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UPPER CAMBRIAN/LOWER ORDOVICIAN
CONODONT AND GRAPTOLOGITE RECORDS
IN THE LARI SECTION, SALAR DEL RINCÓN,
PUNA OF SALTA, ARGENTINA

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GEOLOGIC SETTING AND STRATIGRAPHY

An extensive Paleozoic succession covered by Cenozoic deposits is exposed in the Lari creek (Upper Cambrian-Permian) (Fig. 1). The oldest unit referred to as Tremadocian is the Las Vicuñas Formation (Moya et al., 1993), which is characterized by clastic and pyroclastic rocks, calcarenites and coquinas corresponding to platform environments (Moya et al., 1993; Koukharsky et al., 1996). The basal part of the formation is covered by Quaternary debris, and the upper succession is intruded by Ordovician quartzitic porphyries unconformably covered by the Salar del Rincón Formation (Aceñolaza et al., 1972a y b), which preserves Hirnantian to Llandovery marine faunas (Isaacson et al., 1976; Benedetto and Sánchez, 1990; Vaccari et al., 2010; Galli et al., 2010).

The Cerro Oscuro Formation (Aceñolaza et al., 1972a, b) unconformably overlies the Salar del Rincón Formation. Its age is assigned to the Late Carboniferous according to paleobotanical remains. Lower Permian rocks corresponding to the Arizaro Formation (Aceñolaza et al., 1972a, b) paraconformably overlie the Cerro Oscuro Formation. The youngest units of the area are described as tuffs and ignimbrites of the Tajamar Formation (Neogene), as well as Quaternary clastic deposits and volcanic rocks (Galli et al., 2010, and references therein).

In Lari Creek, the Las Vicuña Formation is ca. 220 m thick (Moya et al., 1993). The lower 5 m are composed of green-gray silty shales overlain by a succession of pyroclastic rocks and
quartz sandstones, ca. 132 m thick. The unconformably overlain upper part of the formation is made up of black shales that are partly silicified, and fine sandstones, calcarenites, calcareous shales and coquinas. This upper part of the unit that bears the conodonts and graptolites studied herein, reaches ca. 124 m thick in the measured profile (Fig. 2). These shales are intruded by a quartzitic porphyry in the uppermost strata of the Las Vicuñas Formation.

Coquinas, calcarenites and calcareous concretions are distributed throughout the upper part of the formation; nevertheless, only the two lower beds yielded conodonts. Rao et al. (2000) documented *Cordylodus caboti* Bagnoli, Barnes and Stevens, *C. intermedius* Furnish, and *Phakelodus tenuis* (Müller) for the same strata. Additionally, our conodont collection includes *Cordylodus lindstromi* Druce and Jones, *C. proavus* Müller, *C. deflexus* Bagnoli, Barnes and Stevens and *Teridontus nakamurai* (Nogami) (Fig. 3).

The uppermost strata of the Las Vicuñas Formation bear an abundant and monotonous graptolite fauna composed of *Rhabdinopora flabelliformis* cf. *f. parabola* (Bulman) (Fig. 3). The first mention of this fauna was made by Rao et al. (2000), who reported the presence of *Rhabdinopora* sp. Recently, Vacarri et al. (2010) and Toro et al. (2011) cited *R. f. parabola*.  

Figure 1. Location map of the study area and geology of Lari Creek, Salar del Rincón (modified from Galli et al., 2010).

Figure 2. Stratigraphic column of the Las Vicuñas Formation at Lari Creek, with the ranges of the conodonts and graptolites and the corresponding biozonation (Cn.: conodont zone; Gr.: graptolite zone; *R. f. parabola*: *Rhabdinopora flabelliformis parabola*. Black stars represent the species records by Rao et al., (2000).

The Tremadocian succession of Lari Creek was folded and faulted during the Ocloyic Phase, as evidenced by the angular unconformity between the Las Vicuñas Formation and the Hirnantian/Llandovery strata of the Salar del Rincón Formation (Donato and Vergani, 1985; Moya et al., 1993). Other tectonic events were dated as Carboniferous and Cenozoic, related to Andean tectonics (Moya et al., 1993). The studied section corresponds to a faulted syncline with minor folds in the hinge.

**BIOSTRATIGRAPHY**

**Conodonts**

All of the conodont species recorded in the studied section span the Cambrian/Ordovician boundary; although, the conodont association documented is characteristic of the *Cordyloodus lindstromi* Zone. It is scarcely represented in coquinas and calcarenites of the basal upper part of the Las Vicuñas Formation, in the samples SR1 and SR2 (Fig. 2). The conodont record includes *Cordyloodus lindstromi* Druce and Jones, *C. preavus* Müller, *C. deflexus* Bagnoli, Barnes and Stevens, and *Teridontus nakamurai* (Nogami) (Fig. 3).

The *Cordyloodus lindstromi* Zone was defined in western North America by Miller (1988), and Barnes (1988) recognized it in western Newfoundland. The records of *C. lindstromi* in Utah, Texas and Oklahoma correspond to the *C. lindstromi* and *Iapetognathus* zones according to Nicoll et al. (1999). This biozone is represented worldwide with records in Australia, Canada, China, Iran, and Kazakhstan (Cooper et al., 2001). In northwestern Argentina, the *Cordyloodus lindstromi* Zone was determined in the Cajás range, Tilcara range, and the Parcha area from Cordillera Oriental and the Salar del Rincón from the Puna of Salta province (Rao, 1999; Tortello et al., 1999; Pacheco, 2009; Zeballo et al., 2011, among others), and in the Volcanicto Formation, Famatina System (Albanesi et al., 1999, 2005).

The base of the *C. lindstromi* Zone was informally considered as the base of the Ordovician System (Barnes, 1988). Later, Cooper et al. (2001) recognized the conodont *Iapetognathus fluctivagus* Nicoll et al. as marker of the Cambrian/Ordovician boundary, including the *C. lindstromi* Zone in the Furongian (Stage 10). When *I. fluctivagus* is absent, *C. lindstromi* can be considered as an approximation of this systemic boundary.

Reassessing the GSSP of Green Point, Terfelt et al. (2012) observed that the specimens of *I. fluctivagus* illustrated by Cooper et al. (2001) would correspond to *I. preavus* Landing, which appears in the *Cordyloodus intermedius* Zone (*Hursutodontus simplex* Subzone) of late Cambrian age. Thereby, if the revision of Terfelt et al. (2012) were verified, the *C. lindstromi* Zone would be reestablished in the Tremadocian Stage.

**Graptolites**

Black shales from the upper Las Vicuñas Formation bear specimens of *Rhabdinopora* (Fig. 3), which are abundant in some levels. It is a monotonous graptolite fauna composed of siculae, proximal ends, and juvenile and mature rhabdosomes, usually incomplete and poorly preserved. Quadriradiate proximal development is observed in growth stages preserved in disoidal view. The rhabdosome outline form is variable, ranging from broad to narrow cone shape. The sicula is 1 mm in length. The stipes are sinous, spaced from 11 to 12.5 in 10 mm in the distal part of the rhabdosomes, but in some specimens this number can be 13 to 13.5. In the proximal part of some rhabdosomes it is possible to measure 9 stipes in 10 mm, but this spacing tends to be variable. Thecae, rarely preserved, are spaced in number of approximately 14 in 10 mm. Dissepiments are thin, normal to inclined to the stipes, and irregularly spaced throughout the mesh, counting more than 17 in 10 mm, in some specimens. This material resembles *R. flabelliformis parabola* in the presence of an irregular meshwork, with sinuous stipes. However, the stipes are closer spaced than in this subspecies (8-11 stipes in 10 mm), a character that does not allow safe taxonomic identification.

The graptolite material studied in the upper part of the Las Vicuñas Formation can tentatively be referred to the *Rhabdinopora flabelliformis parabola* Zone, the second graptolite zone of the Tremadocian Stage (Cooper et al., 1998), until new information about this fauna is obtained.

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Figure 3. Upper Cambrian/Lower Ordovician conodonts (Cordylodus lindstromi Zone) and Lower Ordovician graptolites (Rhabdinopora flabelliformis parabola Zone) from Lari Creek, Puna Occidental, Salta Province, Argentina. 1-4, Teridontus nakamurai (Nogami), 1, Sb element, 2-3, Sd element (CORD-MP 28403/1-24), 4, Sc-Sc7 element (CORD-MP 28048/1). 5-7, Cordylodus lindstromi Druce and Jones, M elements, 5-7, (CORD-MP 28406/1-3). 8, Cordylodus deflexus Bagnoli, Barnes and Stevens, compressed element S (CORD-MP 28405/1), 9-12, Cordylodus proavus Müller, 9, 11, (CORD-MP 28401/1-13), 12, (CORD-MP 28407/1). Scale bar: 0.1 mm. 13-16, Rhabdinopora flabelliformis cf. f. parabola, 13, Proximal part of mature colony with parabolic form (CORD-PZ 33057), 14, detail of meshwork showing dissepiments and stipe dendroid structure (CORD-PZ 33055-b 1), 15, proximal end (CORD-PZ 33055-b 2), 16, mature rhabdosome (CORD-PZ 33061-b). Scale bar: 1 mm.
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