumián and Náñez, 2011; Malumián and Ramos, 1984). In particular, many workers have interpreted the upper Cerro Dorotea through lower Río Turbio formations within the paleoclimatic context of the Paleogene climatic optima (Nullo and Combina, 2011).

Our calculated estimates of maximum depositional ages from detrital zircon U-Pb geochronology of the Río Turbio Fm., indicate Eocene sedimentation starting at 47 – 46 for the base of the Lower member, and ≤ 34 and 26 Ma ages for the mid to upper levels of the Upper member. These data point towards two fundamental stratigraphic *conundrums*; 1) the presence of important temporal hiatuses between and within both members of the formation, and 2) substantially younger sedimentation not associated with the Eocene paleoclimate, for the Upper member of the Río Turbio Fm. This latter finding is also corroborated by the abundant occurrence of fossil *Nothofagus* leafs mixed in the marine levels, and a faunistic turnover observed between both "members", presently not fully resolved. Middle to late Oligocene ages for the upper portion of the Upper member are partially coincident with the deposition of the "*Julian*" beds in the Atlantic coast (Parras et al., 2012), also pointing to a continuous presence of marine conditions for most of the Eocene to the early Miocene at this latitude. The recognition of "*Julian*" ages within these strata is remarkable and will certainly draw the full attention of sedimentologists and paleontologists in the near future. In contrast, the Lower member of the Río Turbio Formation clearly shows similar age, sedimentary facies, fossil content, and mineral composition as the Man Aike Formation near Lago Argentino (Casadío et al., 2009) and Sierra Baguales (Bostelmann et al., 2013, Gutiérrez et al., 2013, Schwartz and Graham, 2015) likely representing the same depositional unit.

Lastly, detrital zircon MDAs estimated for the overlying Río Guillermo Fm. points to an early Miocene age (Aquitanian) for the unit, revealing at least a 3 Myr disconformity and major change in sedimentation style from estuarine to fluvial and coarse-grained sedimentation ≤ 23 Ma until ca. 21.7 Ma (volcanic ash from Fosdick et al., 2011). Moreover, since this unit supposedly underlies (Malumián et al., 2000) or represents the southern correlation of the Río Leona Formation, we contend that all Paleogene ages previously proposed for this lithostratigraphic unit should be dismissed, as previously suggested by Torres et al., (2013).

Our detrital zircon U-Pb geochronology from the Río Turbio and Río Guillermo also reveal changes in relative contributions of Mesozoic and Cenozoic igneous sources (Fig. 2). Preliminary sediment provenance data from the Río Guillermo Fm. document an upsection reappearance of granitoid cobbles, which are noticeably lacking in the underlying Río Turbio Fm., and may suggest uplift and surface exposure of batholith plutons or recycling from the unique conglomeratic member of the Upper Cretaceous Cerro Toro Fm. Further investigation of sedimentary signals would link these clastic units to the deformational history in the nearby fold-thrust belt. Ongoing work explores an integrative comparison of tectonic loading, changes in upland paleogeography, and climate/eustasy.

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