

Los Azules Formation, Cerro Viejo, Huaco, Precordillera of San Juan Province

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Introduction

The Ordovician black shales of the Cerro Viejo of Huaco were originally mentioned by Borrello & Gareca (1951), who reported *Nemagraptus gracilis* in its upper part. The succession was known by different names in the geological literature (Harrington & Leanza, 1957; Turner, 1960) until Cuerdo & Furque (1975), who referred it to the Los Azules Formation, and considered a Llanvirn to Caradoc age. The unit crops out on the western flank of the Cerro Viejo, between 30° 11' 40" and 30° 15' 30" S Latitude, and 68° 34'30" and 68° 35'20" W Longitude, in the Central Precordillera, San Juan Province (Figure 1).

The Los Azules Shale is composed of three members informally named as lower, middle and upper members, cropping out in many sections on the western flank of the Cerro Viejo anticline (Ortega, 1987) (Figures 2, 3). The lower member (*ca.* 6 m thick) is made up of silicified black shales and K–bentonite levels, which conformably overlie the San Juan Limestone. A rich graptolite fauna occurs. It was originally assigned to the *Paraglossograptus tentaculatus* Zone (Alfaro & Cuerdo, 1986; Ortega, 1995) and subsequently to the *Undulograptus austrodentatus* (Darriwilian Da1) and *Undulograptus dentatus* (Da2) zones (Mitchell *et al.*, 1998). Recently, *Undulograptus dentatus* and *Holmograptus lentus* zones were identified in the lower member (Brussa *et al.*, 2003; Ortega & Brussa, 2003).

A study of the K–bentonites of the Cerro Viejo succession infers an isotopic age of approximately 464 Ma for the lower levels of the Los Azules Formation (Huff *et al.*, 1997).

These strata are covered by brownish micaceous sandstones of variable thickness, and succeeded by grey siltstones and thin K–bentonites layers of the middle member. This member is *ca.* 220 m thick at the El Nido creek and *ca.* 95 m thick at the Los Azules creek. In these deposits the *Pterograptus elegans*, probably, *Pseudamplexograptus distichus*, and *Hustedograptus teretiusculus* zones (Darriwilian Da4) (Ortega, 1987; Ortega & Rickards, 2003; Brussa *et al.*, 2003) were recognized. The basal micaceous sandstone yielded conodonts of the *Pygodus anitae* Subzone (*Eoplacognathus suecicus* Zone) (Ottone *et al.*, 1999). A lower palynological assemblage (LAL) composed mainly by acritarchs and chitinozoans were also described for this member (Ottone *et al.*, 1999, 2001).

The upper member (*ca.* 20 m thick) comprises calcareous siltstones and subordinate mudstone lenses. It is only recognized in the Los Azules, Amarilla, and Árbol Seco creeks. The graptolite fauna correspond to the *Climacograptus bicornis* Zone (Gisbornian, Gi2) and it is associated with conodonts of the *Amorphognathus tvaerensis* Zone (Ottone *et al.*, 1999). An upper palynological assemblage (LAU) integrated by acritarchs and profusely ornamented chitinozoans, was identified in these levels (Ottone *et al.*, 1999; 2001).

A stratigraphic gap is present between the middle and upper members embracing the *N. gracilis* Zone interval, and possibly the uppermost part of the *H. teretiusculus* Zone. The Los Azules Formation is unconformably overlain by Carboniferous strata of the Guandacol Formation.

Stop 1. Los Gatos creek

The succession of the Los Azules Formation at Los Gatos creek is incomplete. The lower member and part of the middle member of the formation, which is unconformably covered by the Carboniferous deposits (Guandacol Formation), are exposed.

A rich graptolite fauna including *Loganograptus logani* (Hall), *Pseudobryograptus parallelus* Mu, *Pseudotriconograptus ensiformis* (Hall), *Tetragraptus bigsbyi* (Hall), *T. serra* (Brongniart), *T. reclinatus* Elles & Wood, *T. beadi* (Hall), *T. quadribrachiatus* (Hall), *Xiphograptus lofuensis* (Lee), *Holmograptus bovis* Williams & Stevens, *Holmograptus* sp. nov., *Acrograptus* sp., *Glossograptus acanthus* Elles & Wood, *Glossograptus* sp., *Paraglossograptus tentaculatus* (Hall), *P. tricornis* Mu, Geh & Yin, *Cryptograptus antennarius* (Hall), *Arienigraptus zhejiangensis* Yu & Fang, *Isograptus victoriae divergens* Harris, *I. caduceus caduceus* Salter, *Undulograptus austrodentatus* (Harris & Keble), *U. sinicus* (Mu & Lee), *U. dentatus* (Brongniart), *U. primus* (Legg), and *U. cumbrensis* (Bulman) occurs in the basal part of the lower member of the Los Azules Formation (Figure 4, 5). Most of these graptolites were recorded in the lower part of the Gualcamayo Formation, northern Precordillera (Ortega & Albanesi, 1999).

Approximately 0.60 m above the base of the member, *Arienigraptus angulatus* (Mu) and *Arienigraptus* sp. make their appearance. Some forms, such as *I. v. divergens* are restricted to the base of the unit, while others, e.g. *T. beadi*, are just localized in the middle part of the lower member. *A. zhejiangensis*, *A. angulatus* and *U. dentatus* range upwards throughout the middle part of the member but they were not recorded in our collections from the uppermost strata.

This graptolite assemblage was referred to the *U. dentatus* Zone in accordance with the presence of the nominal species, and *A. angulatus* and *Arienigraptus* sp. It correlates with the *U. dentatus* Zone of the North America (Maletz, 1997b) and the *Undulograptus intersitus* Zone of Australasia (VandenBerg & Cooper, 1992).

In the upper part of the lower member, a thick K–bentonite bed (ca. 0.50 m) contains *Pseudobryograptus* sp. (proximal ends and young colonies), *P. ensiformis*, *Tetragraptus* sp. (a reclinated form), *X. lofuensis*, *X. cf. disermus*, *Brachiograptus etaformis*, *I. c. caduceus*, *A. angulatus*, *Arienigraptus* sp., *Glossograptus* sp., *P. tentaculatus*, *Cryptograptus* sp. (sicalae and early stages), and *U. primus*. The appearance of *Archiclimacograptus*, *Haddingograptus* and *Hustedograptus* allow reference to the *Holmograptus lentus* Zone (upper Da2), following the scheme of Maletz (1995) (see Brussa et al., 2003; Ortega & Rickards, 2003).

In the Precordillera, a similar assemblage was studied in the Corridita creek, to the north of the Cerro Viejo area (Máspero Castro *et al.*, 2003), where scarce rhabdosomes of *H. lentus* were found in the middle member of the Gualcamayo Formation.

We do not have the definitive fauna of Da3 age, equivalent to the *Nicholsonograptus fasciculatus* Zone of Scandinavia and North America (Maletz, 1995; 1997a, b) or *Diplograptus? decoratus* of Australasia (VandenBerg & Cooper, 1992). It is possible that rocks of this age are not represented in the Cerro Viejo area. If that is the case, a hiatus might be present between the lower and middle members of the Los Azules Formation.

The basal coarse sandstone of the middle member bears conodonts, inarticulate brachiopods uniserial stipes and biserial graptolite remains. Immediately above this sandstone we record the entrance of *Pterograptus elegans* Holm, *Acrograptus euodus* (Lapworth), *Kalpinograptus parallelus* (Ni) and *Wuninograptus* sp., associated to *Reteograptus geinitzianus* (Hall), *C. schaeferi* Lapworth, and biserial graptolites (e.g. *Archiclimacograptus*, *Haddingograptus*, *Hustedograptus*, and *Eoglyptograptus*) which become more abundant constituents of the fauna (Figure 6). This graptolite assemblage was assigned to the *P. elegans* Zone, late Darriwilian (Da4a) in age (Ortega, 1995). Equivalent faunas were described in the Potrerillo range and the Corridita creek, northern Precordillera (Ortega & Albanesi, 2000; Máspero Castro *et al.*, 2003).

The occurrence of *Drepanodus robustus* Hadding, *Paroistodus horridus* (Barnes & Poplawski), *Periodon aculeatus* Hadding, *Polonodus tablepointensis* (Stouge), *Polonodus* sp. A of Albanesi, *Protopanderodus robustus* (Hadding), *Pygodus anitae* Bergström, and *Spinodus spinatus* (Hadding) as casts on bedding plane surfaces, in the lower 20 m of the middle member, indicates the presence of the *Pygodus anitae* Subzone (*Eoplacognathus suecicus* Zone) for the bearer strata (Ottone *et al.*, 1999) (Plate 1). The conodont assemblage represents the *Periodon*–*Pygodus* biofacies that characterizes deep–cold waters slope environments (Albanesi & Ortega, 1998).

The graptolite fauna of the lower member of the Los Azules Formation corresponds to the isograptid biofacies (Cooper *et al.*, 1991) of noteworthy Pacific affinity. The graptolite assemblage of the middle member is dominated by biserial rhabdosomes, gradually increases pandemic forms, and incorporates some Baltic elements.

Stop 2. Los Azules creek

This is the classic locality of the Los Azules Formation. A complete sequence of this formation crops out therein; it includes the lower, middle, and upper members (early Darriwilian Da2 to early Gisbornian Gi2) (Figure 3).

The lower member and the lower part of the middle member contain the graptolite assemblages mentioned for the Los Gatos creek (*U. dentatus*, *H. lentus*, *P. elegans*, and probably *P. distichus* zones).

In the upper part of the middle member graptolites dominated by biserial rhabdosomes were referred to the *Hustedograptus teretiusculus* Zone (Ortega, 1987). The assemblage is composed by *Thamnograptus* sp., *Acrograptus euodus* (Lapworth), *Reteograptus geinitzianus* (Hall), *Cryptograptus schaeferi* Lapworth, *Glossograptus* sp., *Hustedograptus teretiusculus* (Hisinger), *H. vikaerbyensis* (Jaanusson), *Hustedograptus* sp., *Gymnograptus* sp., and *Haddingograptus* sp. cf. *H. olivieri* (Boucek) (Figure 6). Same levels yielded conodonts of the *Pygodus serra* Zone. The mentioned fauna is assigned to a late Llanvirn age (late Darriwilian Da4) (Ortega, 1987, 1995).

In the El Nido creek, located few kilometers to the south of the Los Azules creek, the higher strata of the middle member are exposed. The sequence contains *Nemagraptus* sp. cf. *N. subtilis* Hadding, *Dicellograptus* sp., *H. teretiusculus*, *Orthograptus* sp., conodonts of the *Pygodus serra* Zone, and the lower palynological assemblage (LAL) (Ottone *et al.*, 1999, 2001).

The upper member of the Los Azules Formation paraconformably overlies the middle member. In the Los Azules creek the upper member is *ca.* 20 m thick. Graptolites of the *Climacograptus bicornis* Zone are associated to trilobites (*Porterfieldia jachalensis* Harrington & Leanza, and *Guandacolithus* sp. aff. *G. furquei* Harrington & Leanza) and conodonts of the *Amorphognathus tvaerensis* Zone, indicating an early Caradoc age for the bearer strata. A palynological assemblage (LAU) dominated by chitinozoans is present in these layers (Ottone *et al.*, 1999, 2001).

The graptolite fauna is integrated

by *Aspidograptus* sp., *Callograptus* sp., *Dictyonema* sp., *Ptilograptus* sp. cf. *P. delicatulus* Ruedemann, *Thamnograptus capillaris* (Emmons), *Acrograptus euodus*, *Reteograptus geinitzianus*, *Glossograptus ciliatus* Emmons, *Cryptograptus tricornis* (Carruthers), *Nemagraptus gracilis* (Hall), *Dicellograptus salopiensis* Elles & Wood, *Dicellograptus divaricatus* (Hall), *Dicellograptus* sp., *Dicranograptus nicholsoni* Hopkinson, *Pseudoclimacograptus scharenbergi* Lapworth, *Climacograptus bicornis* (Hall), *Orthograptus* ex gr. *calcaratus* (Lapworth), and *Glyptograptus?* sp.

In calcirudite, the presence of *Amorphognathus tvaerensis* Bergström, *Baltoniodus variabilis* (Bergström), *Drepanoistodus suberectus* (Branson & Mehl), *Panderodus gracilis* (Branson & Mehl), *Periodon aculeatus* Hadding, *Pragmodus undatus* Branson & Mehl, *Protopanderodus varicostatus* (Sweet & Bergström), and *Scabbardella altipes* (Henningsmoen), among others, was recorded (Ortega & Albanesi, 1998).

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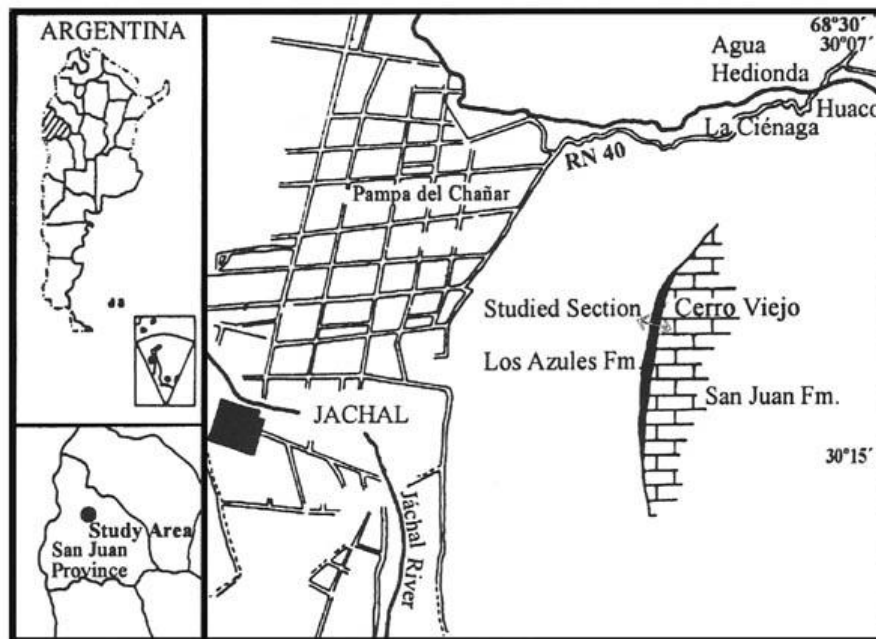


Figure 1. Location map of the Cerro Viejo area (after Ottone et al., 2001).

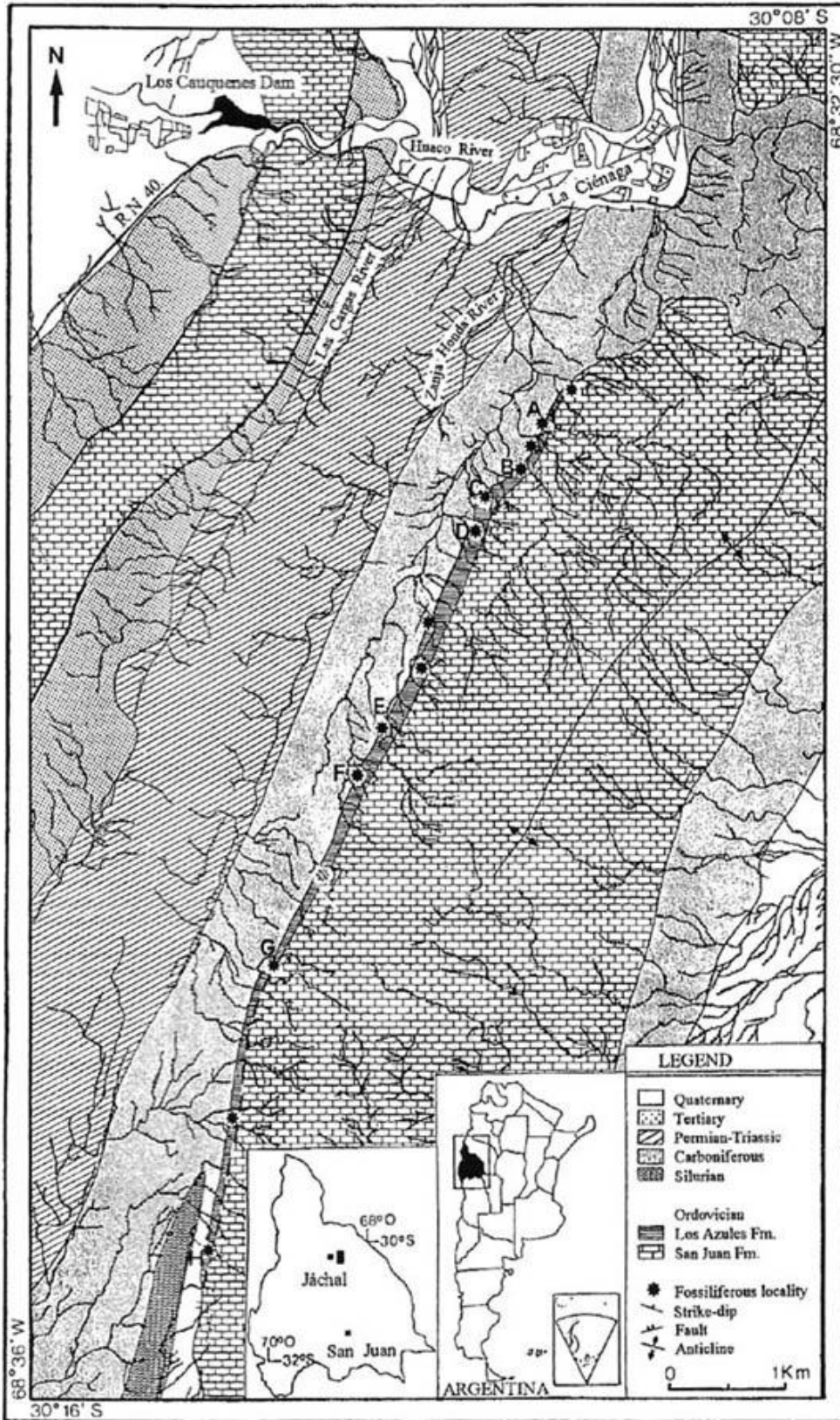


Figure 2. Geology of the Cerro Viejo area (after Ottone et al., 1999).

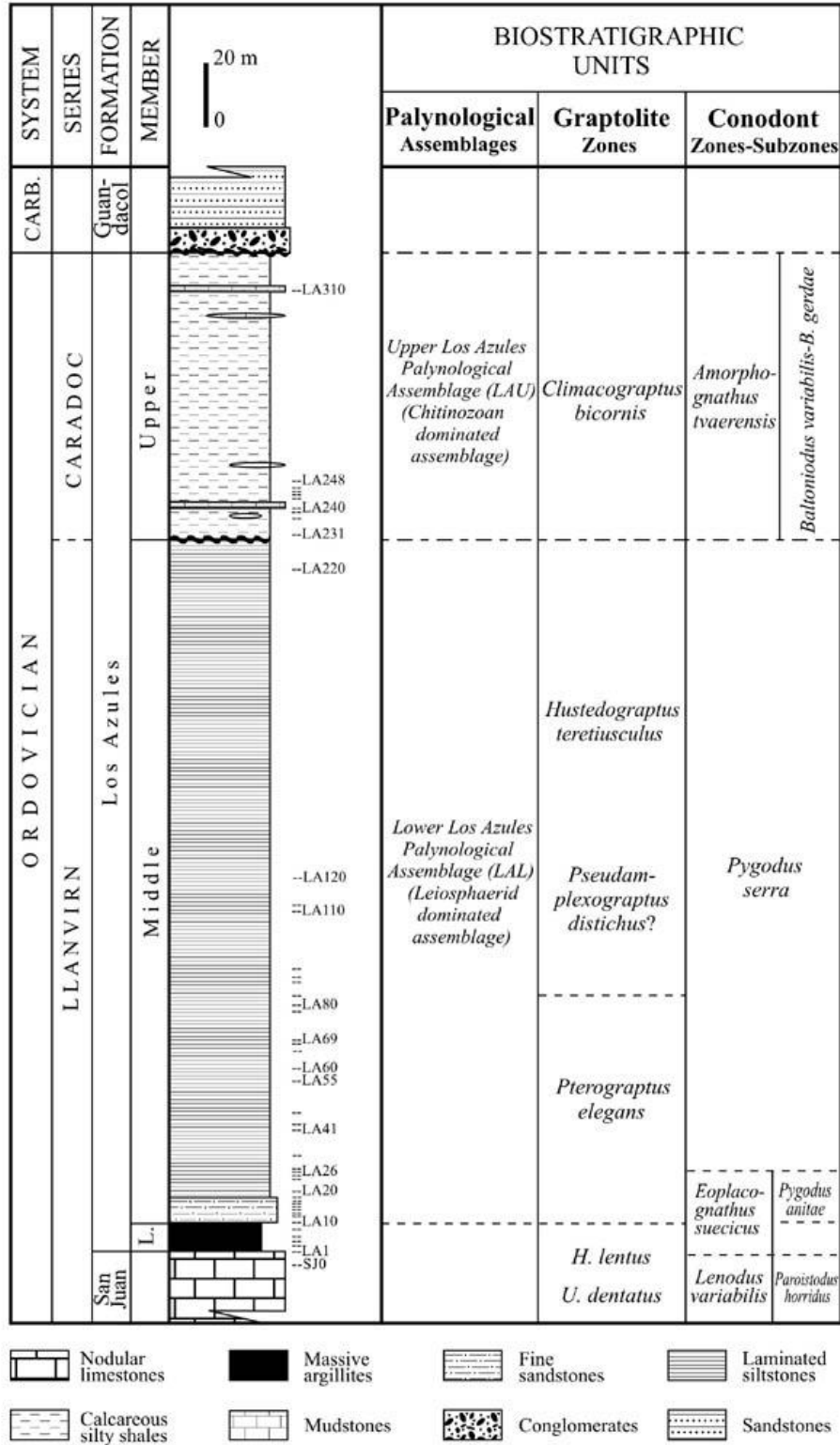


Figure 3. Composite stratigraphic column of the Los Azules Formation and biostratigraphy (modified from Ottone et al., 1999).

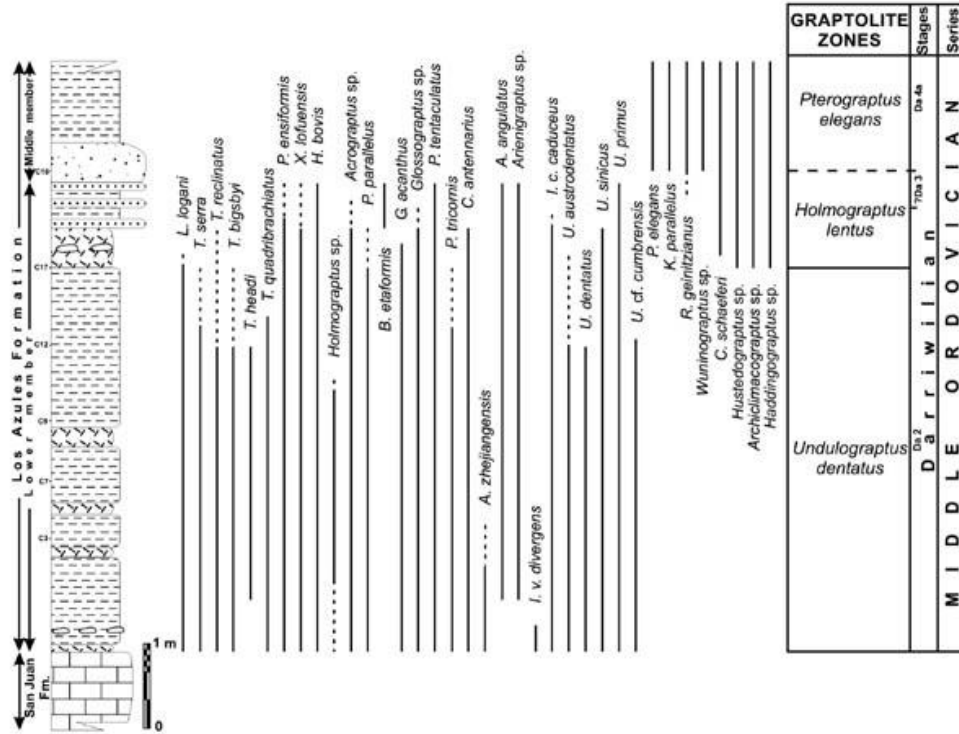


Figure 4. Graptolite ranges of the lower member of the Los Azules Formation at Los Gatos Creek (after Ortega & Rickards, 2003)

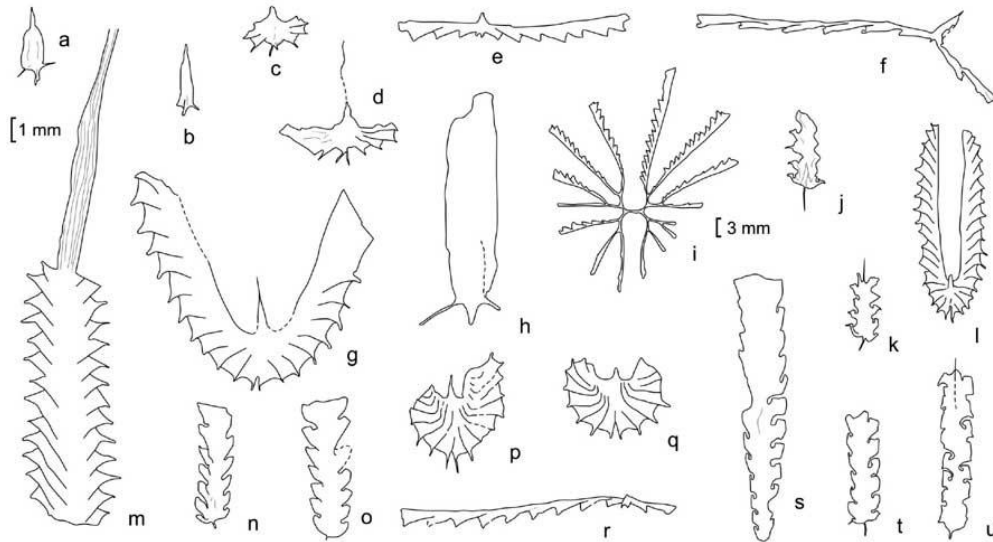


Figure 5. Graptolites of the lower member of the Los Azules Formation. a-h, *Cryptograptus* sp., a, CORD-PZ 18564-B, b, CORD-PZ 18574-A; c-d, *Arenigraptus* sp., c, CORD-PZ 18565-B, d, CORD-PZ 18578-B; e, *Xiphograptus lofiensis* (Lee), CORD-PZ 12368; f, *Holmograptus bovis* Williams and Stevens, CORD-PZ 11591; g, *Isograptus victoriae divergens* Harris, CORD-PZ 13989; h, *Cryptograptus antonariensis* (J. Hall), CORD-PZ 12365; i, *Loganograptus logani* (J. Hall), CORD-PZ 14395; j, k, *Undulograptus sinicus* (Mu and Lee), j, CORD-PZ 12252, k, CORD-PZ 12273; l, *Isograptus caduceus caduceus* (Salter), CORD-PZ 11646; m, *Glossograptus* sp., CORD-PZ 11593; n, *Undulograptus austrodentatus* (Harris and Kehle), CORD-PZ 14000; o, *Undulograptus dentatus* (Brongniart), CORD-PZ 13988; p, *Arenigraptus angulatus* (Mu), CORD-PZ 18591; q, *Arenigraptus zhejiangensis* Yu and Fang, CORD-PZ 11648; r, *Xiphograptus cf. dispersus* (Ni), CORD-PZ 12387; s, *Undulograptus cumbrensis* (Bulman), CORD-PZ 11882-A; t, *Undulograptus primus* (Legg), CORD-PZ 12241; u, *Archiclimacograptus* sp., CORD-PZ 18610. All drawings 4x, except for i: 0.7 x. After Ortega & Rickards (2003).

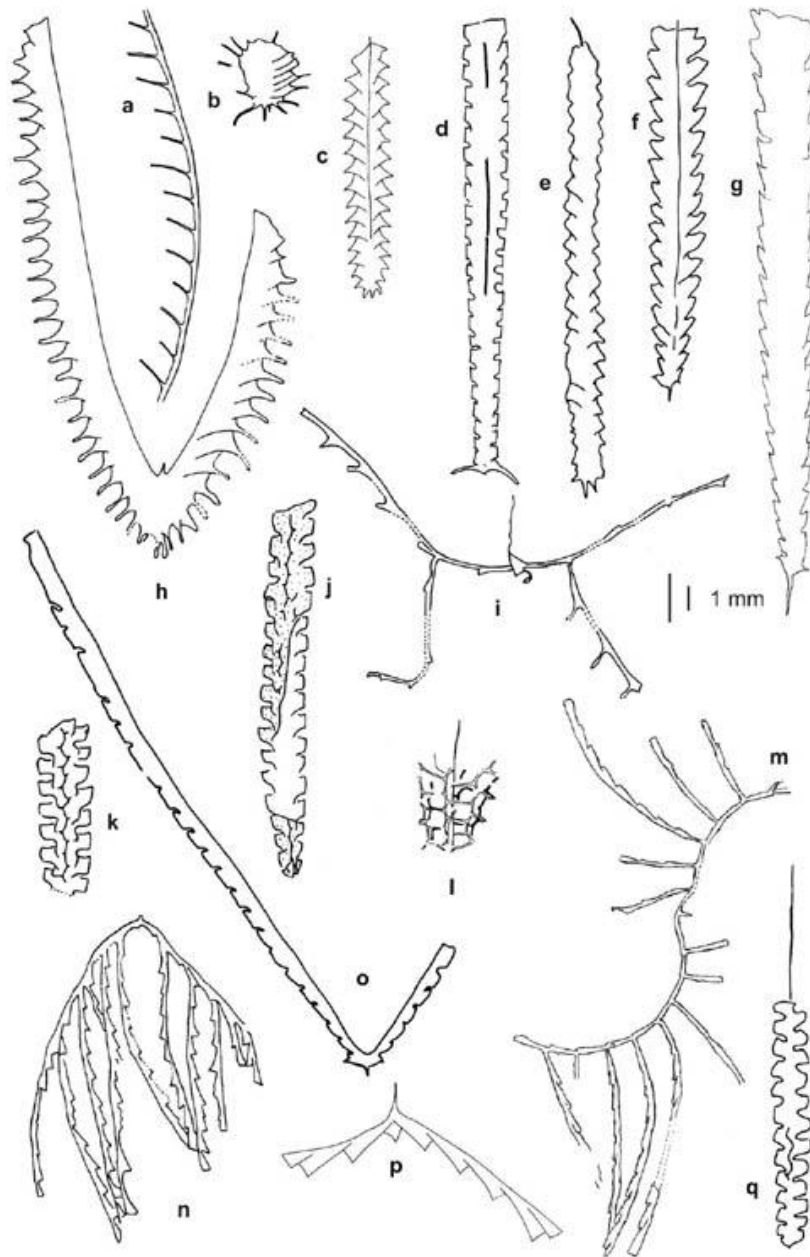


Figure 6. Graptolites of the *Pterograptus elegans*, *Hustedograptus teretiusculus*, and *Climacograptus bicornis* zones from the Los Azules Formation.

a, *Thamnograptus capillaris* (Emmons), CORD-P 13930; **b**, *Glossograptus ciliatus* Emmons, CORD-PZ 13416; **c**, *Cryptograptus schaeferi* Lapworth, CORD-PZ 12953; **d**, *Climacograptus bicornis* (Hall), CORD-PZ 13952; **e**, *Cryptograptus tricornis* (Carruthers), CORD-PZ 13359; **f**, *Glyptograptus?* sp., CORD-PZ 13394; **g**, *Hustedograptus teretiusculus* (Hisinger), CORD-PZ 13596; **h**, *Kalpinograptus parallelus* (Ni), CORD-PZ 14394; **i**, *Wuinograptus* sp., CORD-PZ 12549; **j**, **k**, *Pseudoclimacograptus scharenbergi* Lapworth, **j**, **k**, CORD-PZ 14323; **l**, *Reteograptus geinitzianus* (Hall), CORD-PZ 12822; **m**, *Nemagraptus gracilis* (Hall), CORD-PZ 13893; **n**, *Pterograptus elegans* Holm, CORD-PZ 12758; **o**, *Dicellograptus divaricatus* (Hall), CORD-PZ 13508; **p**, *Acrograptus euodus* (Lapworth), CORD-PZ 13905; **q**, *Haddingograptus* sp. cf. *H. olivieri* (Bouček), CORD-PZ 14121. **a**, **b**, **c**, **e**, **f**, **g**, **h**, **j**, **k**, **m**, **n**, **o**, **q** x3.5; **d**, **i**, **l**, **p** x7 Scale bar: 1 mm.

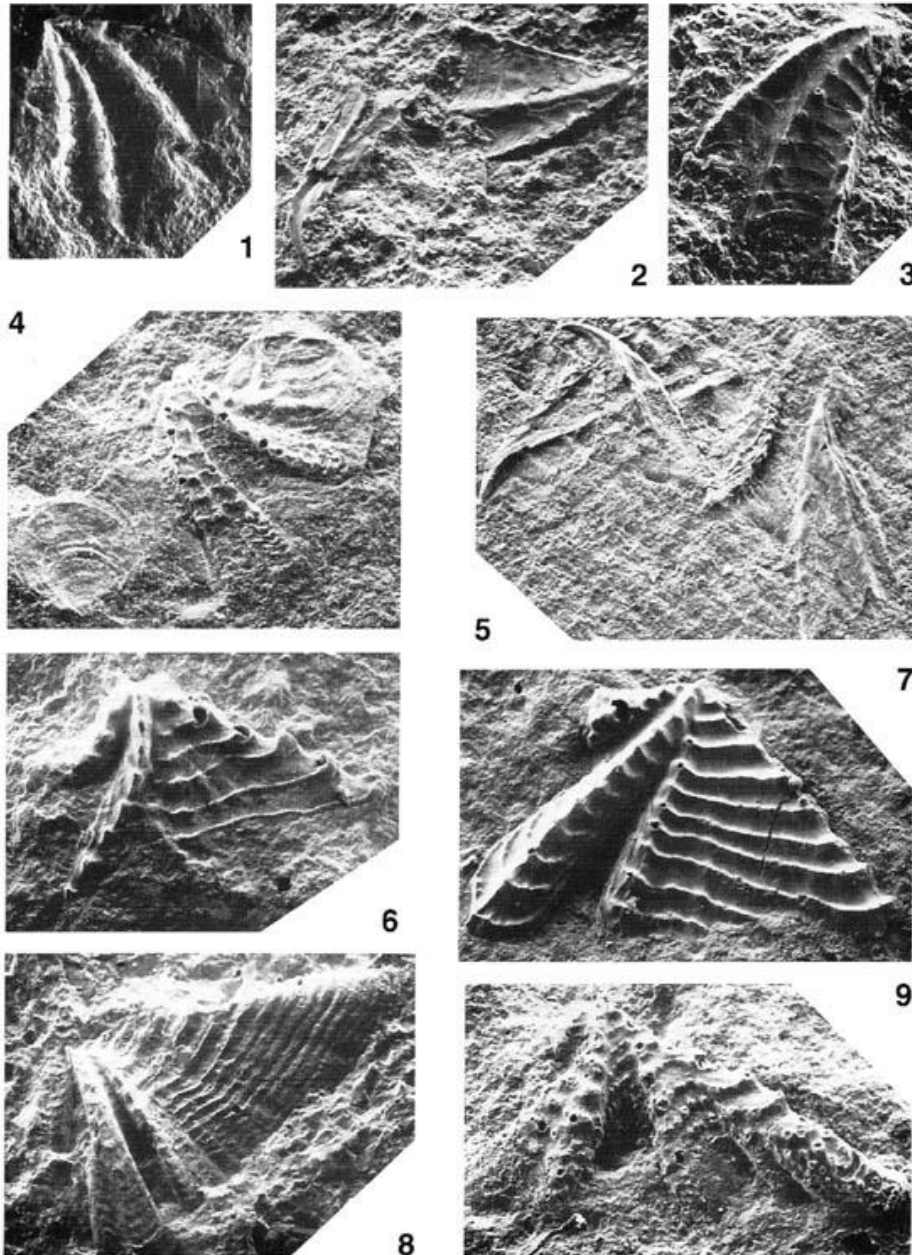


Plate 1

(After Ottone *et al.*, 1999)

1, 4, 5. *Pygodus anitae* Bergström, 1982. 1. Pa element, oral view. Sample LA 25, CORD-PZ 13517, x70. 4. Pa element, oral view. Sample LA 25, CORD-PZ 13596/1, x35. 5. Sd (left), Pb (right) elements, lateral views. Sample LA 25, CORD-PZ 13596/2-4, x35. **2, 3.** *Pygodus serra* (Hadding, 1913). 2. Sd (left) element, Pa (right) element, lateral and oral views, respectively. Sample LA 220, CORD-PZ 14247/1-2, x70. 3. Pa element, oral view, Sample LA 220, CORD-PZ 14365, x90. **6, 7, 8.** *Polonodus magnum* Albanesi, 1998. 6. Pa element (juvenile specimen), oral view. Sample LA 20, CORD-PZ 13859, x70. 7. Pa element (adult specimen), oral view. Sample LA 20, CORD-PZ 13201, x55. 8. Pa element (gerontic specimen), oral view. Sample LA 10, CORD-PZ 13870, x70. **9.** *Dzikodus tablepointensis* (Stouge, 1984). Pa element, oral view. Sample LA 26, CORD-PZ 11963, x55.