The Cerro La Chilca, Central Precordillera, San Juan Province

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Introduction

The Geological Province of Precordillera (*sensu* Furque & Cuerda, 1979) is a typical thin–skinned thrust–and–fold belt, about 600 km in length, extending from the south of the La Rioja Province to the south of the Mendoza River, entirely crossing the San Juan Province. It includes three morphostructural units: Eastern Precordillera (Ortiz & Zambrano, 1981), Central Precordillera (Baldis & Chebli, 1969) and Western Precordillera (see Baldis *et al*., 1982). From a stratigraphic point of view, the Precordillera is characterized by the broad occurrence of Paleozoic rocks, mainly from the Lower Paleozoic, which includes conspicuous Middle–Upper Ordovician graptolite–rich black shales sequences, restricted to shallow–water environments in the Eastern and Central Precordillera, whereas in the Western Precordillera they are related to deep–water environments, evidenced by hemipelagic and turbiditic deposits, intercalated with basaltic rocks related to ophiolitic complex (Ramos *et al*., 1984; Haller & Ramos, 1984; Ramos *et al*., 1986). In contrast to the well studied units of the Eastern and Central Precordillera, the Lower Paleozoic biostratigraphy of the Western Precordillera is still not well–constrained, and only sporadic fossils, mainly graptolites, are known, and a few sections were measured in detail.

Several significant Middle–Upper Ordovician sections are located across the Guandacol, Jáchal and San Juan rivers, where most important exposures are represented by the Trapiche Group and the Gualcamayo, Los Azules, Las Aguaditas, La Cantera, La Invernada, Los Sombreros, and Yerba Loca formations. These units are entirely or partly, Caradoc in age, while the younger Alcaparrosa Formation is uppermost Ordovician (Brussa *et al*., 1999). Far away to the South, in San Isidro Creek, Mendoza province, the Empozada Formation (Middle–Upper Ordovician), includes in the lower part a Darriwilian–Caradoc graptolitic black shale sequence (Cuerda, 1979; Heredia *et al.,* 1996), besides of Hirnantian graptolite faunas of the *complanatus* and *ornatus* zones (Mitchell *et al*., 1998). In some of mentioned lithostratigraphic units, graptolite faunas appear associated with trilobites, brachiopods, and other shelly fossils and microfossils, in particular conodonts.

In the Los Azules Formation, the graptolite *Nemagraptus gracilis* was firstly recorded by Borrello & Gareca (1951), in the reference section located in the Cerro Viejo area. However, in the Ordovician of the Precordillera, the *Nemagraptus gracilis* Zone was formally recognized in a biostratigraphic contribution by Harrington & Leanza (1957). Later, several contributions regarding the occurrence of graptolites from the *N. gracilis* Zone were provided by other authors (Furque & Cuerda, 1979; Peralta, 1986, 1990; Ortega & Brussa, 1990; Brussa, 1996, 1997). On the other hand, Ordovician black shale sequences of the Precordillera and a green–house event during the *N. gracilis* Zone (see Berry *et al*., 1978; Lagget *et al*., 1981; Arthur, 1983;

Jenkyns, 1986) have been widely discussed in previous papers (Peralta & Barrera, 1992; Heredia & Beresi, 1994).

The Cerro La Chilca (La Chilca Hill) section
(See figure 1 for location)

The geological and stratigraphical features of the Cerro La Chilca area were described for the first time by Stappenbeck (1910) (cited by Cuerda & Furque, 1985); later, the lower Paleozoic sequence was revised by Cuerda (1965, 1966), who studied, in particular, the Silurian deposits. Blasco & Ramos (1976) described a Caradoc graptolite fauna that correspond to the *N. gracilis* Zone. This assemblage was collected from the graptolite–rich black shales that overlies fossiliferous limestones of the Lower Ordovician San Juan Formation. Astini & Benedetto (1992) recorded brachiopod remains from the upper part of the Ordovician sequence exposed in the Cerro La Chilca section, which belong to the *Hirnantia* Fauna. In the present Field Guide, the stratigraphic section of the Los Azules Formation, exposed in the Cerro La Chilca area, is considered in accordance to the stratigraphic framework given by Peralta (1998) (Figures 2, 3). In this section, the Lower Paleozoic succession consists, from the base to top, of the following lithostratigraphic units: the Ordovician succession is formed by the San Juan (Tremadoc to Lower Llanvirn), Gualcamayo (Lower Llanvirn), Los Azules (Lower Caradoc), and Don Braulio formations (Late Asghill). This units are followed by the Silurian La Chilca and the Los Espejos formations, and the Devonian Talacasto and Punta Negra formations.

The thick Lower Paleozoic succession crops out towards west of the Cerro La Chilca, which is the type locality for the Silurian Tucunuco Group. On the eastern side of the hill, an impressive thrust fault bounds the block, which can be traced over a hundred of kilometers striking N–S. The Cerro La Chilca is an asymmetric anticlinal structure with the Paleozoic rocks exposed on its western flank. Though the La Silla Formation (Uppermost Cambrian–Lower Ordovician) integrates the base of the sedimentary pile at Cerro La Chilca section, it is not considered in this description because only its uppermost part is exposed, and outcrops are not easily accessible.

The San Juan Formation (Kobayashi, 1937; Furque, 1963) in the sedimentary pile of the Cerro La Chilca section it is fault–bounded at the base. At the top of this unit a prominent hard–ground developed, including vertical burrows that penetrate several centimeters into the uppermost bed of the unit. Complete sections of the San Juan Formation, in which the lower as well as the upper boundary are well exposed (*cf.* Cerro Potrerillos section, Albanesi *et al.*, 1998) are rare or in part too difficult to access as is the case of Cerro La Chilca section, where the contact with the uppermost Cambrian until Tremadocian La Silla Formation is placed upwards into the range. In accordance with Keller *et al.* (1994), the San Juan Formation is a succession of predominantly limestones with only minor marlstones near the top. Dolomite occurs as patches of brown to yellow microspar in connection with pressure solution or particularly as burrow fillings. It differs from the underlying La Silla Formation due to the occurrence of an abundant and diverse fauna of trilobites, brachiopods, crinoids and sponges, among others. Of special interest for the reconstruction of the paleogeography and environments are reefal structures, such as reef mounds composed of stromatoporoids, sponges, algae and receptaculitidis (Cañas & Keller, 1993; Keller & Bordonaro, 1993).

Among the microfossils there are algae and conodonts (Hünicken, 1989; Sarmiento, 1990; Lehnert, 1993, 1995), which are important for the biostratigraphy of the deposits. Here, the lower part of the formation is characterized by the occurrence of massive limestone beds with isolated biolitites. In the upper part a mudstone–wackestone–shale association is preserved in some sections on the top of the San Juan Formation. The association is composed of dark to black mudstones and wackestones with intercalations of black shale beds. The latter may be as thick as 7 cm. The rocks were deposited under quiet water conditions, well bellow the storm wave base. Rare calcisiltite beds within this association are interpreted to represent distal tempestites (Cañas, 1995; Keller, 1999). The limestones are typical deep–water sediments and a hemipelagic origin is invoked. Deposition probably took place near the boundary between oxic and anoxic bottom conditions (Cañas, 1995), shown by the rapid change between trilobite–rich layers and anoxic mudstones without ichnfossils. This association is the "transfacies clacareo–pelítica" of Baldis & Beresi (1981), which marks the drowning of the platform (Keller, 1999). The upper part of the San Juan Formation shows platy limestone with thin intercalations of muddy and K–bentonite layers. The limestone bedding plane surfaces show remains of nautiloids (Orthoceratids) over 50 cm in length. At the top of the San Juan Fm. a prominent hard–ground developed, including vertical burrows that penetrate several centimeters in the top bed of the unit.

According to Keller *et al.* (1994), a complete section of the San Juan Formation in which the lower, as well as the upper boundary, are well exposed, are rare or in part too difficult to access, as it is the case of the Cerro La Chilca section. Therefore, these authors proposed the Cerro La Silla section, as a standard reference section for the San Juan Formation, where about 80% of the formation is well–exposed. Likewise, they proposed the Cerro La Chilca section as a standard for the upper part of this unit for its ease of access. In this section, the upper strata of the San Juan Formation are paraconformably overlain by an alternation of black shales and platy mudstones (in other places the transitional package is absent, and graptolitic black shales overlies the hardground on top of the formation). The upper part of the Early Ordovician carbonate succession, yields abundant shelly faunas but also conodont assemblages have been described (Lehnert, 1995)

A short mixed, carbonate–siliciclastic sequence belonging to the lower member of the Gualcamayo Formation overlies paraconformably the limestones of the San Juan Formation. This unit has been formerly described as the upper part of the San Juan Formation (Cuerda & Furque, 1985), and subsequently correlated with the lower Member of the Gualcamayo Formation by Peralta (1993, 1998), as previously interpreted by other authors for different sections (*cf.* Astini, 1994a, b; Ortega *et al.*, 1995). The Lower Member of the Gualcamayo Formation is 4.31 m thick and it is composed of an alternation of thin to medium layers of black, tabular marly limestones and dark–coloured, laminated shales that bear abundant shelly faunas and graptolites. Bed thickness is variable, ranging from 5 to 28 cm. The whole member shows a limestone/shale ratio of 62% – 38% on average. Its lower limit is separated by mean of paraconformity from the San Juan Fm., whereas the top is marked by the uppermost fossiliferous black limestone, which underlies the graptolitic black shales of the Los Azules Fm. (Peralta, 1998), early Caradoc in age. The limestone beds contain conodont faunas and abundant shelly–fossils dominated by trilobites and brachiopods, whereas the shales mostly bear graptolites. Cuerda (1986) recognized *Paraglossograptus tentaculatus* (Hall) associated with *Tetragraptus bigsbyi* (Hall), *Glyptograptus austrodentatus austrodentatus* Harris & Keble,

and *Glossograptus hincksii* (Hopkinson) in the La Chilca section, and assigned the transfacies to the eponymous biozone (Lower Llanvirn).

A new graptolite collection with *Pseudophyllograptus* sp., *Xiphograptus* sp. aff. *X. lofuensis* (Lee), *Pterograptus*? sp., *Holmograptus bovis* Williams & Stevans, *Acrograptus* sp., *Isograptus caduceus* Salter, *Arienigraptus zhejiangensis* Yu & Fang, *Undulograptus austrodentatus* (Harris & Keble), *U.* sp. cf. *U. dentatus* (Brongniart), *U. sinicus* (Mu & Lee), and *U. primus* (Legg) offers a more detailed information about the faunal composition and age of the Gualcamayo Formation in the studied section (Ortega and Peralta, in progress) (see Figure 5). *P. tentaculatus* and specimens of isograptids and arienigraptids are particularly scarce in our collections. Pendent juvenile rhabdosomes classified as *Pterograptus?* sp. are abundant in the lower calcareous strata of the unit, while biserial graptolites become dominant elements in the upper levels. This graptolite assemblage could be referred to the *U. austrodentatus* Zone or the lower part of the *U. dentatus* Zone considering the scheme of Point Levis, Canada, given by Maletz (1997). It suggests an early Darriwilian age (Da1–Da2) for the bearing rocks. Similar graptolite faunas are present in the lower member of the Los Azules Formation at Cerro Viejo section (Mitchell et al., 1998; Brussa et al., 2003; Ortega & Rickards, 2003).

In addition, conodonts were tentatively assigned to the *Eoplacognathus suecicus* Zone (Keller, 1999). Trilobites from the succession include *Geragnostus* sp., *Neptunagnostella superba* Shergold, *Kweichowilla* sp. nov. A, *Porterfieldia* sp. *Nileus depressus* n. subsp. A, *Mendolaspis salagastensis* Rusconi, *Carolinites* n. sp. A,*Carolinites* aff. *pardensis* Legg, *Macrogrammus pengi* Edgecombe *et al*., and Illaenidae gen. et sp. indet (Tortello & Peralta, 2003). The nileid community, originally described from the Arenig–Llanvirn of Spitsbergen (Fortey, 1975), is mainly characterized by the occurrence of raphiophorids, nileids, shumardids and metagnostids. The genus *Mendolaspis* largely dominates the assemblages of La Chilca, representing more than 75% of the total fauna. Benthic nileids, shumardids and olenids were especially adapted to outer shelf, low–oxygen environments. Likewise, long genal spines of the blind raphiophorids may have favoured the permanence of the animal on the soft floor, preventing a sinking in the mud (see figure 2).

Correlations based on species which show wide geographical distributions and independence of benthic communities are more reliable than those based on comparisons of benthic assemblages occurring in similar biofacies (Fortey, 1975b). The occurrence of the pelagic genus *Carolinites* at the Cerro La Chilca section provides valuable biostratigraphic information. *Carolinites* n. sp. A has been previously recognized from the Lower Llanvirn of the Keele Range (northwestern Yukon Territory, Canada), in association with conodonts tentatively assigned to the *Pygodus serratus* Zone (*Eoplacognathus suecicus*Subzone) (Dean, 1973) (*i.e., Eoplacognathus suecicus* Zone), and from the lower Middle Ordovician of Western Newfoundland (=Carolinites sp. 1 of Whittington, 1965).
Besides, *Carolinites* aff. *pardensis* compares more closely with material from the Goldwyer Formation (Canning Basin, western Australia), from levels assigned to the Lower Llanvirn (Legg, 1976), whereas the metagnostid *Geragnostus* sp. is most similar to material from the upper Arenig of the Guandacol area (Argentine Precordillera) and the lower Llanvirn of Canada (*Geragnostus* cf. *longicolis*, E. *suecicus* Zone).

In this section, the Early Ordovician black shales of the Los Azules Formation (see figure 3), were previously considered by Blasco & Ramos (1976), who called it informally "Cerro La

Chilca Shales", describing a graptolite assemblage that includes *Dicellograptus divaricatus* var. s*alopiensis, Leptograptus flaccidus*var. *macer* and *Climacograptus* sp., which is assigned to the *gracilis* Zone. Subsequently, Cuerda & Furque (1985) and Cuerda (1986) proposed the name of the Los Azules Formation (following original designation by Borrello & Gareca, 1951; see also Harrington & Leanza, 1957) for the black shales sequence bearing this graptolite fauna, being this one the formal name to designate homologous deposits of Caradoc age, which appears in the same stratigraphic position towards the northeast, in the Cerro del Fuerte and Cerro Viejo sections. Astini & Benedetto (1992) included this unit within the upper Member of the Gualcamayo Formation. However, it is possible to recognize typical Llanvirn fossiliferous black shales sequences, intercalated between the top of the limestones of the San Juan Formation and the base of the Caradocian units (*i.e.,* Los Azules Formation). For this reason, the stratigraphic arrangement given by Astini & Benedetto (1992) to Caradoc graptolitic shales from the Cerro La Chilca section should no longer be followed.

The Los Azules Formation is composed by a conspiscuous graptolitic black shales sequence with seven interbedded black limestone levels, which bear the trilobite genus *Guandacolithus* (Tortello & Peralta, in progress), and conodonts of the upper part of the *Pygodus anserinus* Zone (Albanesi, in progress) that characterize the early Caradoc. This formation is paraconformably, (erosional surface) overlain by coarse debris flow deposits of the Don Braulio Formation, late Ashgill in age. According to Peralta (1998), the Los Azules Formation is composed of 78 m of graptolitic black shales, interbedded with thin argillaceous limestone levels occurring intercalated into the sequence, bearing graptolites, conodonts, brachipods and trilobites. The graptolite fauna from the *gracilis* Zone, which indicates an early Caradoc age, was described by Blasco & Ramos (1976). Same criteria is supported by Cuerda & Furque (1985), who remarked the occurrence of an important hiatus between the top of the Llanvirn deposits of the Gualcamayo Formation, bearing graptolites of the *Paraglossograptus tentaculatus* Zone, and the base of the Los Azules Formation, which contains the Caradoc graptolite fauna. The associated trilobite and conodont fauna is recorded for the first time in this area of the Precordillera; in particular, the conodont record supports the graptolite biostratigraphy for world–wide correlation.

In last years, findings of graptolites in various stratigraphic levels of the Los Azules Formation, in the sense given by Cuerda & Furque (1985), made possible more detailed analyses of the age of this unit. We can observe that in the lower part of the section, the graptolitic fauna occurs in the whole black shales succession, as well as in the interbedded limestone lenses, where *Nemagraptus gracilis*, *Dicellograptus alabamensis*, *Dicellograptus gurleyi gurleyi, Cryptograptus marcidus*, *Leptograptus flacidus macer*, *Hustedograptus teretiusculus,Glyptograptus euglyphus* and *Dicranograptus irregularis?* are dominant, associated with the genera*Glyptograptus* and *Diplograptus*. However, in the middle part, *Nemagraptus gracilis*, *Dicellograptus gurleyi gurleyi*, *Leptograptus trentonensis*, occur together with *Climacograptus, Amplexograptus,* and *Cryptograptu*s. In the upper part, *N. Gracilis* is scarce or absent. In the limestone lenses a graptolite fauna is mainly composed of *Dicellograptus alabamensis, Dicellograptus gurleyi gurleyi* and *Dicranograptus* sp., whilst *Climacograptus*, *Amplexograptus*, and *Leptograptus* are less abundant, and the trilobite *Guandacolithus* appears together with this graptolite assemblage.

According to Peralta (1998) the graptolite assemblages included in the black shales, the age of the Los Azules Formation might be related to the *Nemagraptus gracilis* Zone (Finney & Bergström, 1986). In agreement with mentioned authors, such biozone is characterized

by *Nemagraptus gracilis* and other
nemagraptids, *Dicellograptus*, *Dicranograptus*, *Cryptograptus*, *Glossograptus*, *Glyptograptu*s, *Climacograptu s, Leptograptus*, and *Orthograptus*, among other genera. On the other hand, the lower and upper boundaries of the *N. gracilis* Zone can not be recognized because of the incomplete sedimentary record of the Los Azules Formation. However, the graptolite taxa suggest the lower part of *gracilis* Zone (Peralta & Finney, 2003). On the basis of the biostratigraphic significance of the collected faunas, and sedimentological studies, the black shales of the Los Azules Formation were deposited during the basal Caradoc epoch, in agreement with the occurrence of graptolites of the lower part of the *Nemagraptus gracilis* Zone. The whole euxinic sequence of the Los Azules Formation, very rich in organic remains, may be related with the transgressive and anoxigenic event, recognized world wide, and its facies sequence could be interpreted as a main rise in the sea level. This sequence in the Ordovician of Precordillera, is followed by a lowering at the Late Ordovician, during the Gondwanan glacial episode (Peralta & Carter, 1990).

At the top, the Los Azules Formation is disconformably (erosional surface) overlain by the basal coarse debris flow deposits of the Don Braulio Formation. These deposits are succeeded by bioturbated mudstones, which pass upward to fossiliferous mudstones and siltstones deposits bearing well preserved rest of brachiopods of the *Hirnantia* Fauna (Astini & Benedetto, 1992), including *Paromalomena polonica, Drabovia undulata,*and *Plectothyrella crassicosta* associated with the trilobite *Dalmanitina sudamericana* (Peralta, 1998), Hirnantian in age. Basal debris flow are composed mainly of calcareous clasts showing provenance from the underlying Ordovician units, but also minor chert and siliciclastic clasts are present in these deposits. It is paraconformably overlain by the basal cherty pebbly conglomerate of the Tucunuco Group. The Don Braulio Formation is also exposed in the Sierra de Villicum, at Eastern Villicum, where the Hirnantian fauna, and trilobites are associated to mono–type graptolite assemblage of the *persculptus* zone (Peralta & Baldis, 1990).

The Cerro La Chilca section is the type locality to the Tucunuco Group, about 370 m thick, including the lower La Chilca, and upper Los Espejos formations (Cuerda, 1965, 1966, 1969) (figure 4). For many years the age of this group has been thought as Silurian *sensu lato*. However, since the contributions by Cuerda *et al.* (1982) and Benedetto *et al.* (1991) papers, the age range was extended from the Hirnantian, *persulptus* Zone in the base at the Talacasto section, until Lower Lochkovian at the Cerro del Fuerte section. The Tucunuco Group paraconformably overlies the Hirnantian Don Braulio Formation, and is disconformably (erosional surface) overlain by glaci–marine Upper Carboniferous deposits of the Guandacol Formation. This erosional surface is related to the Chánica tectonic phase, which marks the beginning of the Gondwanan upper Paleozoic succession over all Argentina. Towards the south, at the La Dehesa and San Juan River area, within the Central Precordillera setting, the Tucunuco Group correlates with the equivalent Tambolar Formation (Peralta *et al.*, 1997).

Siliciclastic deposits of the Silurian La Chilca Formation, 110 m thick, continue upward in the succession, conformably overlying the Hirnantian deposits of the Don Braulio Formation. At the top it is overlain through a paraconformity by the upper Los Espejos Formation. The base of this unit is characterized by the occurrence of a conspicuous thin tabular conglomerate level ubiquitous in the Central Precordillera setting at the base of both Tucunuco Group and the Tambolar Formation. From a sequential point of view, the La Chilca Formation represents an unconformably bounded shallowing–upper sequence, starting with a basal cherty pebbly

conglomerate, 15–20 cm thick, and succeeded by a thin ironstone bed, 10–20 cm in thickness. The succession continues up with bioturbated phosphate rich siltstones and mudstones passing transitionally upwards to fine grained quartz sandstones with HCS structures, and scarce interbedded carbonate level in the upper part. A ferriferous–phosphate level appears to the top, as a conspicuous diagnostic level, evidencing slow sedimentation rate but high bioturbation rate, which might be considered as a condensed level. It is related to the drowning surface as a result of the transgressive event that evolved since deposition of the overlying Los Espejos Formation.

From a biostratigraphic point of view, the age of the La Chilca Formation ranges from the Late Ashgill until Late Llandovery–Early Wenlock. However, no Late Ashgillian fauna has been found at the basal part of the formation in this section. A Hirnantian age is assumed taking into account the record of*persculptus, acuminatus*, and probably *atavus* zones in the Los Baños section at Talacasto area (Cuerda *et al*., 1982, 1988; Melendi & Volkheimer, 1982). In same way, the Late Llandovery–Early Wenlock age has only been recorded in the Quebrada Ancha de Talacasto section, based on the finding of the*Monograptus priodon* (Bronn) in a siltstone level at the upper part of the formation. In the La Chilca section, brachiopod faunas were only described by Benedetto (1995) which correlate with the Early Silurian (Llandovery). The sandy part of the formation bears abundant trace fossils, such as *Planolites, Paleophycus, Arenicolites* and *Chondrites,* indicating the *Cruziana* Ichnofacies.

The succession continues up with the 260 m thick Los Espejos Formation (Upper Silurian), that conforms an unconformity–bounded, shallowing upward sequence, conformably overlying the La Chilca Formation, which in turn is conformably overlain by the Lower Devonian Talacasto Formacion. The lower part of the Los Espejos Formation is predominantly composed by reddish and greenish phophaste–rich bioturbated mudstones and shales, containing a shelly fauna that includes brachipods as *Harringtonina, Clarkeia* and *Australina,* among others, associated with trilobites, nautiloids, ostracods, and crinoids. In the middle part, the shaly succession includes thin sandstone beds bearing shelly fauna and abundant trace fossils of the *Cruziana* Ichnofacies. In the upper part, sandstone beds become thicker showing HCS structures associated to storm and shell–beds. Most beds bear coquinas and trace fossils of the *Cruziana* Ichnofacies: *Cruziana, Rusophycus, Rhyzocorallium, Planolites, Paleophycus, Thalassinoides, Arenicolites,* and *Chondrites,* among others. In the middle part, *Saetograptus argentinus* occurs associated with shelly fauna, while *Monograptus uncinatus* var. *notouncinatus* occurs at the upper and uppermost part of the formation.

Lower Devonian rocks are represented by the Talacasto Formation, over 350 m in thickness (Lower Devonian). This unit conformably overlies quartz sandstones of the La Chilca Formation and at the top is in paraconformity contact with transgressive shales of the Punta Negra Formation. The contact surface between these units is interpreted as a drowning surface in which ferriferous and phosphate mineralizations are widely distributed. This formation show typical coarsening–thickening upward sequence, paraconformity–bounded, and is made–up of fossiliferous mudstones and siltstones prevailing at the base, which bear brachiopods, corals, bivalves, bryozoans, and trilobites, among others. These deposits pass upwards to fossiliferous siltstones and fine–grained sandstones, which are succeeded by coarse sandstone beds as main components in the upper part. The age of this unit, based mainly on its brachiopod and trilobite faunas is assigned to the Early Devonian, Lochkovian, Pragian up to Upper Emsian, according to data provided by Baldis (1975) and Herrera (1990). The last

author gave a detailed list of the brachiopod fauna and recognized 35 genera and 46 species collected from six stratigraphic sections, including among them, the Cerro La Chilca section.

The Lower (Emsian) to probably Middle? Devonian is represented by the siliciclastic marine deposits of the Punta Negra Formation, over 1000 m thick. This formation, as well as, the underlying Talacasto Formation, shows a thickening–coarsening upward sequence arrangement, which a remarkable shallowing features as demonstrated by sedimentology and ichnologic assemblages that occur in the whole formation. This unit conformably overlies the Talacasto Formation, and is erosionally overlain by Upper Carboniferous glaci–marine deposits of the Guandacol Formation. This erosional surface is interpreted as result of the Chánica tectonic phase, which marks the beginning of the Gondwanan geotectonic cycle overall Argentina and South America. Formerly, the age of this unit was supported on the basis of plant remains (Baldis, 1975). At present, the Early to probably Middle Devonian age of this formation is constrained on the basis of the brachiopod fauna recorded by Peralta *et al.* (1995) in the Pachaco section, at San Juan River area, and by Herrera & Bustos (2001) at Las Chacritas section.

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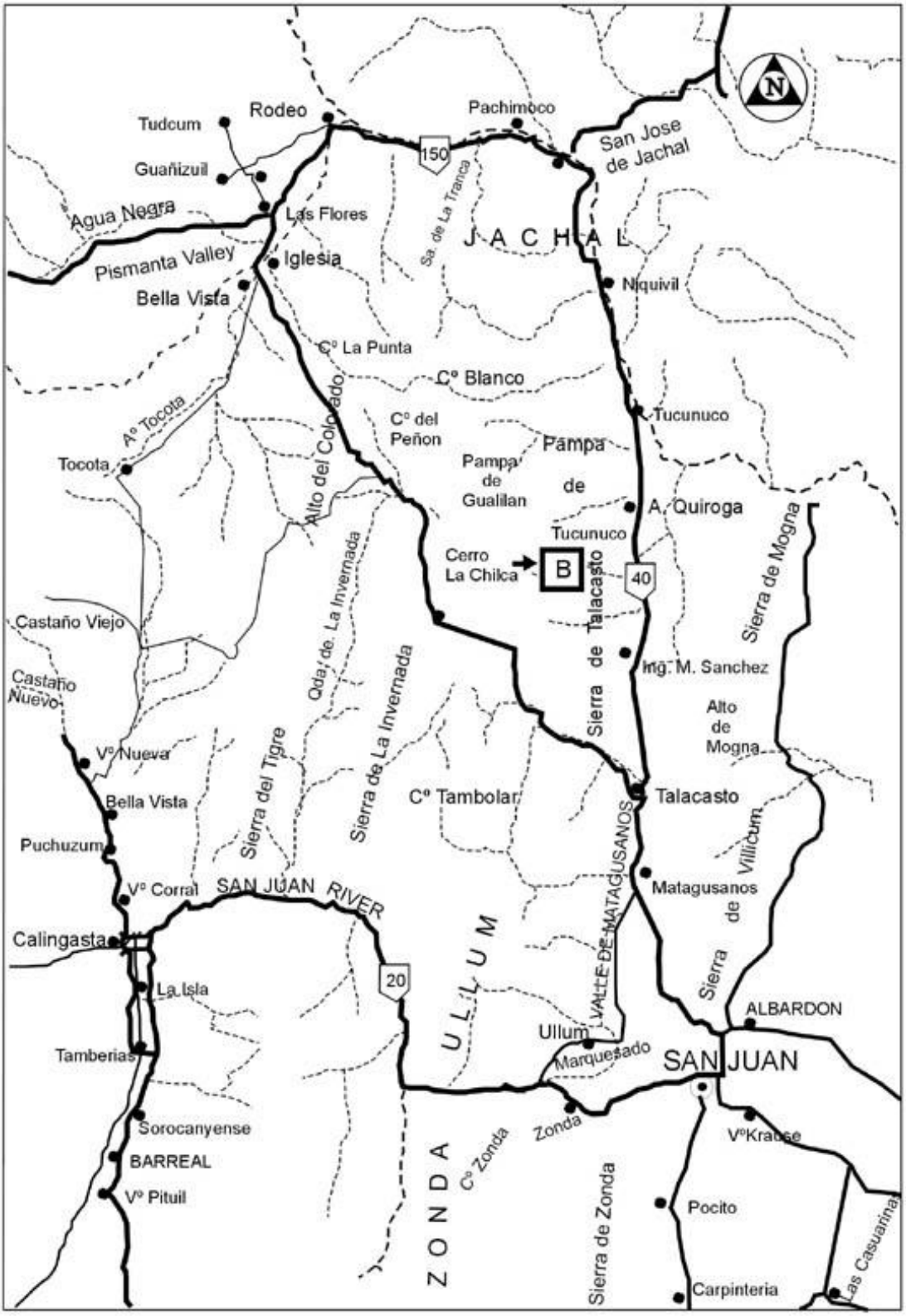


Figure 1. Location map of the Cerro La Chilca section (B).

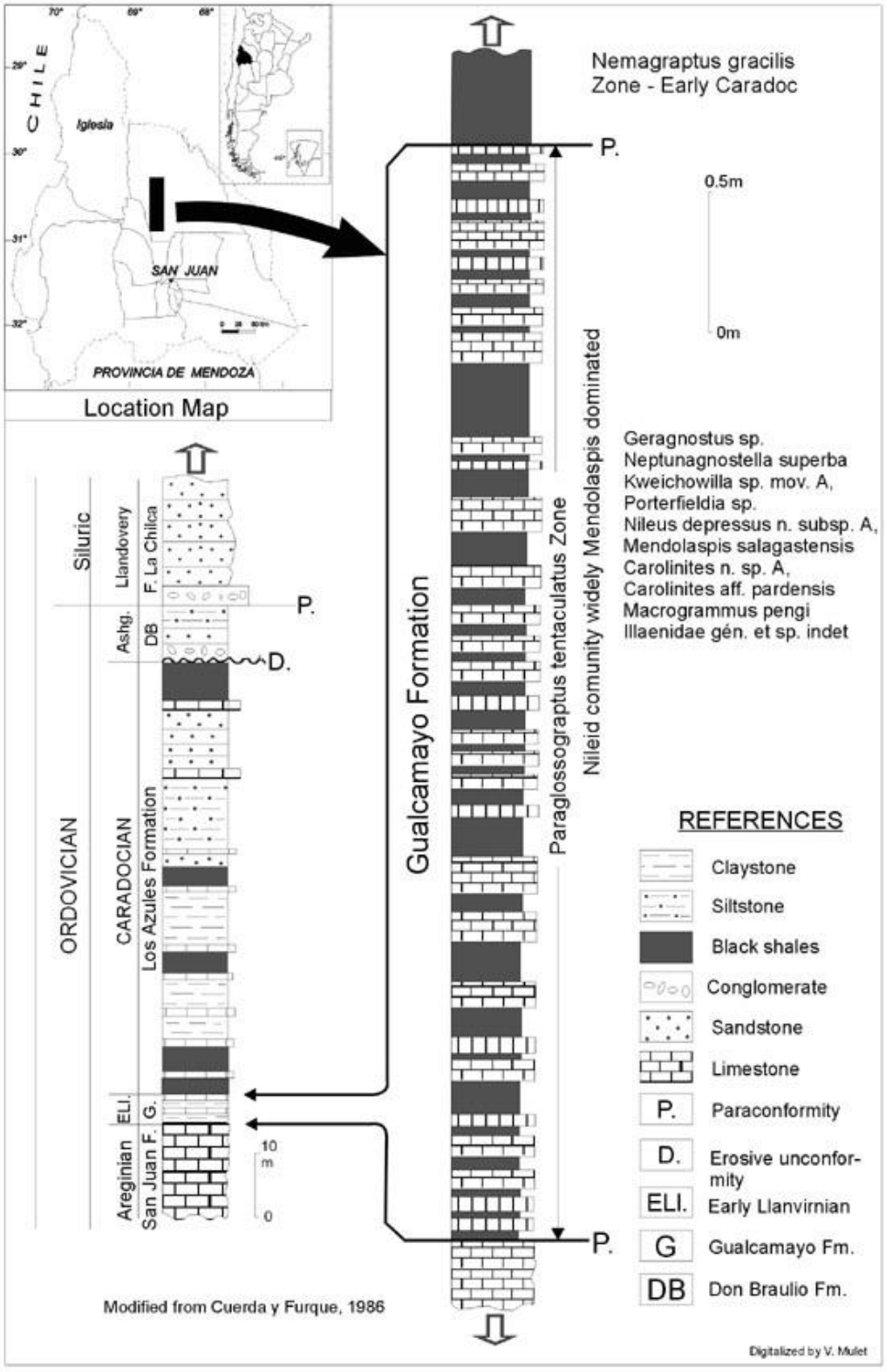


Figure 2. Stratigraphic column of the Gualcamayo Formation (Llanvirn).

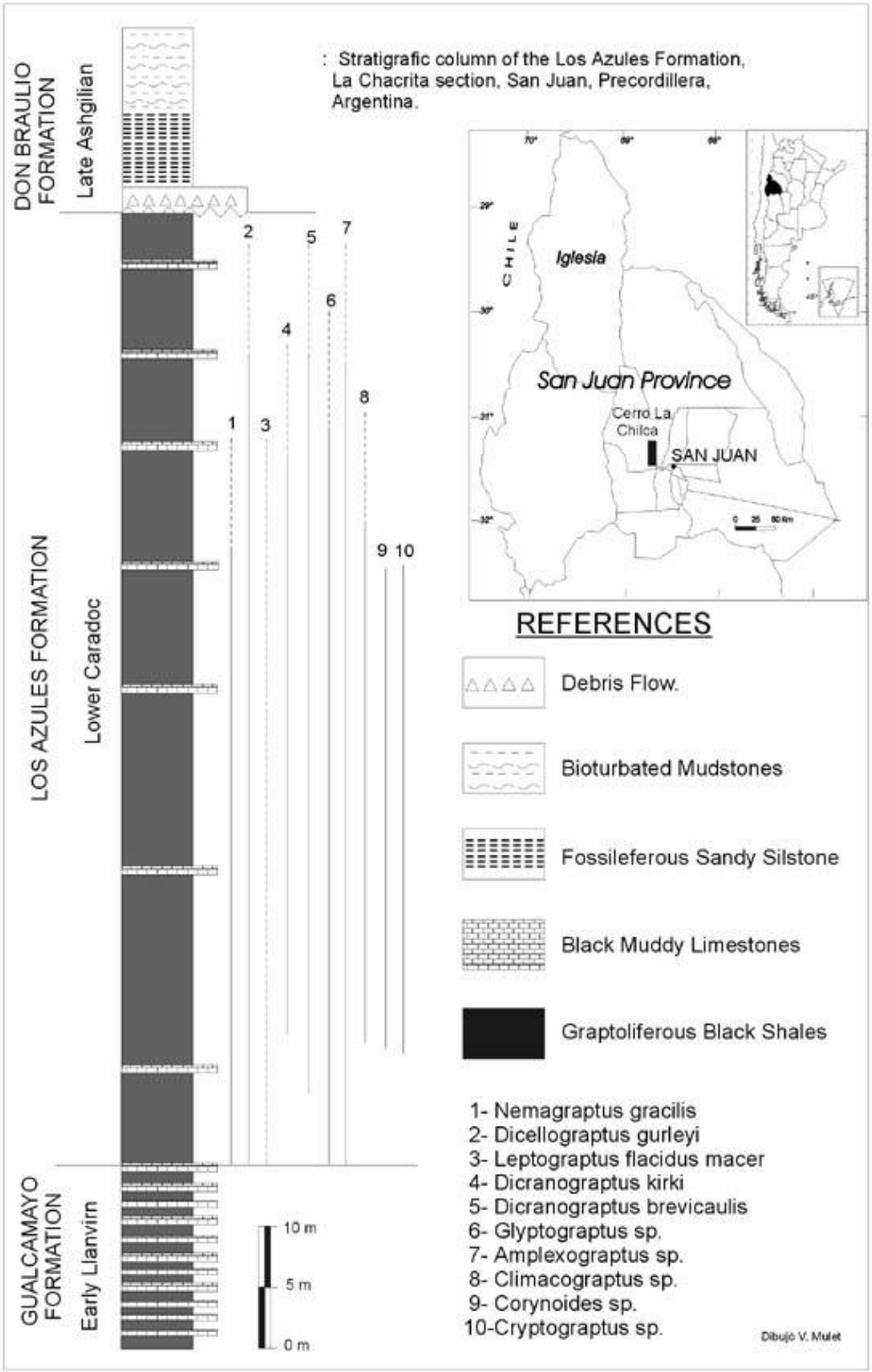


Figure 3. Stratigraphic column of the Los Azules Formation (lower Caradoc).

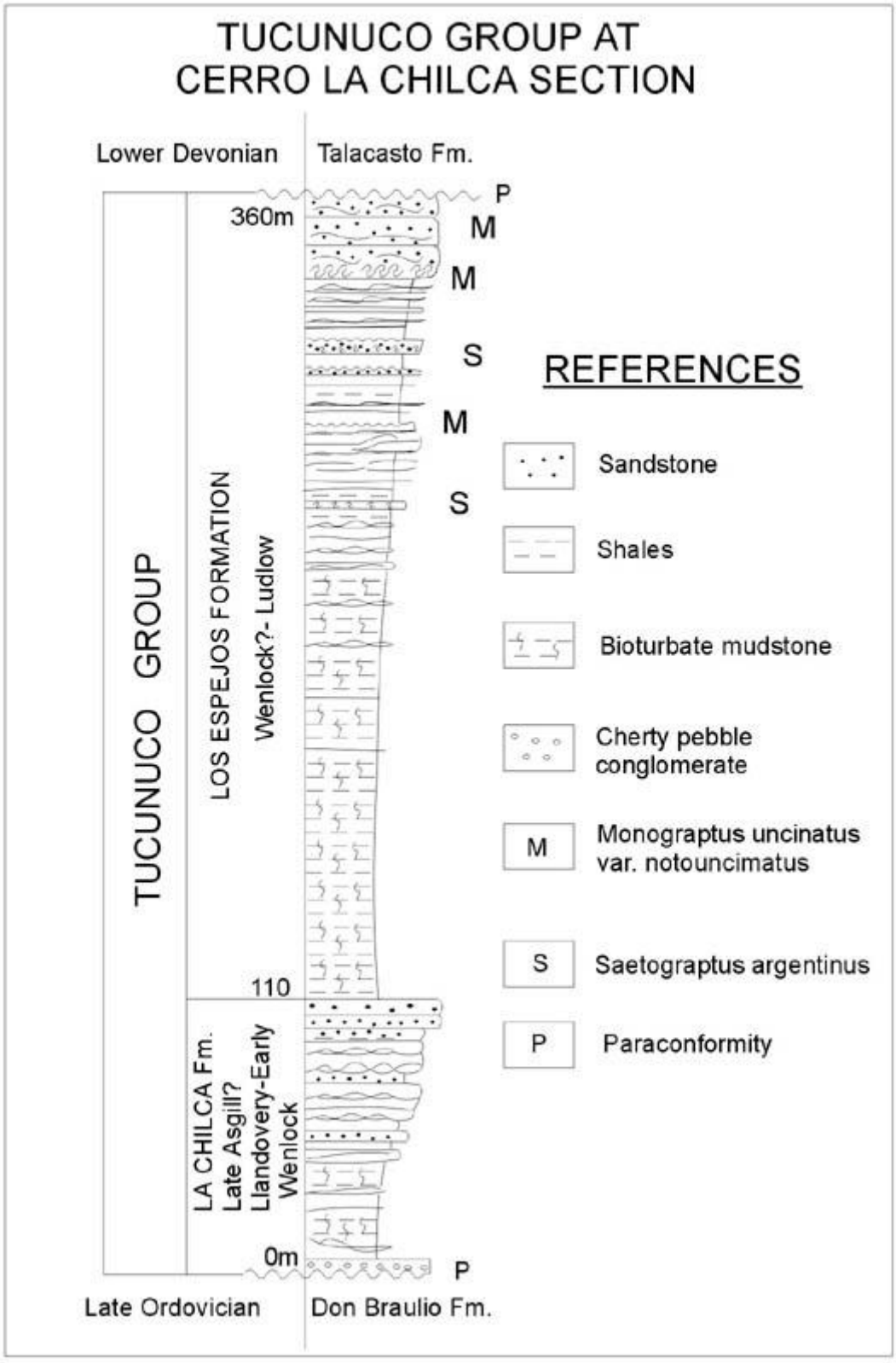
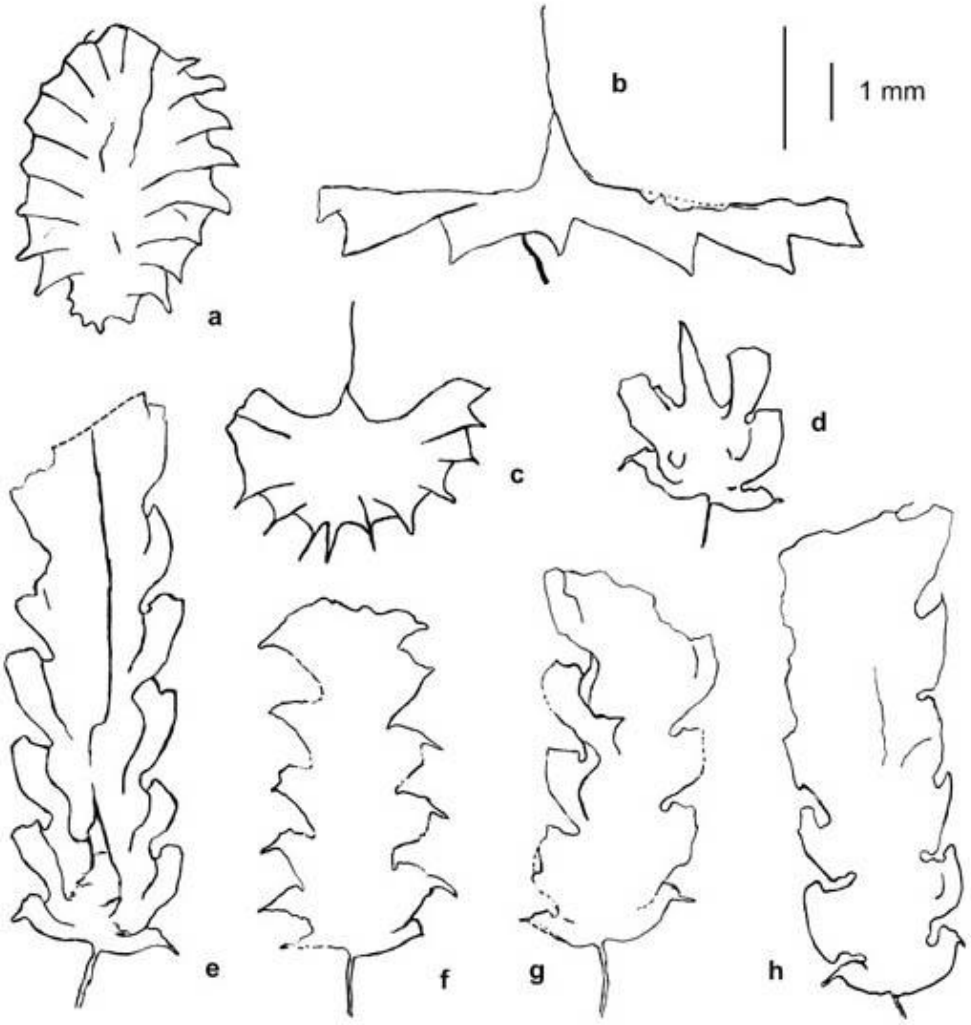


Figure 4. Stratigraphic column of the Tucunuco Group (upper Ashgill–Silurian–Lochkov).



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Graptolite assemblage of the Gualcamayo Formation from the Cerro La Chilca section, Precordillera of San Juan.
a, *Pseudophyllograptus* sp., CORD-PZ 22327; **b**, *Xiphograptus* sp. aff. *X. lofuensis* (Lee), CORD-PZ 22249; **c**, *Arienigraptus zhejiangensis* (Yu & Fang), CORD -PZ 22410; **d, e, g**, *Undulograptus austrodentatus* (Harris & Keble), d, CORD-PZ 22456, e, CORD-PZ 22410, g, CORD-PZ 22456; **f**, *Undulograptus sinicus* (Mu & Lee), CORD-PZ 22328; **h**, *Undulograptus primus* (Legg), CORD-PZ 22470. All figures x12 except for a, b x6. Scale bar: 1 mm (Ortega & Peralta, in progress).

Fig. 5