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New U-Pb age from the Cretaceous Cerro Barcino Formation, Patagonia: stratigraphic and palaeoseismic implications

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ABSTRACT

We present a new U-Pb crystallization/deposition age from the Cretaceous Cerro Barcino Formation (Chubut Group), based on a volcaniclastic sample collected near the locality of Alto de Las Plumas. The sample comes from an alluvial succession previously assigned to the Cenomanian Las Plumas Member, which includes seismites interpreted as the result of palaeoearthquakes likely related to movement along a nearby normal fault. U-Pb zircon dating by LA-ICP-MS yields a crystallization/deposition age of 116.7 ± 0.75 Ma (2σ). This new age suggests that the stratigraphic interval may more accurately correspond to the Aptian Cerro Castaño Member, and that the associated seismic activity responsible for the seismites likely occurred during the Aptian rather than Cenomanian.

Keywords: Somuncurá-Cañadón Asfalto Basin, Chubut Group, Cerro Barcino Formation, Aptian.

RESUMEN

Nueva edad U-Pb de la Formación Cerro Barcino (Cretácico), Patagonia: implicancias estratigráficas y paleosísmicas

Presentamos una nueva edad U-Pb de cristalización/depositación de la Formación Cerro Barcino (Grupo Chubut) del Cretácico, basada en una muestra volcaniclástica colectada cerca de la localidad Alto de Las Plumas. La muestra proviene de una sucesión aluvial previamente asignada al Miembro Las Plumas (Cenomaniano), que incluye sismitas interpretadas como el resultado de paleosismos probablemente relacionados con el movimiento a lo largo de una falla normal cercana. La datación U-Pb del circón por LA-ICP-MS arroja una edad de cristalización/depositación de 116,7 ± 0,75 Ma (2σ). Esta nueva edad sugiere que el intervalo estratigráfico puede corresponder con mayor precisión al Miembro Cerro Castaño (Aptiano), y que la actividad sísmica asociada responsable de las sismitas probablemente tuvo lugar durante el Aptiano y no durante el Cenomaniano.

Palabras clave: Cuenca de Somuncurá-Cañadón Asfalto, Grupo Chubut, Formación Cerro Barcino, Transición Aptiano-Albiano.

INTRODUCTION

The Cretaceous Chubut Group, extensively distributed across the central region of Chubut Province, extra- Andean Patagonia (Fig. 1a), represents the post-rift phase in the infill sequence of the Somuncurá-Cañadón Asfalto Basin and comprises the Los Adobes and Cerro Barcino Formations (for more details, readers are referred to the recent stratigraphic review by Allard et al., 2021). The Cerro Barcino Formation is a volcaniclastic succession deposited in a nonmarine setting widely distributed in the Somuncurá-Cañadón Asfalto Basin. Following the stratigraphic scheme proposed by Silva Nieto et al. (2017), the Cerro Barcino Formation includes, in ascending stratigraphic order, the Puesto La Paloma (PLPM), Cerro Castaño (CCM) and Las Plumas (LPM) Members (Fig. 1b). The Cerro Barcino Formation presents a transitional contact with the underlying Los Adobes Formation, reflecting a palaeoenvironmental scenario controlled by a higher volcaniclastic sediment supply from western sources (Villegas and Umazano, 2024). Towards the central and eastern sectors of the basin, the Cerro Barcino Formation commonly overlies uncomfortably Jurassic volcano-sedimentary rocks assigned to the Marifil Formation (and lateral equivalents) in a context of a compartmentalized basin. The PLPM, which is mostly composed of greenish, sheet-like, volcaniclastic sandstones considered as deposited during the Aptian according to two radioisotopic ages of tuffaceous strata (Fig. 1b). The dated samples are located in the lower and middle parts of PLPM succession, which present U-Pb (CA-ID-TIMS) crystallization ages of 118.5 ± 0.04 and 115.5 ± 0.04, respectively (Krause et al., 2020). The reported ages were established from samples collected in the western sector of the basin (Fig. 1a), where the PLPM records mostly unconfined fluvial conditions with local development of feeder channels, aeolian dunes associated with different types of interdune zones and preservation of ash-fall strata (Umazano et al., 2017; Krause et al., 2020; Villegas and Umazano, 2024). The CCM is typically reddish-brown and has a greater proportion of sandstones compared to PLPM (Fig. 1b; Krause et al., 2020 and references therein) representing sedimentation in fluvial channels and associated floodplains affected by minor volcaniclastic sediment input. The lower section of the Albian CCM was dated to 110.8 ± 0.04 Ma (CA-ID-TIMS, Krause et al., 2020). In the central and eastern sectors of the basin, the LPM, which overlies the CCM, predominantly consists of reddish tuffaceous sandstones and conglomerates of fluvial-alluvial origin (Villegas, 2022) and is assigned to the Cenomanian. The radiometric constrains of the LPM consist of two U-Pb crystallization ages; one of 98.5 ± 0.05 Ma located near the top of the LPM succession (CA-ID-TIMS, Krause et al., 2020) and the other of 97.4 ± 0.8 Ma in the overlying the Puesto Manuel Arce Formation (SHRIMP, Suárez et al., 2014) (Fig. 1b). In the central-eastern sector of the basin, the spatial distribution of the members of the Cerro Barcino Formation is unclear, mainly because they have been mapped together, even with different grouping criteria on adjacent geological maps (Anselmi et al., 2004a, b). Moreover, the identification of the members using the typical lithology and colour (Codignotto et al., 1978), both in outcrops and satellite images, is complex and does not follow the characteristics observed in the western sector. Villegas (2022) presented detailed interpretations for palaeoenvironments of the Cerro Barcino Formation succession in the central-eastern part of the basin without radioisotope ages. In this conceptual framework, we present a new U-Pb depositional/crystallization age (LA-ICP-MS) of the Cerro Barcino Formation from the eastern margin of the basin; specifically, from a zone herein named Alto de Las Plumas (Fig. 1c), where an alluvial succession previously assigned to the LPM is laterally related to a normal fault (Fig. 1c-d; Villegas et al., 2019). The sampled layer is a massive volcaniclastic mudstone included within a stratigraphic interval characterised by the presence of soft-sediment deformation structures (SSDS) that were interpreted as seismites genetically related to fault activity (Fig. 1e, f, g; Villegas et al., 2019). A depositional/ crystallization age was estimated using the new data, which was used in this study to: i) revise the stratigraphy of the Cerro Barcino Formation in the Alto de las Plumas zone; and ii) obtain an age constrain on the palaeoearthquakes that would have caused the seismites.

SEDIMENTARY SECTION

The studied sedimentary succession, mostly pink to light red in colour, corresponds to the LPM according to the detailed geological map of the zone (Villegas et al., 2019; Villegas, 2022). It is ≈45 m thick and overlies Jurassic ignimbrite rocks of the Marifil Formation in angular unconformity (Fig. 1c-d). The succession is mainly composed of conglomerates and breccias with a common channel geometry and an erosive base, interbedded with sheet- like volcaniclastic sandstones (Fig. 1e). A 3 m thick deformed stratigraphic interval lies 35 m above the contact with the underlying Jurassic substrate and has a lateral extent of ≈800 m. This interval involves both conglomerate-breccia beds and finer grained deposits; it is characterised by the occurrence of SSDS including load casts, pseudonodules, flame structures and contorted bedding. Readers are referred to Villegas et al. (2019) for additional

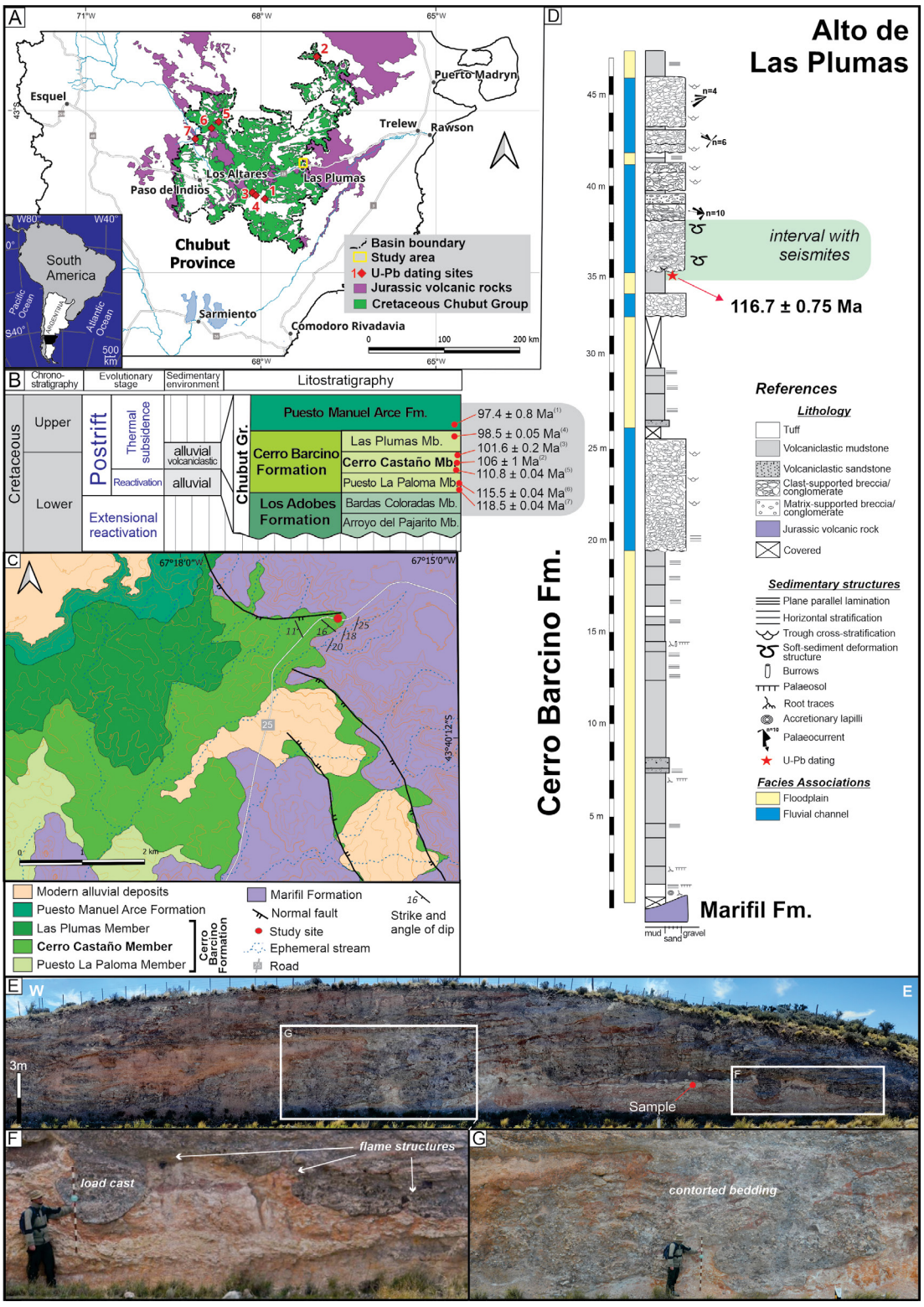

Figura 1. a) Distribution of the Cretaceous Chubut Group in the Somuncurá-Cañadón Asfalto Basin; the location of the dated samples prior to this contribution and the study site are shown. b) Chronostratigraphy of the Chubut Group following Silva Nieto et al. (2017), based on U-Pb ages from previously published data according to Suárez et al. (2014, 1), Navarro et al. (2015, 2), Carballido et al. (2017, 3) and Krause et al. (2020, 4-5-6-7). The stages of evolution of the basin following Figari et al. (2015). c) Geological map of the study zone. d) Sedimentary log and palaeoenvironments of the Cerro Barcino Formation in the Alto de Las Plumas locality; the stratigraphic position of the interval with seismites and dated sample is highlighted (cf. Villegas, 2022). e) Panoramic view of the stratigraphic interval with seismites and analysed sample. f-g) Details of the stratigraphic interval with seismites showing large-scale load casts, flame structures and contorted bedding (further details in Villegas et al., 2019); person for scale is 172 cm tall.

details. In particular, the sample for radiometric dating was collected from a deformed, massive, volcaniclastic mudstone beneath a deformed gravelly channel deposit bearing load casts and contorted bedding. The decimeter- to meter thick composite layers from where the sample was collected can be interpreted as fluvial resedimented deposits, broadly contemporaneous with direct volcanic ash fall. Episodic volcaniclastic input from subduction-related active volcanoes to the west may plausibly account for the volcaniclastic components identified in the Cerro Barcino Formation (Manassero et al., 2000). The now-exhumed volcanic edifices could have been located in the present outcrops of the North Patagonian Batholith or even in the retroarc region (Butler et al., 2020), as has been proposed for analogous units of the Chubut Group in the western San Jorge Basin (Umazano et al., 2009). SHRIMP U-Pb zircon ages ranging from 118 to 102 Ma from subaerial volcanic rocks in Chile and Argentina further confirm the occurrence of a major volcanic episode in central Patagonia during the Aptian and Albian (Suárez et al., 2009). The studied succession records a fluvial system composed of gravelly, low-sinuosity channel belts, whereas the SSDS are clustered in pedogenized volcaniclastic floodplain deposits (Villegas et al., 2019; Villegas, 2022).

U-PB GEOCHRONOLOGY

The zircon U/Pb analyses were carried out at the R&D Productive Technology Center of LA.TE. ANDES (Salta, Argentina). The zircon concentrate was obtained from ≈2 kg of rock, using gravity, magnetic, and optical techniques, while the last mineral purifying phase has been performed by hand picking under a binocular loupe with 15X magnification. The handpicked zircons were mounted in epoxy resin on a 25 mm diameter mount, which was subsequently mirror polished by grinding and polishing with diamond pastes. The analyzed zircons are predominantly euhedral, with no evidence of detrital components or reworked grains (Fig. 2C-D).

The dating was performed with a combination of LA-ICP-MS instrumentation (Laser Ablation – Inductively Coupled Plasma – Mass Spectrometry, a RESOlution 193 nm laser ablation system manufactured by Australian Scientific Instruments and an 8900 triple quadrupole ICP-MS model produced by Agilent Technologies). U-Pb ages were calculated from the isotopic ratios using 91500 zircons as reference material (Wiedenbeck et al., 2004) and repeated measurements on Plesovice zircon (reference TIMS age 337.13 +/- 0.37 Ma; Slama et al., 2008). The spots were analyzed at a frequency of 9 Hz, fluence of 3 J.cm-² and spot diameter of 38 µm. LADR Software 1.1.0.7 (Norris and Danyushevsky, 2018) was used for data reduction. IsoplotR (Vermeesch, 2018) was used for further processing to obtain the depositional/crystallization age from the U-Pb data, with 100 ± 10% concordance cut-off based on $^{206}Pb/^{238}U$ versus $^{207}Pb/235U$ ratios, which was represented in the weighted mean diagram and the Kernel Density Estimates diagram showing a low dispersion (Fig. 2A-B). From a total of 83 spots, 55 concordant U-Pb ($^{206}Pb/^{238}U$) values were used to calculate the depositional/crystallization age of 116.7± 0.75 Ma. (2 σ).

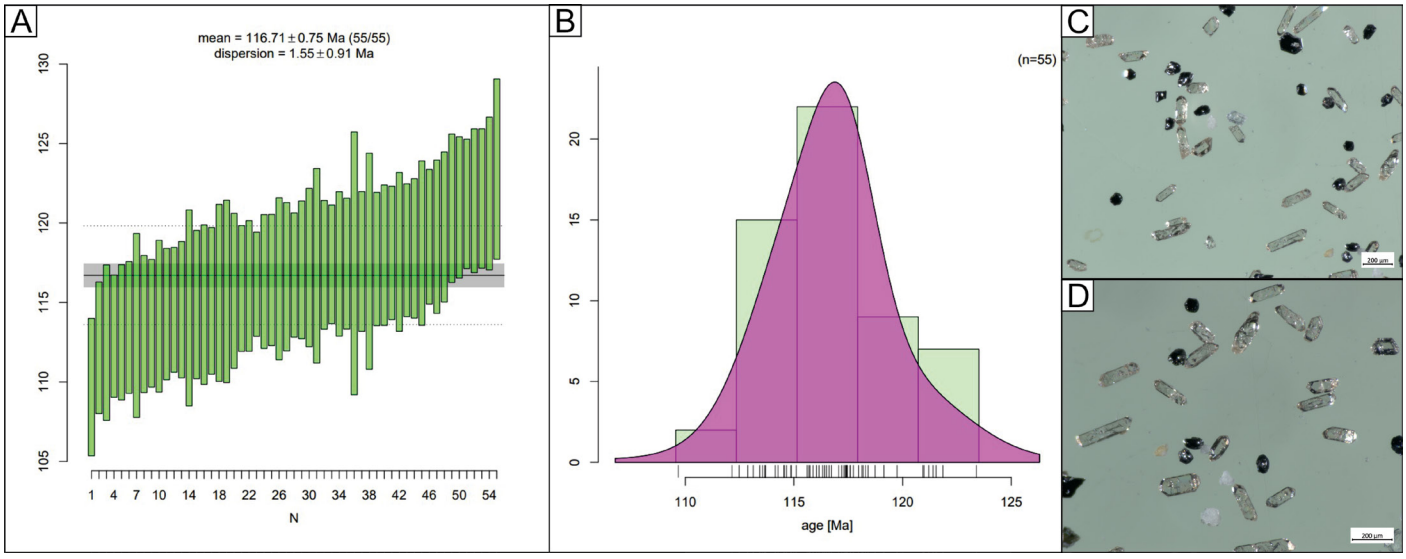

Figura 2. a) Weighted Mean and b) Kernel Density Estimates, both diagrams (Vermeesch, 2018 - IsoplotR version 6.3.5) with the 55 concordant data included in the age calculation. c) and d) Examples of analysed zircons with typical euhedral shape.

STRATIGRAPHIC AND PALAEOSEISMIC SIGNIFICANCE

In previous mapping of the study zone by Sacomani et al. (2007), as well as in detailed local studies by Villegas et al. (2019) and Villegas (2022), the succession containing both the seismites and the dated sample have been included in the Cenomanian LPM. However, our new Aptian crystallization/depositional age suggests three potential scenarios (A, B and C), each with distinct stratigraphic implications.

The first two scenarios suggest that the studied succession has been misassigned to the LPM and should instead be reassigned to an older unit of the Cerro Barcino Formation, such as the PLPM or CCM (scenarios A and B, respectively), both of which crop out in the southern sector of the study zone (Fig. 1C). The analyzed succession, characterized by fluvial gravelly deposits associated with alluvial fans systems in the eastern sector of the basin (Villegas et al., 2019; Villegas, 2022), could be broadly contemporaneous to the sandstone-dominated fluvial sections assigned to the PLPM and CCM towards the west (Umazano et al., 2017; Krause et al., 2020). Typically, the PLPM have been recognized throughout the basin by its distinctive greenish volcaniclastic sandstones. In this context, the lithofacies descriptions of the analyzed deposits are more consistent with those of the CCM (scenario B) in the southern sector, exhibiting a broad lateral continuity, albeit without the presence of fluvial gravelly deposits (see Villegas, 2022). These lithofacies variations may reflect palaeoenvironmental changes commonly recorded at basin margins. In this scenario, the CCM deposits could be slightly older (diachronous) relative to the western sector.

Scenario C suggests that the deposition of the LPM in the eastern sector of the basin is diachronous relative to other parts of the basin. Thus, the deposition of the LPM, potentially linked to marginal fault activity affecting Jurassic volcanic rocks in the study area, could be older than equivalent sections to the west.

Of the three proposed scenarios, scenario B appears to be the most likely although more information is necessary to be certain. Therefore, the stratigraphic position of the studied section may need to be revised.

On the other hand, since soft-sediment deformation occurs in unconsolidated sediments during or shortly after deposition and before significant diagenesis, the new U-Pb crystallization/depositional age suggests an Aptian age for the fault activity that triggered the palaeo-earthquakes recorded in the stratigraphic interval containing the SSDS. Furthermore, the eastern margin of the Cretaceous basin preserves additional evidence of synsedimentary tectonic activity. For instance, Navarro et al. (2010) reported seismites in breccias of the Cerro Castaño Member near Telsen. However, there is no conclusive evidence (e.g. growth strata, either synextensional or syncontractional) to determine whether the fault experienced extensional reactivation or tectonic inversion, the former being consistent with the classical model of thermal subsidence (e.g., Figari et al., 2015) or with the more recent broken foreland proposal (e.g., Gianni et al., 2015; Echaurren et al., 2016).

FINAL REMARKS

In summary, the new U-Pb age of 116.7 ± 0.75 Ma from the Cerro Barcino Formation at the Alto de Las Plumas locality is the first radiometric age data of the Chubut Group in the eastern sector of the Somuncurá-Cañadón Asfalto Basin. The U-Pb data from zircons of the Cerro Barcino Formation in the study zone suggests that the sediment accumulation was during the Aptian. This new age highlights the necessity for: i) a detailed stratigraphic reassessment of this sector of the basin and, ii) systematic sampling of adjacent stratigraphic sections of the Cerro Barcino Formation to better understand the timing of volcaniclastic transport in distal alluvial environments. The dated horizon contains seismites related laterally with a normal fault, indicating the occurrence of palaeoearthquakes during the Aptian.

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