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The Permian-Triassic boundary in Northern Patagonia (Argentina): eochronological and palaeontological issues of the Los Menucos Basin

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Introduction

In the last five years, a profound revision of the stratigraphy and geochronology of northern Patagonia has been carried out. The volcanic and sedimentary succession of the Los Menucos Basin has become the focus of paleontological and geochronological studies to determine and correlate the Permian-Triassic boundary in Argentina. Luppo et al. (2018) have initially proposed a correlative of the P-T boundary (Fig. 1) within a 6 km thick concordant volcanic and sedimentary succession, which was dated between 257 ± 2 and 248 ± 2 Ma (SHRIMP U-Pb in zircon). More recently, Falco et al. (2020, 2022a, 2022b) revised the volcanic and sedimentary stratigraphy of the same succession, proposing the existence of a low angle unconformity between the volcanic and sedimentary beds. With this unconformity in mind, a novel stratigraphic scheme for the Los Menucos Group was proposed, in which the P-T boundary is expected to be found within the succession because it was constrained between 253 ± 3 (LAICMPS U-Pb in zircon) and 250 ± 2 Ma (see further details in Falco et al., 2020, 2022b).

Sedimentology

The Los Menucos Group, *sensu* Falco et al. (2020), is divided into the Puesto Tscherig, Puesto Vera and Sierra Colorada formations. The Puesto Tscherig Formation (PTF) is up to 70 m thick at its type locality and two members are recognizable. The lower member, the Cerro La Laja Member, is dominated by sandstone, mudstone, conglomerate, and breccias resulting from

Figure 1. Barrancas Grandes Member of the Puesto Tscherig Formation, in which the Permian-Triassic boundary are located according to Bodnar et al. (2021).

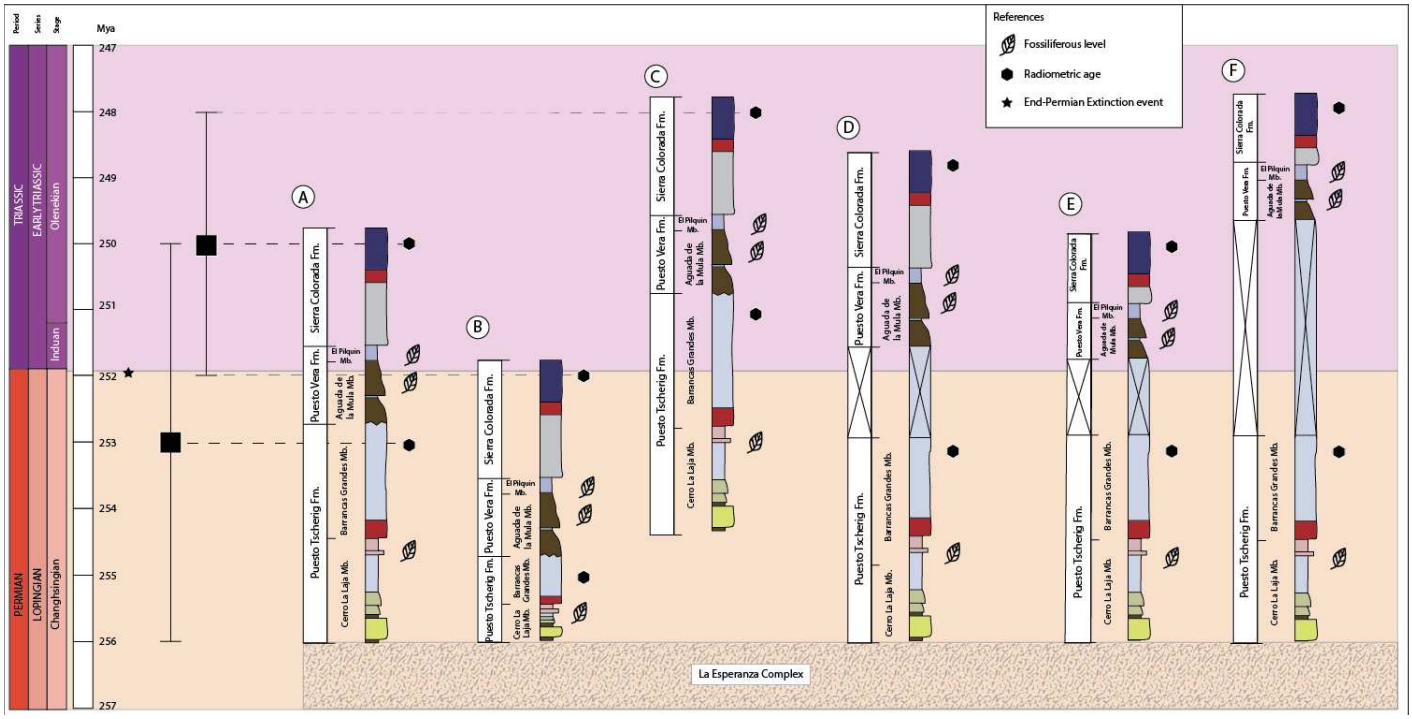

Fig. 2. Simplified figure of how the known geochronological dates of the sedimentary column and the error of the methods used can affect the comparisons and interpretation of the timing of the recovered flora. The older and youngest age hypothesis are related to the age obtained from the Sierra Colorada Fm. The basin overlies the La Esperanza Complex, an ignimbrite whose age is constrained between c. 257 Ma at the bottom (sample M265 in Luppo et al. 2018) and c. 256 Ma at the top (Falco et al., 2022b), so the Los Menucos Group deposition started as older as the top age.

the reworking of unconsolidated pyroclastic deposits. While debris flows dominate the proximal zones, distal sectors are characterized by deposition in ephemeral swamps. The upper part of the Puesto Tscherig Formation, named the Barrancas Grandes Member, is composed of a dacitic ignimbrite deposit (with an age of 253 ± 3 Ma at its type locality).

The overlying Puesto Vera Formation (PVF) is up to 20 m thick and has been divided into the Aguada de la Mula and El Pilquin members. The lower Aguada de la Mula Member is dominated by gravelly sandstone, medium to fine sandstone, and mudstone, deposited in fluvial channels and on floodplains affected by volcanism. The upper El Pilquin Member is exclusively composed of ash fall deposits.

The Sierra Colorada Formation is composed of three ignimbrite pulses that reach up to 80 m thick, of which the upper two pulses are well developed throughout the basin (with an age of 250 ± 2 Ma at the Puesto Tscherig locality).

Regarding the Puesto Tscherig type locality, in which the three formations of the Los Menucos Group were recognized (Fig. 2), latest geochronological and palaeontological latest results suggest that it could represent the P-T transition (Fig. 2A, as in Bodnar et al., 2021). The 253 ± 3 Ma age obtained for the ignimbrite of the Barrancas Grandes Member (Fig. 1) and the 250 ± 2 Ma age for the ignimbrite of the Sierra Colorada Formation in the Puesto Tscherig locality, together with the palaeontological record, suggest that the P-T boundary (placed at 251.902 ± 0.024 Ma) should be in this succession. The Cerro La Laja Member (PTF) is Chansinghian in age, and the Barrancas Grandes Member could include the P-T Boundary. Given the known ages and errors from the locality and the basin, El Pilquín Member of the Puesto Vera Formation could encompass the P-T boundary or the Early Triassic.

Palaeontology

Abundant fossil flora, and fauna have been recovered from both the Cerro la Laja Member of the Puesto Tscherig Formation, and the Puesto Vera Formation (Fig. 3).

The Cerro La Laja Member of the Puesto Tscherig Formation bears a diverse fossil plant assemblage that was described by Artabe (1985a, b) and revised by Bodnar et al. (2021). It is composed of *Ctenis japonica* (Cycadales), *Ginkgoites* (=*Ginkgo*) *digitata*, *Gontriglossa moribunda* (Gnetales), *Heidiphyllum elongatum* (Voltziales), *Lepidopteris madagascariensis*, *Moltenia wardii*, *Pachydermophyllum praecordillerae* (Peltaspermales), *Pseudoctenis grandifolia*, *P. spectabilis*, *P. capensis*, *Pterophyllum inconstans* (Bennettitales), *Rhipidopsis densinervis* (Ginkgoales), *Sphenobaiera stormbergensis*, *S. argentinae*, *Taeniopteris lata*, *T. magnifolia*, *T. crassinervis*, *T. wianamattae*, *T. lentriculiformis*, *T. vittata* (Cycadales or Bennettitales), and *Zuberia sahnii* (Um komasiales=Corystospermales). According to the radiometric dating, this would be restricted to the latest Permian. Although this assemblage is different from other Lopingian taphofloras of Argentina, it has various taxa in common with the Lopingian palaeoflora from the Umm Irna Formation (Dead Sea, Jordan; Blomenkemper et al. 2018). The Puesto Tscherig Formation vegetation was exclusively composed of seed plants, most of which are considered as xeromorphic (Bodnar et al., 2021, and references therein), that would have allowed them to live in

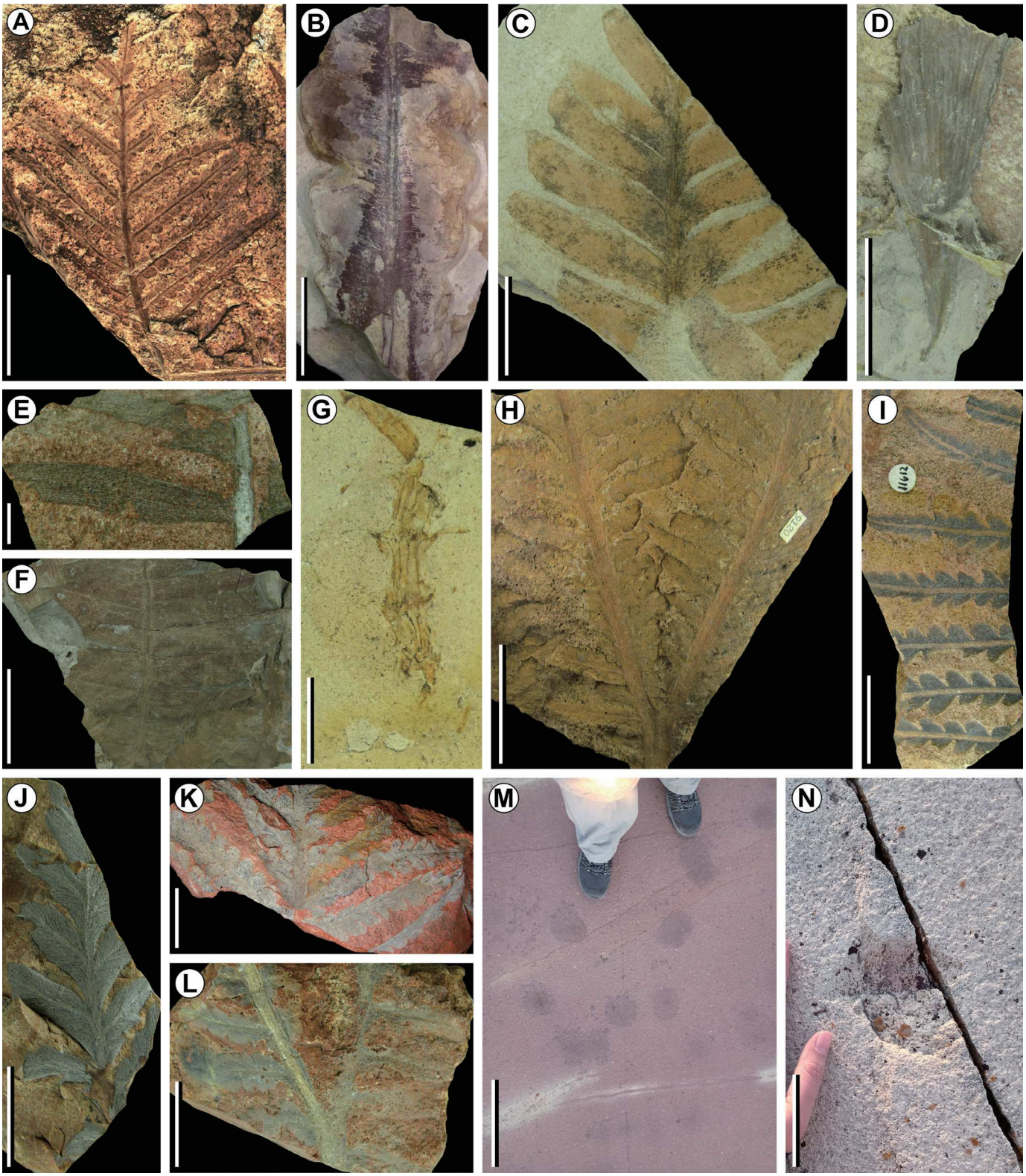

Fig. 3. Fossiliferous content of the Los Menucos Group. **A-F**. Fossil flora of the Cerro La Laja Member of the Puesto Tscherig Formation. **A**. *Zuberia sahnii* (leaf of Umkomasiales). Scale bar= 5 cm. **B**. *Taeniopteris lata* (leaf of Cycadales or Bennettitales). Scale bar= 6 cm. **C**. *Moltenia wardii* (leaf of Cycadales). Scale bar= 4cm. **D**. *Rhipidopsis densinervis* (leaf of Ginkgoales). Scale bar= 3 cm. **E**. *Pseudoctenis capensis* (leaf of Cycadales). Scale bar= 1 cm. **F**. *Pterophyllum inconstans* (Bennettitales). Scale bar= 2 cm. **G-L**. Fossil flora of the El Pilquín Member of the Puesto Vera Formation. **G**. *Phyllotheca australis* (stem of Equisetales). Scale bar = 1 cm; **H**. *Zuberia sahnii* (leaf of Umkomasiales). Scale bar= 4 cm. **I**. Z. *feistmantelii* (leaf of Umkomasiales). Scale bar= 4 cm. **J**. *Dicroidium incisum* (leaf of Umkomasiales). Scale bar= 4 cm. **K**. *Z. papillata* (leaf of Umkomasiales). Scale bar= 3 cm. **L**. *D. dubium* (leaf of Umkomasiales). Scale bar= 3 cm. **M-N**. Tetrapod tracks of the Cerro La Laja Member of the Puesto Tscherig. **M**. *Dicynodontipus*-like track. Scale bars= 30. **N**. detail of a *Dicynodontipus*-like footprint. Scale bar= 3 cm.

stress-related environments and arid circumstances caused by the active volcanism of that time in the area.

The Puesto Vera Formation paleoflora is constituted by *Dicroidium dubium*, *D. incisum*, *Equisetites fertilis*, *Phyllotheca australis*, *Pseudoctenis spathulata*, *Pteruchus barrealensis*, *Zuberia feistmantelii*, *Z. brownii*, *Z. zuberi*, *Z. sahnii*, *Z. papillata*, and undetermined gymnosperm woods (Artabe, 1985a,b; Bodnar et al., 2021; Falco et al., 2020). A diversification of corystosperms occurs in the Puesto Vera Formation. Unlike the Puesto Tsherig Formation paleocommunity, the arboreal and shrubby corystosperms are here dominant, while cycads are subordinate. The Puesto Vera Formation exhibits species considered as indicative of the Early Triassic-Anisian interval (Retallack, 1977; Bodnar et al., 2021).

The fossil faunas are not as diverse as the fossil floras. In the Cerro La Laja Member of the Puesto Tscherig Formation and in the Puesto Vera Formation, one species of fossil spinicaudata (Gallego 2010), abundant tetrapod tracks (Diaz-Martinez & De Valais 2014), and remains of an amiiform fish (Bogan et al. 2013) were found. Casamiquela (1964) indicated that the tetrapod fauna from Los Menucos is younger than the Late Triassic and older than the Late Jurassic. Gallego (2010) proposed an early Late Triassic age based on the clam shrimp *Menucoestheria wichmanni*. More recently, Citton et al. (2021) suggested a Lopingian-Early Triassic age for the *Dicynodontipus*-dominated record of the Puesto Tscherig and Puesto Vera Formations based on the global record of that genus. This is broadly consistent with the age obtained by radiometric methods.

In summary, the Los Menucos Group includes a Changhsinghian paleoflora without *Glossopteris*, the Permian-Triassic boundary, and a biota that developed probably during or after the end-Permian crisis, but for the moment appears to be without the record of a *Pleuromeia* flora, which was very conspicuous in the Early Triassic world. A palynoflora with elements of the *Pleuromeia* flora was recently recorded in La Veteada Formation (Gutiérrez et al., 2018) but the age is disputed between the Late Permian and the Olenekian (César et al., 2022). Therefore, the data gaps still need to be filled, by finding more fossiliferous levels, calculating deposition rates of sedimentary sequences, and especially by dating with lower error methods. The ultimate objective is to know exactly where we are in the events related to the end Permian extinction and to propose high-resolution evolution models for Southwestern Gondwana.

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Late Early Permian timescale correlations between International scale and Tethyan scale: new evidence from the Lugu Formation in the South Qiangtang Block, Tibet

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Introduction

During the Permian time, conodonts, fusulines, ammonites, brachiopods, radiolarians, and corals all have more or less biostratigraphic significance (e.g., Henderson, 2018; Zhang and Wang, 2018; Shen et al., 2019). Of these marine groups, conodonts and fusulines are two major taxa in Permian biostratigraphy and chronostratigraphy. The conodont biostratigraphy has been widely acknowledged by ICS to represent the International Permian Timescale, in which the Permian timescale has been divided into Asselian, Sakmarian, Artinskian, Kungurian, Roadian, Wordian, Capitanian, Wuchiapingian and Changhsingian (Jin et al., 1997). By contrast, Tethyan Permian timescale was established based on the evolution of fusulines (Leven, 2003). In this scale, the Permian was gradually divided into Asselian, Sakmarian, Yakhtashian, Bolorian, Kubergandian, Murgabian, Midian, Dzhulfian and Dorashamian in past decades. Both scales were all widely applied and cited in the Permian community.

The correlations between the conodont-based chronostratigraphy and fusuline-based chronostratigraphy were a contentious issue because conodonts did not always coexist with fusulines that makes a direct correlation difficult. For example, late Cisuralian and early Guadalupian chronostratigraphic correlations between the International and Tethyan scales have been differently interpreted (Table 1). Jin et al. (1997) proposed that Kungurian stage is correlative with the Bolorian stage. However, the discovery of fusulines *Neoschwagerina simplex* and *Praesumatrina neoschwagerinoides* within the conodonts *Mesogondolella siciliensis-Sweetognathus subsymmetricus* zone in the Luodian Section in South China suggests that the base of the Murgabian stage was in the Kungurian stage (Henderson and Mei, 2003). This correlation was not widely accepted in the later correlations (e.g., Gaillot and Vachard, 2007; Leven and Gorgij, 2011). Another study from the Hatahoko, Japan confirmed again the coexistence of Kungurian conodonts and Murgabian *Neoschwagerina simplex* fusuline fauna (Shen et al., 2012; Ueno et al., 2006). However, it was not fully accepted by Permian experts (e.g., Gaetani and Leven, 2014; Nejad et al., 2015; Angiolini et al., 2015, 2016). In this contribution, we will report a fauna consisting of both conodonts and fusulines from the South Qiangtang Block (SQB), Tibet. The description of this fauna has been published in the journal *Palaeogeography, Palaeoclimatology, Palaeoecology* but focused on the paleobiogeographic significance of the fauna in that paper (Yuan et al., 2022). Here, we will highlight the correlations between the International and Tethyan scales.

Geological background

The South Qiangtang Block lies between the Bangong-Nujiang suture zones in the south and the Longmu Co-Shuanghu suture zone in the north (Fig. 1). The Permian in the South Qiangtang Block is very complex and composed of two different sequences

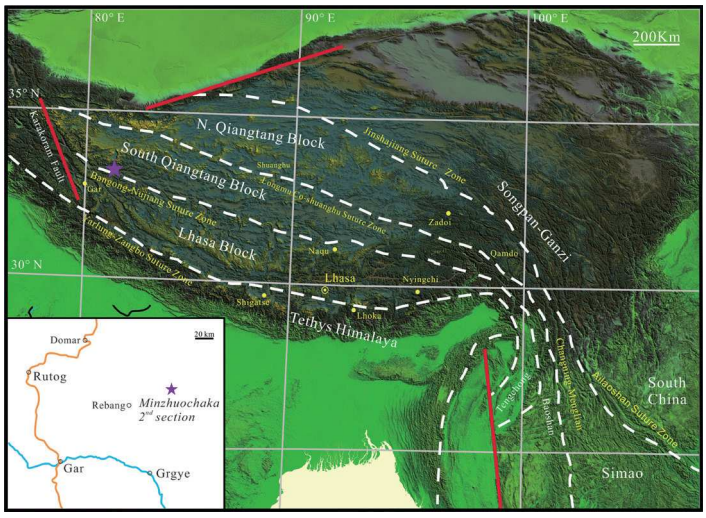

Fig. 1. The tectonic subdivisions of the Qinghai-Tibetan Plateau with the locality of the studied section.