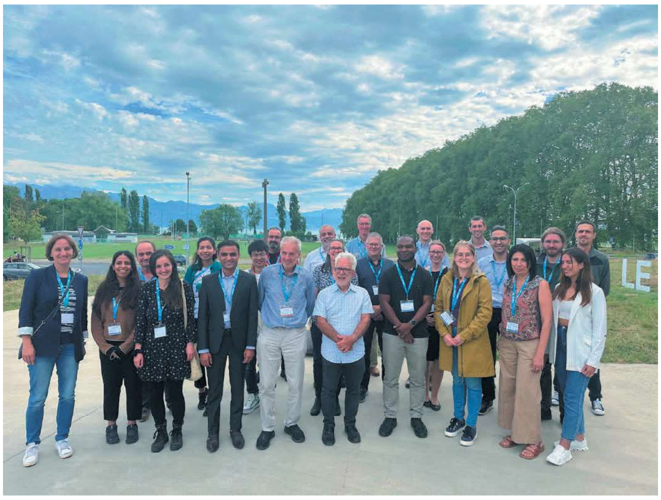
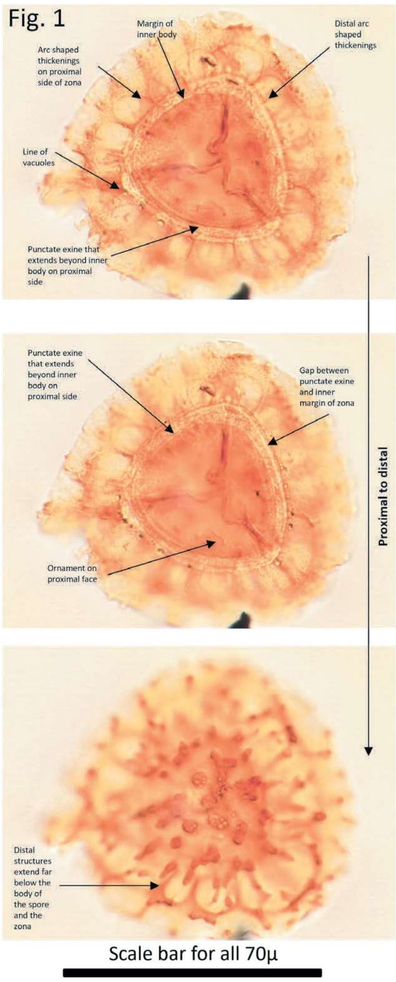
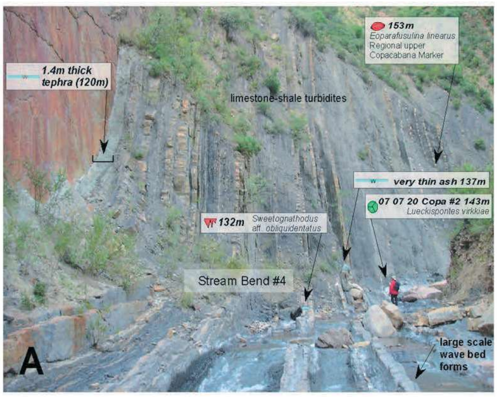
# Permophiles

International Commission on Stratigraphy







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that may obscure detail.

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## The Apillapampa section (Bolivia): field trip accomplished in July 2023-a report of “Gondwana to Euramerica Correlations Working Group"

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### Introduction

The Permian marine to transitional deposits at Apillapampa in Bolivia matches Permian Stratigraphy Working Group (WG) goals because of co-occurrence of several species of conodonts and fusulinids with abundant other taxa including plants and palynology, as well as volcanic tuffs (some U-Pb dated). ‘Bridge taxa’ occur throughout different Gondwanan provinces and support correlations with northern hemisphere Cisuralian ‘standard sections’ (including GSSPs) in Russia, USA, and China (Cisterna et al. 2022, in *Permophiles* 72). As part of an on-going project on Carboniferous – Permian fossiliferous successions of Bolivia (Grader et al., 2008; di Pasquo et al., 2009, 2013, 2014, 2015, 2019, 2022), a field trip to the Apillapampa section was carried out in July 2023.

New data over the last 20 years suggest Asselian and Sakmarian sequences at Apillapampa extend about 100+ m higher into the Sakmarian (vs. previously determined Artinskian ages). This changed regional interpretations of upper Cisuralian strata in Bolivia with many attendant paleontological questions. To further test these data, four of the authors (Mercedes di Pasquo, Gabriela A. Cisterna, Abner Salcedo and Shirley López), went to Apillapampa (Fig. 1) to collect invertebrates and samples for microfossils and palynology. We searched for key Gondwanan taxa among different fossil groups useful for taxonomic revision and regional stratigraphic distribution. We aim to share these data by digital means, including galleries of photographs and taxonomic notes (another aim of the WG), as addressed further below.

**Brief geologic and paleontologic notes**

The Copacabana Formation crops out along Chulpanimayu Creek at Apillapampa near Cochabamba, west-central Bolivia. Sharp stream bends along strike, and waterfalls, characterize this well exposed Permian section that overlies Devonian rocks at c. 3043 m elevation (17.86669°S, 066.24495°W). The stream was surveyed and the strata were lithostratigraphically described by Chamot (1965), who documented a high-diversity brachiopod fauna in the lower limestones including *Gypospirifer condor*, *Linoproductus cora*, *Waagenoconcha humboldti*, *Kozlowskia capaci* and *Rhipidomella cora*. Grader (2003) tied the Apillapampa section to regional Carboniferous-Permiansequences, later visiting with Iannuzzi and again with Lopez, V. Davidov and C. Henderson in 2007. New mapping, palynology, ash layers dates, plant and marine biostratigraphy were reported by Iannuzzi et al. (2008), Grader et al. (2008); Henderson et al. (2009), di Pasquo and Grader (2012), and di Pasquo et al. (2015, 2019). Copacabana strata lie disconformably over middle Paleozoic rocks, above basal sandstones. Chamot divided the Copacabana Formation into two members: a lower marine member and an upper transitional "coal member," known only in the Cochabamba region, although with correlatives in Peru. Di Pasquo et al. (2015) identified overlying volcaniclastics and silicified mudstones of Permian "Vitiacua Formation" and redefined Copacabana lithosomes and nomenclature. Whereas Chamot's "Coal Member" started at ~195 m above the base of basal sandstones (0 m), we have re-defined the coal member as bounded by sequence boundaries between 242 m to 310 m - both intervals that crop out at major waterfalls.

The marine lower Copacabana strata yielded conodonts (*Neostreptognathous pequopensis* - *Sweetognathodus behnkeni* Assemblage Zone), small foraminifers (*Frontinodosaria-Robuloides*), and fusulinids (*Eoparafusulina gracilus* Subzone), and other invertebrates such as crinoids, bryozoans, coral, brachiopods, bivalves, gastropods that are shelfal marine deposits (Chamot, 1965; Suárez-Riglos et al., 1987; Dalenz and Merino, 1994, see these references in Grader et al., 2008; di Pasquo et al., 2015, 2019). Figure 1 shows a 33 m interval of shaley, fossiliferous distal ramp turbidites - "Apillapampa facies" - that were originally broadly correlated by Grader (2003) above a regional Artinskian sea level rise with high-energy fusulinid platform shoals ("Huarina-Yaco" facies). Like all the Copacabana sections in Bolivia, abundant airfall tuffs occur throughout the Apillapampa section within a relatively deep-water marine association as well as higher in the section in the carbonaceous shales and swamp environments of the "Coal Member". For example, the thick sandy tephra unit at 120 m (Fig. 1.A), overlies a resistant fossiliferous mudstone unit with abundant *Zoophycos* sp., and is overlain by thin to medium-bedded limestone beds and laminated to bioturbated dark shale.

The Upper Coal member overlies marine Copacabana strata and is here at Apillapampa, broken into four new lithosomes, including discovery of 45 m of uppermost volcaniclastics and silicified mudstones that share facies with the Vitiacua Formation located in southern Bolivia (cf. Grader et al., 2008; di Pasquo et al., 2019). Carbonaceous shale with lycopods and a tuffaceous bed overly a prominent cherty laminated dolostone at 242 m. This is the base of the sandy, shaley, coal-bearing lithotope ("coal member" sensu di Pasquo et al., 2015) and suggests significant basinward shift of depositional environments. Plant remains are mostly related to lycophytes and pteridophytes (*Dizeugotheca branisae*, *Pecopteris* sp.), and one new sphenophyte (Chamot, 1965; Iannuzzi et al., 2008; see these references in Grader et al., 2008). Cousminer (1965) described 30 species of palynomorphs from six samples in the Coal Member, and found that 64% of the palynomorph assemblage was composed of pteridophytes, and 21% were gymnosperm pollen grains. An updated list of Cousminer´s palynotaxa can be found in Pasquo and Grader (2012).

In 2007, two field trips were carried out by different researchers guided by George Grader, and samples were extracted for multidisciplinary studies (palynology, paleobotany, microfossils, and geochemistry and isotopic analyses).

CA-ID-TIMS radiometric dates from volcanic ash beds within the section were first cited by Henderson et al. (2009) as 298 Ma (40 m), 295.2 Ma (120 m), 293.3 Ma (154 m), 293 Ma (185 m), and 291.6 Ma (242 m). This suggested that the lower marine to transitional strata are Asselian to Sakmarian and most of the coal member above 247 m sensu di Pasquo et al. (2015) is probably Artinskian. However, the precision of zircon dating performed at Boise State University by Jim Crowley and Mark Schmitz, should be reanalysed using current tracers and statistical protocols that have not been published yet. The presence of the conodont *Sweetognathus* cf. *obliquidentatus* at 132 m in the marine lower Copacabana rocks corroborates with a Sakmarian correlation. *Sweetognathus whitei* and *Sw.* aff. *behnkeni* and the fusulinid *Eoparafusulina linearis* occur lower in the section as well, which are typical of the late Asselian and early Sakmarian (Henderson, 2018; Petryshen et al., 2020; Chernykh et al., 2022 in *Permophiles* 72). The presence of these key taxa in this Cisuralian succession was the main reason for making the proposal to the SPS Working Group for considering it a key Gondwanan section (see Cisterna et al. 2022 in *Permophiles* 73).

Twelve shale samples collected for palynology were processed and studied by M. di Pasquo in 2009. They yielded 92 spores, pollen and other taxa and their quantitative taxonomic and stratigraphic distribution published by di Pasquo et al. (2009), di Pasquo and Grader (2012) and di Pasquo et al. (2022). The biostratigraphic proposal of informal palynozones *Vittatina costabilis* and *Lueckisporites virkkiae* of Early Permian age established by di Pasquo and Grader (2012), composed of gymnosperms (coniferaleans, cordaitaleans, and pteridosperm-like plants), with significant contributions from lower vascular plants (variably pteridophytes, sphenophylls and lycophytes). These palynoassemblages were based on the first appearance of some key taxa, especially those aforementioned, and compared and correlated with palynozones of South America and elsewhere by di Pasquo et al. (2013, 2014, and 2015). Plates with illustrations of palynomorphs are included in di Pasquo et al. (2015, 2022). Hence, the lower assemblage was correlated with the South American *Vittatina costabilis* (VcZ) Souza, *Pakhapites fusus-Vittatina subsaccata* (FSZ) Césari and

Gutiérrez, *Cristatisporites inconstans-Vittatina subsaccata* (ISZ) Beri et al. palynozones due to the presence of species such as *Converrucosporites confluens*, *Polypodiisporites mutabilis* and, *Lunatisporites pellucidus*.

The upper assemblages correlated to the *Lueckisporites virkkiae* (LvZ) Souza, *Lueckisporites-Weylandites* (LWZ) Césari and Gutiérrez, and *Striatoabieites anaverrucosus-Staurosaccites cordubensis* (ACZ) biozones (e.g. *Lueckisporites virkkiae*, *Lunatisporites acutus*, *Protohaploxypinus samoilovichii*, *Thymospora criciumensis*, *T. rugulosa*, and *Convolutispora uruguaiensis*).

Considering the five isotopically- dated volcanic ash layers that constrained the lower member of Copacabana Formation and part of the overlying "Coal Member" (sensu Chamot, 1965) as Asselian and Sakmarian through probably Artinskian (see Henderson et al., 2009, and di Pasquo and Grader, 2012), di Pasquo et al. (2015) discussed the disagreement between a late Asselian FAD age of *Lueckisporites virkkiae*, and the mid- Artinskian documented in Brazil, Uruguay, Precordillera Argentina and elsewhere in Africa, Australia, Oman, and Saudi Arabia, also radiometrically- constrained. Particularly in the Paraná Basin of Brazil, Boardman et al. (2012a, 2012b) reported the presence of *Lueckisporites virkkiae* in the Faxinal Coal Field (Rio Bonito Formation), where radiometric dating suggests a late Sakmarian- early Artinskian age (see Souza et al., 2021). Therefore, whether the radiometric data are correct, Bolivia would have been an older center of dispersion for some striate and taeniate pollen grains and monolete spores since the Asselian, including *Lueckisporites virkkiae*. The relationship between the palynofloral evolution and near-field glaciation and deglaciation as likely responsible for migration of plants throughout Gondwana was the explanation given by di Pasquo et al. (2015, 2019). The plant assemblages akin to the *Glossopteris* Flora (e.g. lycophytes and pecopterids) documented in the coal beds of the Copacabana Formation at Apillapampa are part of the records of this long-ranged flora in South America and elsewhere in Gondwana (Rischbieter et al., 2022; Kavali et al., 2022). An approach to climatic and paleogeographic changes reflected by provincialism during the Asselian-Sakmarian to Late Permian is addressed by di Pasquo et al. (2022). Actually, as this disagreement has not been refuted or confirmed and, globally, Lower Permian palynoassemblages mostly shared long- ranged taxa and those key taxa exhibit diachronic ranges, therefore, the precise stratigraphic location of microfossil markers aforementioned, along with the ranges of key palynomorph and a detail taxonomy of brachiopods is mandatory for a correlation with paleo-equatorial successions.


Fig. 1. A. Apillapampa outcrop at Quebrada Chullpanimayo showing vertically bedded, fossiliferous limestone and shale of the Lower Copacabana Member. Photograph taken during medium water level, March 2007. Up-section is to the right; person for scale (see di Pasquo et al., 2015, included in Cisterna et al., 2022). B. The picture corresponds to the same place (120 m) over the Google map image both taken in 2023.

**Notes on Field trip 2023**

The new sampling carried out in the recent field trip will allow a revision of palynotaxa appearances along with a detailed study of the associated invertebrates, which are now part of a taxonomic study to find out potential bridge-taxa, focused on the presence of cosmopolitan and endemic species, and the updating of their age ranges. It will also allow the recognition of global diachronism among key species.

We expect to establish accurate regional and global correlations based on our new collection of fossils from 2024. The new updates of ages based on conodont and fusulinid taxa globally, and the reanalysis of radiometric data from Apillapampa will be published. In addition, a local biostratigraphic scheme based on palynomorphs, as preliminary proposed by di Pasquo et al. (2014), is required for the Permian of Bolivia and Peru. Furthermore, a proposal of brachiopod zones is needed, after revision of key species such as *Gypospirifer condor*, *Linoproductus cora*, *Waagenoconcha humboldti*, *Kozlowskia capaci* and *Rhipidomella cora*, among others takes place. These will be useful for biostratigraphic correlations in South America, i.e. Bolivia, Perú and north-central Chile (Cisterna et al., 2014; Cisterna and Sterren, 2022). On the other hand, preliminary quantitative studies of the brachiopod assemblages recorded at different latitudes of the Pennsylvanian-Cisuralian platform of western South America, suggest significant variations in terms of composition and diversity (Halpern et al., 2018). In this context, a better taxonomic knowledge of the brachiopods from the Apillapampa section can contribute to understanding the diversity patterns along the latitude gradient in this carbonate platform.

**Preliminary comparison with the Usolka section (URSS)**

A palynological comparison between the sections “Usolka and Apillapampa” was attempted by MDP with the aim of identifying "potential palynomorphs as bridge-taxa"and presented in Meeting of the WG Gondwana to Euramerica correlations held in March 17, 2023. Illustrated palynomorphs published by di Pasquo et al. (2015, 2022) and the images included in Chernykh et al. (2022) and those uploaded by Stephenson in 2023 in the virtual gallery (https://permian.stratigraphy.org//Gallery/Usolka) were considered (see also Stephenson, 2016, 2017). Particularly, the Dal'ny Tulkas section proposed as a candidate for the reference section of the Artinskian Stage and ratified as the GSSP for the Sakmarian in 2020 (see Chernykh et al., 2020, 2021). Comments published in *Permophiles* 72 (2022) and also, in *Permophiles* 73 (Horacek, 2022) are out of the scope of this contribution. Chernykh et al. (2022) documented a complete paleontological record for three key Permian biostratigraphic groups of microfossils (conodonts, ammonoids, and foraminifers), as well as macrobiota (e.g. brachiopods, fishes), and plant remains and palynomorphs. The lower boundary of the Artinskian Stage was located at 0.6 m above the base of bed 4b in Dal'ny Tulkas section due to the record of the FAD of the marker species *Sweetognathus asymmetricus* in the continuous phylogenetic lineage of development of *Sweetognathus expansus - Sw. aff. merrilli - Sw. binodosus - Sw. anceps - Sw. asymmetricus* (see Henderson et al., 2019; Henderson, 2018). Geochronologic ages of zircons interpolated between 290.1 Ma ± 0.2 Ma and 290.5 Ma ± 0.4 Ma (Sakmarian), and many additional fossils groups, particularly ammonoids and fusulines, serve as additional markers to correlate the boundary. This information and that one from the Apillapampa section will enable to make correlations between different fossil groups of Cisuralian successions in both Gondwanan and northern hemisphere regions, also supported by radiometric ages.

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## Stratigraphy of the Early Permian Bromacker locality (Tambach Formation, Sakmarian, Germany)

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The Early Permian Bromacker locality of central Germany (near the village of Tambach-Dietharz, Thuringia) yielded one of the most important tetrapod associations of this time interval as regards diversity and preservation, consisting of both skeletons and footprints (e.g., Lucas, 2018; Voigt and Lucas, 2018). So, it is important to know a precise age for this site. Unfortunately, radiometric ages are not available within the Tambach Formation, but its fossil content can be used for a reliable biostratigraphy, which can be combined with the recent radiometric ages on underlying formations (Lützner et al., 2021). The Bromacker locality belongs to the Tambach Sandstone Member of the Tambach Formation, consisting of typical fluvial red beds. At this locality, the succession is exposed for about 10 m and consists of tabular to cross-stratified sandstone beds interbedded with thin laminated mudstone horizons, passing upwards to cross-stratified fine-grained sandstone and laminated thin mudstone layers (Eberth et al., 2000).

Tetrapod footprints, known since the 19th century because of quarrying activities, include exceptionally-preserved and long trackways, mostly preserved in convex hyporelief on the bottom of sandstone beds (e.g., Voigt and Haubold, 2000; Marchetti et al., 2020). The ichnoassociation includes the ichnogenera *Ichniotherium* (diadectomorphs), *Amphisauropus* (seymouriamorphs), *Dimetropus* (non-therapsid synapsids), *Notalacerta* (captorhinomorphs), *Varanopus* (bolosaurian parareptiles), and *Tambachichnium* (varanopids). New research part of the BMBF funded project Bromacker 2020-2025 highlights the additional occurrences of the ichnogenera cf. *Batrachichnus* and *Limnopus* (temnospondyls) and *Dromopus*