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Depositional environment of *Stelloglyphus llicoensis* isp. nov.: a new radial trace fossil from the Neogene Ranquil Formation, south-central Chile

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ABSTRACT. *Stelloglyphus llicoensis* isp. nov. is a large radial, discoidal to ellipsoidal trace fossil with a central shaft and single to bifurcating branches radiating from different levels. A 30 m thick measured section of the Ranquil Formation at Punta Litre contains an associated trace fossil assemblage including *Zoophycos*, *Chondrites*, *Phycosiphon*, *Nereites missouriensis*, *Lockeia siliquaria*, *Psammichnites*(?), *Parataenidium*, *Ophiomorpha*, and *Rhizocorallium*, some of which reworked the *Stelloglyphus* traces. The sedimentology, together with micro- and macrofossils and the associated trace fossil assemblage, suggest that the succession was deposited in an outer continental shelf to slope environment in subtropical to tropical waters.

Keywords: Continental shelf, Slope, Radial trace fossil, Ichnofacies, Stelloglyphus, Dactyloidites.

RESUMEN. **Ambiente depositacional de *Stelloglyphus llicoensis* isp. nov.: una nueva traza fósil radial de la Formación Ranquil (Neógena), centro-sur de Chile.** *Stelloglyphus llicoensis* isp. nov. es una traza fósil grande, radial, y discoidal a elipsoidal con una asta central y ramas sencillas a bifurcadas que radian desde diferentes niveles. Un perfil estratigráfico de 30 m medido en la Formación Ranquil en Punta Litre contiene una asociación de trazas fósiles asociadas que incluye *Zoophycos*, *Chondrites*, *Phycosiphon*, *Nereites missouriensis*, *Lockeia siliquaria*, *Psammichnites*(?), *Parataenidium*, *Ophiomorpha*, y *Rhizocorallium*, algunas de las cuales retrabajaron las trazas de *Stelloglyphus*. La sedimentología, junto con los micro- y macrofósiles y la asociación de trazas fósiles, indican que la sucesión fue depositada en la parte exterior de la plataforma continental hasta el talud continental en aguas subtropicales a tropicales.

Palabras claves: Plataforma continental, Talud, Traza fósil radial, Ichnofacies, Stelloglyphus, Dactyloidites.

1. Introduction

The Ranquil Formation, south of Concepción, is equivalent to the Navidad Formation of central Chile in sedimentology, faunal content, age, and depositional history (Finger *et al.*, 2007), but well separated geographically. It consists of fine conglomerates, sandstones, siltstones and mudstones (García, 1968) reflecting different environments (Nielsen *et al.*, 2004; Nielsen and Frassinetti, 2007a; Finger *et al.*, 2007). Besides the well known mollusk fauna, trace fossils are also ubiquitous and, although less studied, are common in both the Navidad (Encinas *et al.*, 2006) and Ranquil Formations. Since trace fossils are known to be an excellent tool for reconstructing paleoenvironments, they are employed here as an additional means to determine the paleobathymetry, supplementing the microfossil data from nearby outcrops provided by Finger *et al.* (2007).

Trace fossils are generally visible only on bedding planes or in cross sections, so that they can normally be examined in two dimensions only. Three-dimensional studies are sometimes possible due to the removal of softer, surrounding deposits, for example where sand-filled galleries of *Ophiomorpha* or *Thalassinoides* within mudrocks are accentuated by erosion of the latter. Here we describe a new radial trace fossil, perfectly preserved in calcareous concretions that were eroded from their sedimentary host rocks and washed up on a beach east of Llico, south-central Chile. This provides a unique opportunity to study the morphology of this new ichnospecies in 3 dimensions.

2. Geological Setting

The radial trace fossil occurs in the Ranquil Formation of the Arauco Basin, which forms part of a series of basins developed along the Chilean continental margin (Aguirre, 1985; Le Roux and Elgueta, 1997). The basin is filled by Upper Cretaceous to Pleistocene deposits represented by the Maastrichtian Quiriquina Formation, the Paleogene Lebu Group, the Neogene Ranquil, Tubul and Albarrada formations, and younger, unconsolidated Holocene sediments (Pineda, 1986).

The Ranquil Formation, as originally defined by García (1968), crops out locally along the coast between Punta Millongue (73º38'W-37º33'S) in the south and Punta Pichicui (73º27'W-37º12'S) in the north (Fig. 1). Tavera (1942) proposed a Miocene age for this formation on the basis of echinoderm fossils. Groves and Nielsen (2003), based on unpublished foraminiferal data of M. Marchant (personal communication to SNN, 2001) and supported by molluscan faunal similarities with the Navidad Formation in the coastal sector west of Santiago, suggested a Tortonian age for this formation. Finger *et al.* (2007) recorded the presence of the planktonic foraminifers *Neogloboquadrina continuosa* (N4b-N16), *Globoquadrina dehiscens* (N4b-N17), *Globigerinella obesa* s.l. (since P22), *Globoturborotalia apertura* (N16-N21), *Neogloboquadrina acostaensis* (N16-N23), *Globorotalia spheriomiozea* (N18-N19a), and *Globorotalia puncticulata* (N19a-N21) from the Ranquil Formation at Punta El Fraile (their locality FRA), 5 km east of the beach where the trace fossils were subsequently discovered. The overlapping range of these species confirms a Zanclean age (N19a) of 4.4 to 4.6 Ma, which we accept. Benthic foraminifers include *Bulimina spicata*, *Pullenia bulloides*, *Ammodiscus discoideus*, *Ehrenbergina fyfei*, *Pyrgo murrhina*, *Sphaeroidina bulloides*, *Bathysiphon* spp., and *Melonis pompilioides*, which suggest downslope mixing of shelf and bathyal species (Finger *et al.*, 2007). The presence of the gastropods *Zonaria frassinetti* and *Solatisonax bieleri* in nearby outcrops of similar age indicates subtropical to tropical water temperatures (Groves and Nielsen, 2003; Nielsen and Frassinetti, 2007b). This is supported by the occurrence of the foraminifer *Pulleniatina primalis* (Kennett and Srinivasan, 1983). However, deep-water gastropod genera living today off the Chilean coast, *e.g.*, *Bathybembix*, have also been reported from Punta El Fraile (Nielsen *et al.*, 2004).

At the base of the Ranquil Formation, a unit consisting of intercalated shale and fine-grained sandstone, overlain by paraconglomerates containing fine-grained sandstone and siltstone clasts within a clayey to silty matrix, can be distinguished. It is followed by grey mudstones intercalated with fine-grained, calcareous, well-laminated sandstones containing abundant plant material and calcareous concretions, as well as fluid escape structures. Hummocky cross-lamination was observed at some localities. This unit fines upward into poorly exposed mudrocks with calcareous

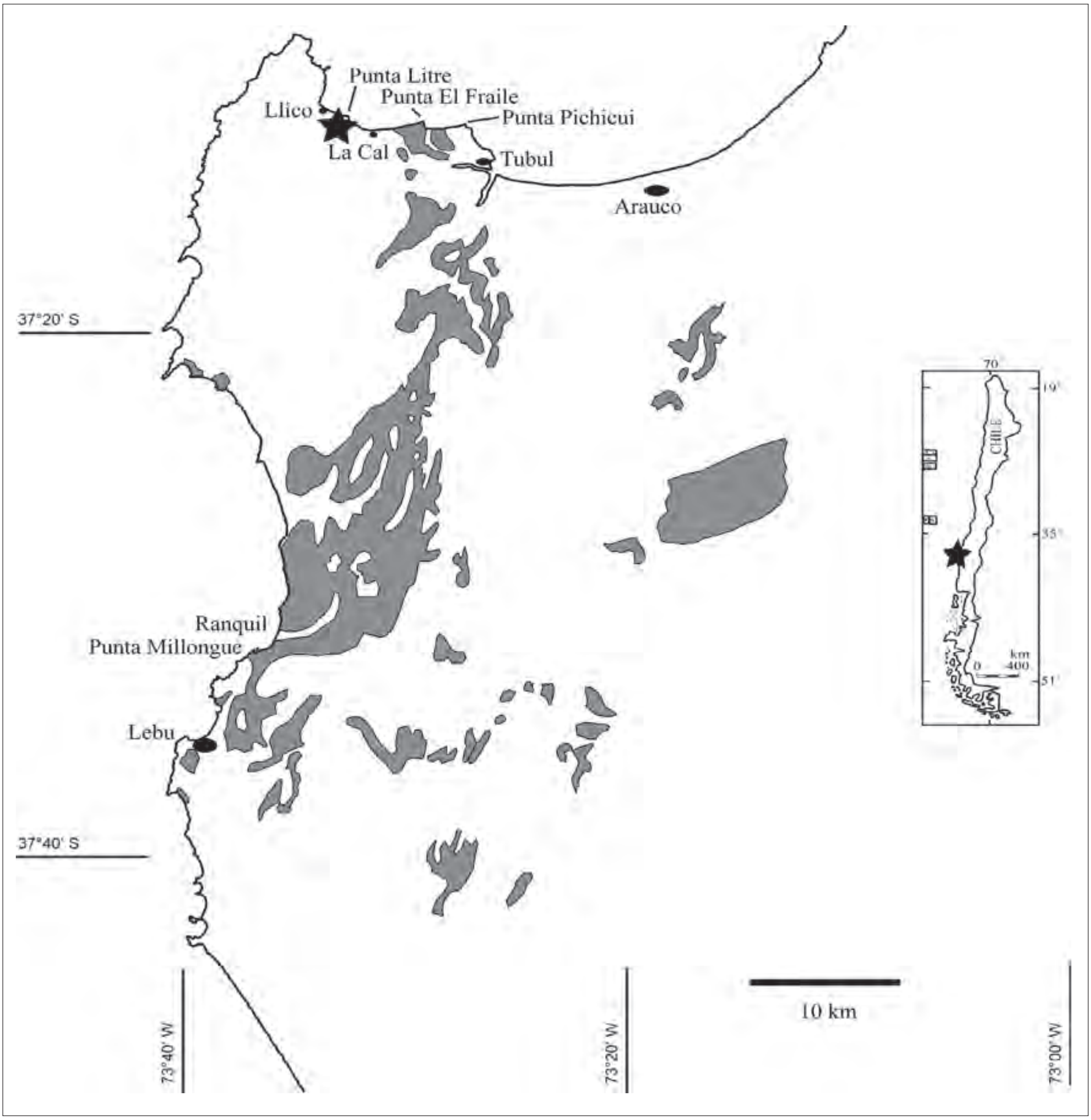

FIG. 1. Location map showing distribution of the Ranquil Formation on the Arauco Peninsula and localities mentioned in text. Star marks the type locality of *Stelloglyphus llicoensis* isp. nov.

concretions (containing the trace fossils described here), which are locally interbedded with mudstone breccias. In some areas (for example, Ranquil and Punta El Fraile) the mudrocks are deeply eroded by channels filled with medium- to very coarse-grained sandstone containing abundant mudstone clasts, interpreted by Le Roux *et al*. (2008) as resulting from a tsunami backwash which eroded coastal beach sand and dunes and redistributed them over the continental shelf and slope. Sandstone dykes penetrating the mudrocks from above are common at these localities (Le Roux and Vargas, 2005; Le Roux *et al*., 2008).

The greatest concentration of trace fossil-bearing concretions occurs on the beach between Estero Pajonal and Punta Litre (37º11’43.80”S-37º11’57.02”S; 73º33’38.49”W-73º32’46.24”W; Fig. 1). At this locality, there is a beach cliff composed of mudrocks with *in situ* calcareous concretions (Fig. 2), some of which contain the radial trace fos-

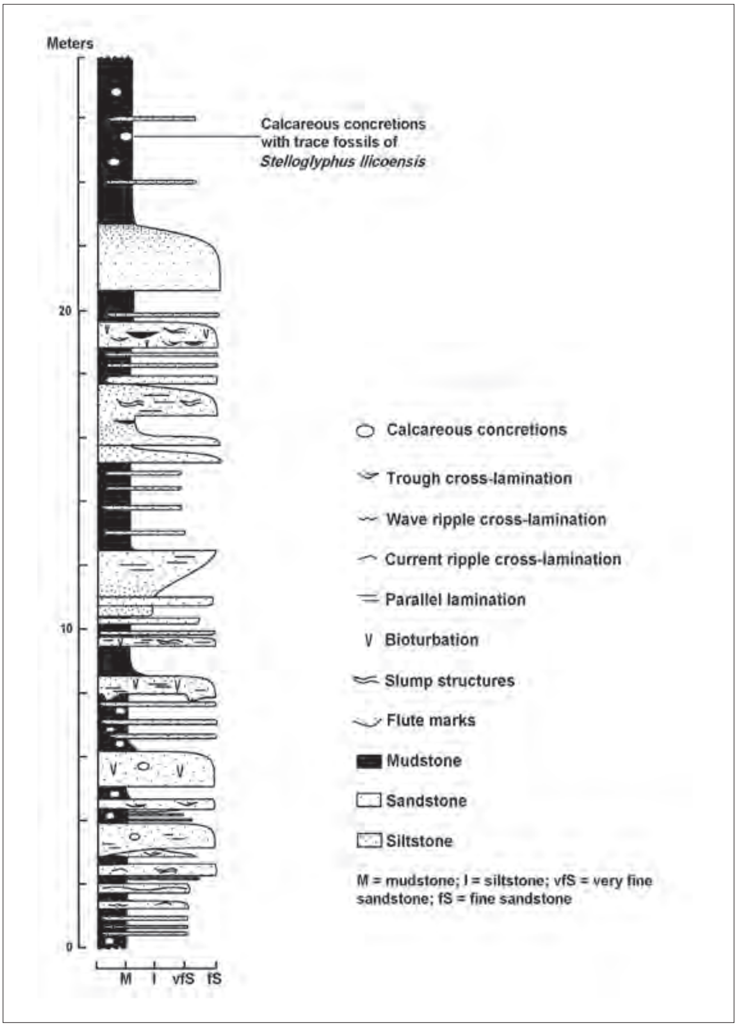

FIG. 2. Measured section of the Ranquil Formation between Punta Litre and Estero Pajonal.

sils (Fig. 3). It is very unlikely that these concretions could have been reworked from older beds, because the mudstones in which they occur represent a very low-energy environment where currents would have been incapable of transporting them.

The beds in this section dip gently westward, so that the measured section at Punta Litre (Fig. 2) depicts the immediately underlying succession of intercalated mudstones and fine- to very fine-grained sandstones. The latter show parallel lamination, current and wave ripple lamination, small-scale trough cross-lamination, as well as flute, slump and fluid escape structures.

Trace fossils are fairly common in the interbedded sandstone-mudstone unit and include *Zoophycos*, *Chondrites*, *Phycosiphon*, *Nereites missouriensis*, *Lockeia siliquaria*, *Parataenidium, Ophiomorpha, Rhizocorallium* and *Psammichnites*(?). Because the last ichnogenus is known only from the Paleozoic, the traces could alternatively represent *Scolicia*.

The Zoophycos ichnofacies seems to best represent the trace fossil assemblage mentioned above. *In* Seilacher's (1964, 2007) original model, this ichnofacies occurs between the Cruziana and Nereites ichnofacies on the external shelf to upper continental slope. The Zoophycos ichnofacies is dominated by *Zoophycos*, *Phycosiphon,* and *Chondrites*, although *Nereites missouriensis*, *Planolites*, *Thalassinoides*, and *Cladichnus* may also

FIG. 3. **A**. *In situ* calcareous concretions containing radial trace fossils (*Stelloglyphus llicoensis* isp. nov.); **B**, **C**. *In situ* ellipsoidal concretion showing B, top surface with radial downward-curving tunnels and C, (turned around) bottom surface with tunnels in cross-section.

be present. In general, the presence of *Zoophycos* and *Chondrites* indicates sediments poor in oxygen, especially where occasional turbidity currents occur (Buatois and Mángano, 1992) or where there is a high input of nutrients (Buatois and López Angriman, 1991). However, in higher diversity assemblages such as the one described here, these traces usually occupy deeper tiers where sediment could be poor in oxygen, whereas the shallow tier and the sea floor may be well oxygenated (J.M. de Gibert, personal communication, 2007).

Ophiomorpha, *Lockeia,* and *Rhizocorallium* are more typical of the Cruziana ichnofacies (Buatois *et al*., 2002), which represents the lower shoreface to shelf environment. The observed trace fossil assemblage thus indicates a shelf to upper continental slope environment, which agrees with the benthic foraminiferal data. The presence of hummocky cross-lamination and (storm?) wave ripples in some beds supports an environment just above the storm wave base, *i.e*., the lower shoreface to continental shelf. The fining-upward sandstones and flute marks at the base of some beds, however, also indicate occasional turbidity currents, which are more typical of the continental slope.

The mudrocks containing the radial trace fossils form part of a generally fining-upward succession, so that they probably indicate deeper water than that represented by the underlying sandstone-mudstone unit described above. A continental slope environment is therefore envisaged. The brecciated mudstones within this unit were probably deposited by debris flows triggered by storms or earthquakes on the steeper slopes.

3. Systematic Ichnology

Ichnogenus: *Stelloglyphus* Vialov, 1964.
Type ichnospecies: *Stelloglyphus turkomanicus* Vialov, 1964; Late Cretaceous (Turonian), Turkmenistan

Stelloglyphus llicoensis isp. nov. Figs. 4A-C and 5A-C.

Type material: Holotype SGO.PI.6424 (Fig. 4A) and four paratypes SGO.PI.6425 (Figs. 4B and 5A-C). Two further paratypes SMF XXX 849 and SMF XXX 850. SGO.PI is the collection prefix related to the Sección Paleontología, Museo Nacional de Historia Natural, Santiago, Chile; SMF refers to the Naturmuseum Senckenberg, Frankfurt am Main, Germany.

Other material examined: One specimen cut for examination (SGO.PI). Many more specimens, all from the area east of Llico, were observed at the type locality.

Derivation of the name: After the fishing village of Llico located just west of the ichnofossil type locality.

Type locality: The Pacific coast near the fishing village of Llico; Ranquil Formation, about 5 km west of the succession at Punta El Fraile, which has been dated as late Miocene to early Pliocene in age by Finger *et al*. (2007).

Occurrence: Concretions containing trace fossils of the new ichnospecies *Stelloglyphus llicoensis* were washed up on beaches east of Llico, between Estero Pajonal (73º33’25’’W) and La Cal (73º31’05’’W). *In situ* occurrences were found at 73°33’00’’W (Figs. 2, 3).

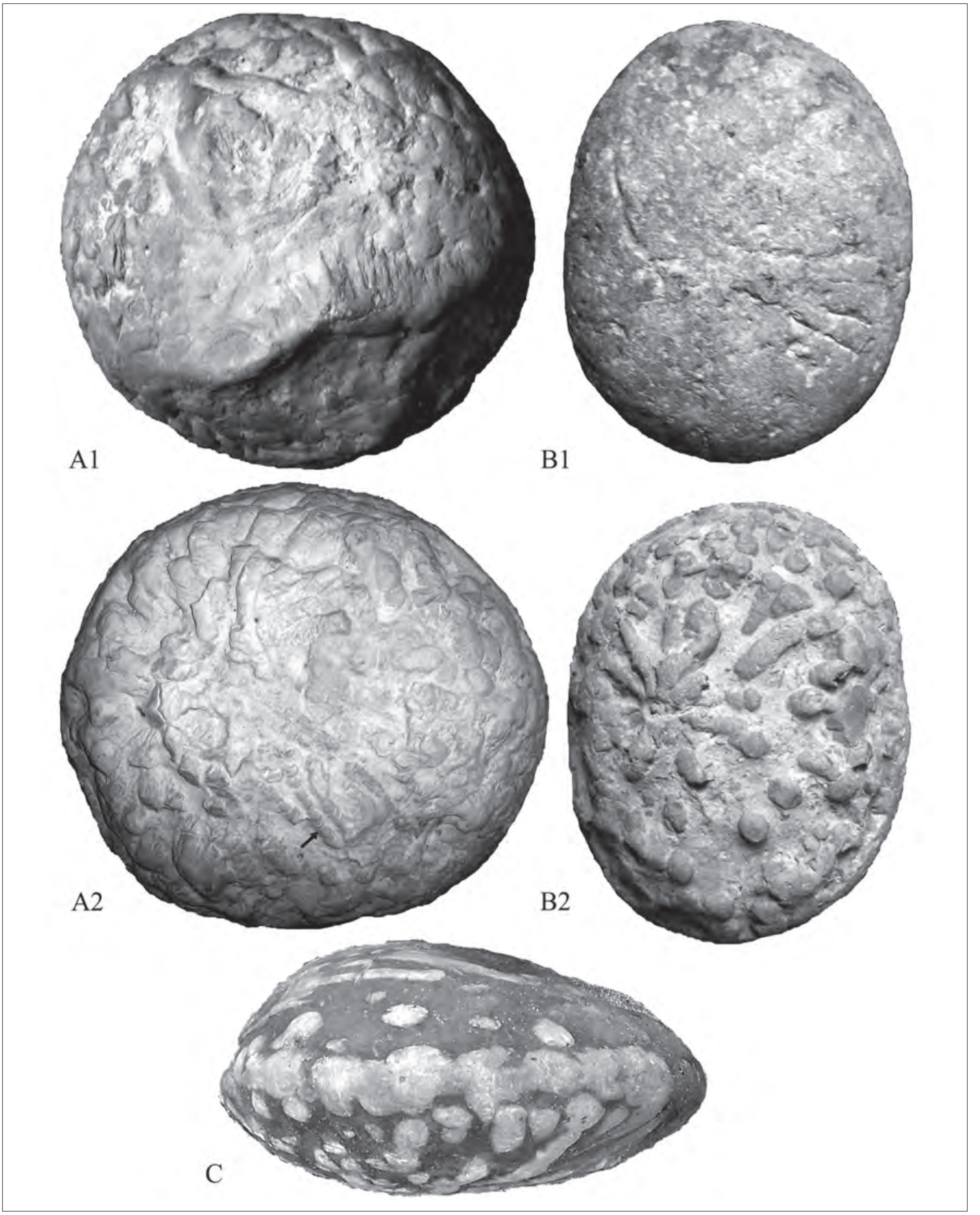

FIG. 4. *Stelloglyphus llicoensis* isp. nov. **A1**, **A2**. Discoidal concretion with holotype SGO.PI.6424, showing downward-curved radial tunnels. Note meniscate shapes (arrow) in some tunnels. A1, top, and A2, bottom views; **B1**, **B2.** Ellipsoidal concretion with paratype SGO.PI.6425a, showing central shaft and radial, downward-curving tunnels. Note double-ring structure and outward-widening radial tunnels with smooth walls. Both rings of central shaft in some cases have a hard, protruding layer on their outside, possibly of organic origin. B1, top, and B2, bottom views; **C.** Lateral view of ring structure formed by fused radial tunnels about halfway from the base. This concretion was not recovered.

Diagnosis: Multi-level, meniscate, rarely branched tunnels normally radiating and curving downward from a central shaft, but bottom tunnels in some cases also curve upward. Filling of tunnels different from surrounding sediment. Central shaft well developed, less than 10 mm in diameter, with distinct inner and outer rings sometimes separated by a hard, protruding layer.

Description: The concretions containing *Stelloglyphus llicoensis* are generally discoidal (Figs. 4A, 5C) to ellipsoidal (Figs. 2, 4B, 5A) and flattened along the bedding. The tops of the concretions are slightly cone- or dome-shaped, with flatter, less curved bases. The shapes of these concretions have clearly been controlled by the traces, because their outlines follow the curvature of the tunnels. Fifty-six measured concretions had long diameters (D_l) ranging in size from 150-400 mm, compared to 140-310 mm for the intermediate diameters (D_i) and 80-180 mm for the short (vertical) diameters

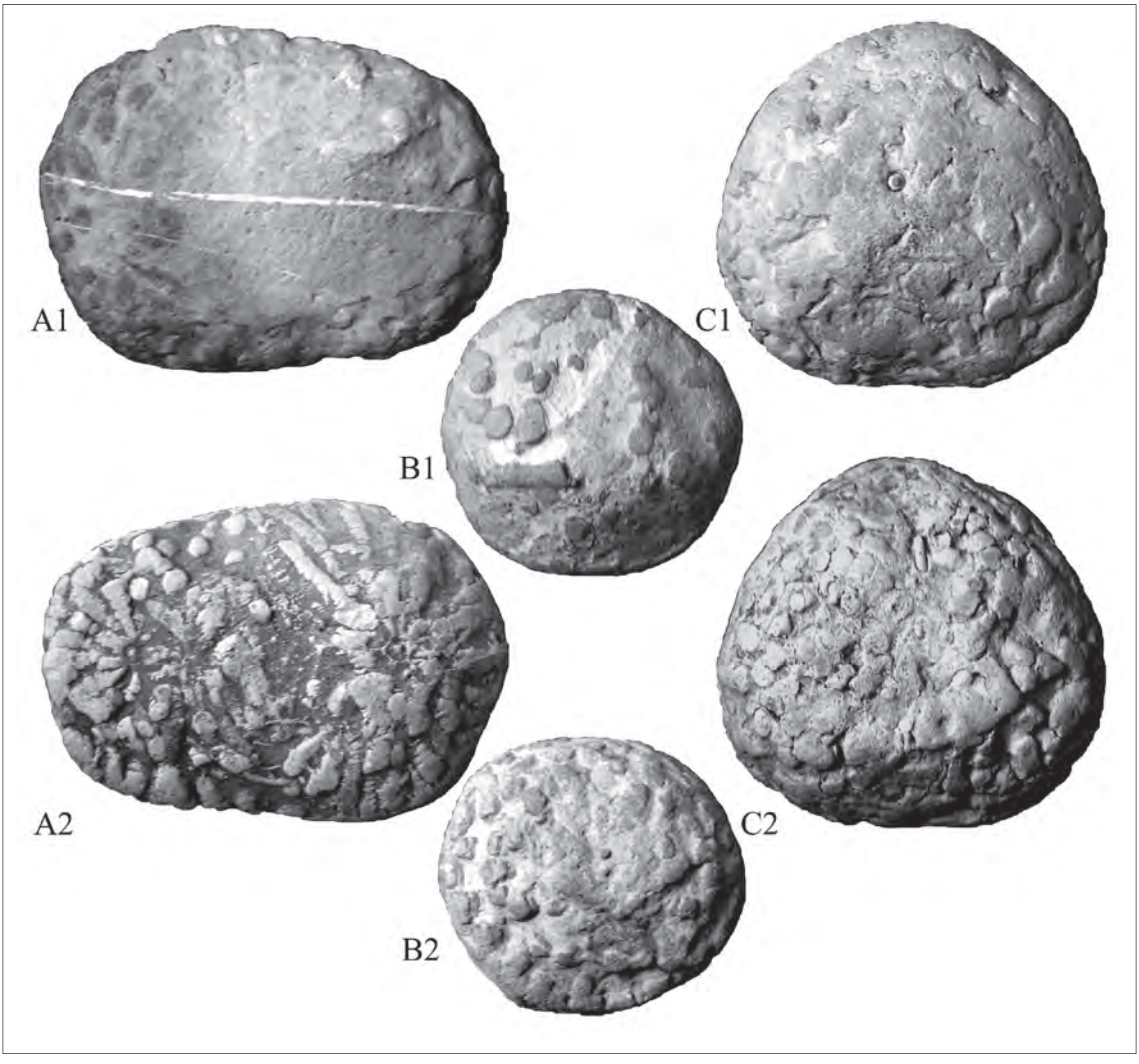

FIG. 5. *Stelloglyphus llicoensis* isp. nov. **A1**, **A2**. Paratype SGO.PI.6425b, two specimens of *Stelloglyphus llicoensis*, with interpenetrating radial elements displaying distinctly segmented or meniscate structures. A2, top, and A1, bottom views; **B1**, **B2**. Paratype SGO.PI.6425c showing cross-sections of tunnels and central shaft. B1, bottom, and B2, top views; **C1**, **C2**. Paratype SGO.PI.6425d, showing rare case of elements radiating upward from central shaft and surrounded by vertical tunnels penetrating from the top of the structure. C1, top, and C2, bottom views.

(D_s), with means of 265(±53.6) mm, 225(±40.2) mm and 123(±24.5) mm, respectively. The mean D_i/D_l ratio is 0.86(±0.10) with a range of 0.65-1.00, whereas the D_s/D_l ratio is 0.47(±0.10) with a range of 0.32-0.73. Although this discoidal to ellipsoidal form is due to concretion-formation processes, it was clearly controlled by the burrow systems and thus reflects the actual geometry of the latter.

The trace fossil consists of a central shaft from which radiate single and occasionally branched, unwalled tubes (Fig. 4A2) with common constrictions and menisci, filled with light pinkish brown, very fine- to fine-grained, calcareous sandstone or limestone within a buff, muddy, calcareous matrix containing scattered sand grains. The central, vertical to oblique shaft measures less than 10 mm in diameter and has an inner and an outer ring (Figs. 4B2, 5A2, 5C1) separated by a groove, both rings being formed by micritic mud. This probably represents a lining or reinforcement of the shaft (J.M. de Gibert, personal communication, 2007). The two ring structures are occasionally separated by a hard, protruding layer up to 2 mm thick, with a similar layer lining the outside of the outer ring. The shafts penetrate to the base of the structures, although in some cases they cannot be distinguished from radial tunnels that become sub-vertical towards the base. In rare cases, there are two or more shafts within the same concretion, with their radial tunnels interpenetrating (Fig. 5A2). This does not necessarily mean that the two tunnel systems were formed simultaneously, however. A longitudinal section cut through one shaft shows a segmented structure, with the inner ring broken into fragments 2-5 mm long and arranged in an *en echelon* manner. This possibly resulted from compaction after the structure had been formed. The outer ring is vague in longitudinal section, being hardly discernible from the matrix.

The trace fossils are visible in the concretions only because of chemical and physical weathering enhancing their external features. Natural cracks exposing the interior of *in situ* concretions show only a very homogeneous mass of fine-grained sandy limestone, which is also the case with a laboratory-cut concretion containing clear *Stelloglyphus llicoensis* on its external surface.

The tubes radiating from the central shaft are in a stellate pattern, each with a diameter of 10 to 20 mm and circular to oval in cross-section. Their longitudinal shapes vary widely, from almost smooth to regularly pinching and swelling, and in some cases are distinctly segmented or meniscate (Fig. 5A), but in general they become wider away from the shaft. On the domed upper surface of the concretions, 20 to 40, partly overlapping stellate burrows may be preserved, curving downward along the surface but in some cases also laterally. About one-third to halfway from the top of the concretions, many stellate burrows fuse to form an irregular, ring-shaped structure around the perimeter (Fig. 4C). The lower part of the concretions generally displays the tunnels in cross-section (Figs. 2, 5C2). However, in some cases the lowermost tunnels branch horizontally from the central shaft and curve upward, so that the basal and top sections may be similar in appearance (Fig. 4B).

Stelloglyphus llicoensis is associated with and in some cases reworked by *Zoophycos*, which reaches more than 500 mm in diameter and displays whorls with spreiten in cross-section, up to 3 storeys deep. Minute to mm-scale *Chondrites* also commonly occurs at the top of the *Stelloglyphus llicoensis* concretions, where they are locally associated with large, horizontal gastropod-produced trails.

A thin section of one of the concretions shows a very fine, unlaminated, micritic mudstone with spherical to slightly oval, calcareous framboidal structures 0.l-0.35 mm across, probably formed by microbes under reducing conditions. This supports the oxygen-poor environment (at least in the subsurface) suggested by the occurrence of the Zoophycos ichnofacies trace fossils in areas subject to occasional turbidity currents (Buatois and Mángano, 1992). These framboidal structures are surrounded and partially to completely replaced by calcite crystals somewhat larger than the matrix. Small, spherical carbon grains less than 0.01 mm across as well as larger, irregular flakes probably representing leaf or wood fragments are also common. All of these are partly replaced by calcite, which also forms veinlets up to 0.4 mm wide, consisting of larger crystals. An unbroken, delicate ostracod tests preserved within the thin section consists of slightly larger calcite crystals largely destroyed during polishing.

Remarks: Star-shaped or radial trace fossils may be caused by different behaviors - including resting traces, farming structures, feeding structures and possible nests - and have been described from a wide variety of environments (Grubić, 1970; Häntzschel, 1970; Bromley, 1990; Seilacher, 2007). These include ichnotaxa without a central shaft, such as *Asteriacites* Schlotheim, 1820 (Mángano *et al*., 1999), *Asterosoma* Otto, 1854 (Pervesler and Uchman, 2004), and *Lorenzinia* Gabelli, 1900 (Uchman, 1998), as well as ichnotaxa in which a central shaft or knob is present. Among the latter are *Arenituba* Stanley and Pickerill, 1995, *Asterichnus* Bandel, 1967, *Atollites* Maas, 1902, *Capodistria* Vialov, 1964 (Vialov, 1968), *Dactyloidites* Hall, 1886 (Fürsich and Bromley, 1985), *Estrellichnus* Uchman and Wetzel, 2001, *Glockerichnus* Pickerill, 1982 (Książkiewicz, 1977), *Gyrophyllites* Glocker, 1841 (Fischer-Ooster, 1858; Fürsich, 1974), *Maiakarichnus* Verde and Martínez, 2004, *Phoebichnus* Bromley and Asgaard, 1972, *Sphaerichnus* Fürsich, 1998 and *Stelloglyphus* Vialov, 1964 (Häntzschel, 1975).

Of those traces radiating from a central shaft, all except *Dactyloidites*, *Maiakarichnus*, *Phoebichnus*, *Sphaerichnus* and *Stelloglyphus* have tunnels, lobes, ridges or grooves developed essentially along the same horizontal plane, or curving upward towards the surface only at their extremities. The burrows described here do not form a ring structure on bedding surfaces, which is distinct from, for example, *Estrellichnus jacaensis* Uchman and Wetzel, 2001 or *Capodistria vettersi* Vialov, 1968 (Uchman and Wetzel, 2001).

Among those traces with multi-level radiating tunnels, only *Dactyloidites* and *Stelloglyphus* have characteristics similar to the new traces found at Llico, as discussed below. *Maiakarichnus currani* Verde and Martínez, 2004, recently described from the Late Miocene of Uruguay by these authors, is preserved in full relief as a subspherical chamber with numerous thin shafts radiating upward from its upper part and sides. It has been interpreted as a callianassid brood structure. *Phoebichnus*, with its type ichnospecies *P. trochoides* (Bromley and Asgaard, 1972), has been described from the Jurassic of Greenland and its occurrence elsewhere is restricted to a few other Mesozoic successions. It has a large central disc and double-walled tunnels radiating horizontally at different levels, containing bi-directional back-fill menisci. Related forms include *Phoebichnus bosoensis* Kotake, 2003, which derives from the Neogene, and *Phoebichnus minor* that occurs in the Cambrian (Li and Yuan, 1999). The monotypic ichnogenus *Sphaerichnus*, described from the Jurassic of India 'lacks any internal structure such as spreiten' (Fürsich, 1998).

The type ichnospecies of *Dactyloidites*, *Dactyloidites bulbosus* Hall, 1886 [=*Dactyloidites asterioides* (Fitch, 1850)] from the Early Cambrian of New York State, and other ichnospecies such as *Dactyloidites cabanasi*, which is a stellate form with 4-6 broad, leaf-shaped radial tunnels around a central shaft (Vintaned *et al*., 2006), are restricted to one bedding plane. Some of the better known ichnospecies like *D. ottoi* and *D. peniculus* do not occur only in a single plane, but are multitiered and resemble our new ichnospecies to a certain extent. However, because of their differences from the type ichnospecies, it is doubtful whether these two forms really belong within the ichnogenus *Dactyloidites*. *Dactyloidites ottoi* Geinitz, 1849 is the type ichnospecies of *Haentzschelinia* Vialov, 1964, a placement regarded as appropriate by Seilacher (2007) and followed here, and we regard *D. peniculus* as being closer to *Stelloglyphus llicoensis* than to *Dactyloidites asterioides*. However, a revision of the ichnogenus *Dactyloidites* is beyond the scope of this work.

Stelloglyphus llicoensis differs widely from *Haentzschelinia ottoi*, which is characterized by protrusive spreiten (Gibert *et al*., 1995). Although it superficially resembles *Dactyloidites peniculus* D'Alessandro and Bromley, 1986, from the Pleistocene of southern Italy (D'Alessandro and Bromley, 1986; Uchman and Pervesler, 2007), it differs from the latter through better defined lateral tunnels (some of which bifurcate in contrast to those of *D. peniculus*), in having non-symmetrical tunnels, and in that its tunnels generally do not curve upwards after reaching the distal part and thus do not produce a concave centre at the base. The latter feature was not observed in any of the more than 60 specimens examined by us. The tunnels are also much wider (10-20 mm) than those of *D. peniculus* (5-6 mm).

Stelloglyphus llicoensis also resembles some ichnospecies of *Gyrophyllites* (*e.g*., Fürsich, 1974; Fu, 1991) but differs from these in being tridimensional (Fig. 6). That is, while ichnospecies of *Gyrophyllites* are star-shaped planar constructions, specimens of *Stelloglyphus llicoensis* radiate in three dimensions. According to Fürsich (1974), *Gyrophyllites* may have several storeys, but each storey is restricted to a single bedding surface. However, individual branches of *Gyrophyllites* are leaf-shaped and contrast strongly with the tubes of *S. llicoensis*. Especially *Gyrophyllites* isp. from

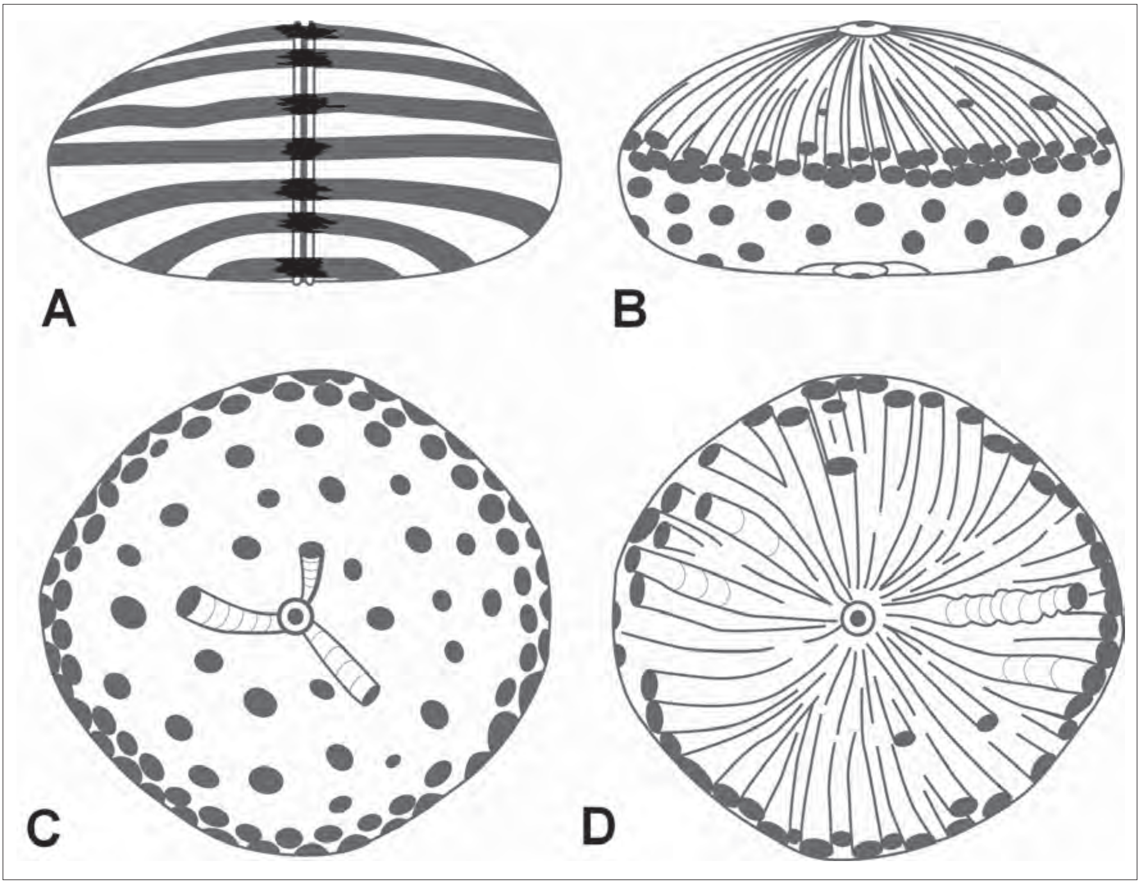

FIG. 6. Schematic reconstruction of *Stelloglyphus llicoensis* isp. nov. in a discoidal concretion. **A**. Vertical cross section through the axis of the trace fossil; **B**. Lateral view; **C**. Bottom view; **D**. Top view.

the Miocene flysch of Langun, Borneo (Fu, 1991, pl. 6 figs. A, B) looks similar. However, it seems to be the same specimen that was later figured as *Stelloglyphus* by Seilacher (2007, pl. 47). Some ichnospecies of *Stelloglyphus* (see Häntzschel, 1975, fig. 69) seem to be restricted to individual bedding planes, but published figures are rather poor. Others, like one example from the Miocene of Borneo (Seilacher, 2007, pl. 47 upper left) are very similar to the here described *Stelloglyphus llicoensis* in being multitiered but not restricted to individual bedding planes. Because of this we classify our new ichnospecies within the ichnogenus *Stelloglyphus*, although the tridimensional morphology can only be guessed at for the type ichnospecies (Häntzschel, 1975, fig. 69).

The ichnogenera *Stelloglyphus*, *Gyrophyllites*, and *Dactyloidites* are interpreted as fodinichnia, *i.e.*, backfilled burrow-systems of stationary deposit-feeding organisms, and were grouped as 'gyrophyllitids' by Seilacher (2007). Consequently, *Stelloglyphus llicoensis* is here interpreted as a feeding burrow system. Fodinichnia commonly display active filling due to food processing and typically have unwalled burrows, which fit in with our observations (Buatois *et al.*, 2002).

4. Conclusions

The radial trace fossil *Stelloglyphus llicoensis* occurs in an early Pliocene sedimentary succession rich in organic material, deposited in subtropical to tropical waters in an outer shelf to upper continental slope environment, in contrast to similar ichnospecies that occur in shallow water environments, *e.g., Dactyloidites peniculus* (D'Alessandro and

Bromley, 1986), *D. cabanasi* (Vintaned *et al*., 2006) and *Haentzschelinia ottoi* (Gibert *et al*., 1995; Agirrezabala and Gibert, 2004). Turbidity currents occasionally disturbed the generally calm environment. The sediment pore-water was probably poor in oxygen, at least in the subsurface, as indicated by calcareous framboidal structures and preserved plant fragments. The trace fossil consists of a central, double-ringed shaft with single to branched, smooth to meniscate tunnels radiating downward from different levels. Only in rare cases do the basal radial elements curve slightly upward. *Stelloglyphus llicoensis* is interpreted as a backfilled burrow-system of a stationary deposit-feeding organism. The ichnofossil is associated with the Zoophycos ichnofacies, although it may also have some affinity with the Cruziana ichnofacies.

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