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Trace fossils from the Upper Member of the Duolbagáisá Formation (Cambrian Series 2–Miaolingian), northern Norway, with the first diverse Cambrian record of *Halimedides*

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New information is provided on trace fossils from the Cambrian Series 2 to Miaolingian in the Upper Member of the Duolbagáisá Formation of northern Norway. This includes the first rich Cambrian material of *Halimedides*, a trace fossil with more or less regularly spaced swellings of different shapes connected by a median string. It is known principally from Mesozoic and younger deep-sea deposits, with a scarce Paleozoic record, making this one of the oldest occurrences of this ichnogenus. Other trace fossils occurring with *Halimedides* include the rare *Bergaueria sucta, Palaeophycus imbricatus* and *Cruziana tenella. Psammichnites gigas* and *Syringomorpha nilssoni* are documented photographically for the first time from this unit. The trace fossil association shows general similarity with that of the slightly older Mickwitzia Sandstone Member of southern Sweden and suggests a broad distribution of late early Cambrian trace-fossil producers across Baltica.

Keywords Trace fossils, Cambrian, Norway, *Halimedides*

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Introduction

The Digermulen Peninsula, Finnmark, northern Norway, yields outcrops of sedimentary rocks spanning from Ediacaran glacial sediments to the Lower Ordovician (Fig 1A, B). Within this succession, the Cambrian sandstone-dominated Upper Member of the Duolbagáisá Formation forms prominent cliff-faces along large stretches of the Digermulen Peninsula. This unit, approximately 400 m thick, consists of thick-bedded, medium- and coarse-grained sandstone, and minor thin-bedded sandstone and shale, within which Banks (1973) identified facies representing deposition in a tidally influenced offshore setting. Body fossils include horizons with trilobites, notably *Kjerulfia* and ellipsocephalids, high up in the unit (Nikolaisen & Henningsmoen, 1990; Ebbestad et al., 2017). These trilobites, together with organic-walled microfossils, constrain the member to Cambrian Stage 3 and Stage 4, with the uppermost part being Miaolingian in age (Palacios et al., 2020).

Trace fossils are common within the Upper Member of the Duolbagáisá Formation, but to date have been mostly reported in the form of lists of ichnotaxa and only a few specimens have been figured. Banks (1970) reported *Skolithos*, *Diplocraterion, Syringomorpha* and *Rusophycus* in the high-energy sandy parts in thick-bedded units, and additionally listed *Cruziana*, *Dimorphichnus*, *Diplichnites* and *Rhizocorallium*, as well as horizontal radial burrows. Nikolaisen & Henningsmoen (1990) reported large *Bergaueria*. Later on, McIlroy & Brasier (2017) described *Phoebichnus* and *Monomorphichnus,* and in the supplementary material illustrated *Cruziana*, *Rusophycus* and other unidentified trace fossils.

Here we provide new information on trace fossils from the Upper Member of the Duolbagáisá Formation, based on two slabs with well-preserved trace fossils. Remarkable are numerous specimens of *Halimedides*, an ichnogenus consisting of strings with ring-like swellings, with the only previous Cambrian record consisting of single specimens from Sweden and eastern USA (Bjerstedt & Erickson, 1989; Jensen, 1997). These slabs also provide new records of the rare *Bergaueria sucta*.

Geological setting

The Caledonian Lower Allochthon Gaissa Nappe Complex (GNC) in northern Norway consists of a nearly 3000 m-thick Neoproterozoic to Lower Ordovician succession of mainly fluvial and shallow-marine sedimentary rocks formed in a foreland basin marginal to Baltica (Townsend et al., 1986; Gayer et al., 1987; Meinhold et al., 2022). The GNC is divided into the Cryogenian–Terreneuvian Vestertana Group and the overlying Cambrian Series 2–Lower Ordovician Digermulen Group (e.g., Reading, 1965; Banks et al., 1971; Nielsen & Schovsbo, 2015). The Digermulen Group is known only from the Digermulen Peninsula. Well-exposed outcrops can be followed along the entire Digermulen Peninsula (Fig. 1).

The 650 m-thick Duolbagáisá Formation represents the lowermost unit in the Digermulen Group. The lower boundary of the formation, and thereby the base of the Digermulen Group, is currently set at an interval recognised by the rich occurrence of large trace fossils (Reading, 1965), and as such is not defined following lithostratigraphical criteria and it needs a revision. The Duolbagáisá Formation is divided into two members constrained temporally by a biostratigraphically diagnostic micro-and macrofossil record (Palacios et al., 2020).

The 256 m-thick Lower Member of the Duolbagáisá Formation consists mainly of siltstone and a few sandstone-dominated intervals (1–20 m thick). Its basal part is within the uppermost part of the Terreneuvian Stage 2 and continues into the Cambrian Series 2, Stage 3, corroborated by the occurrence of an acritarch assemblage of the *Skiagia ornata–Fimbriaglomerella membranacea* Zone (Palacios et al., 2020). The 394 m-thick Upper Duolbagáisá Member consists of thick quartzite beds intercalated with minor laminated sand-, silt- and mudstone. Several coarsening upward parasequences are recognised within the Upper Member, representing the Cambrian Stage 3 and 4, and straddling into the lower part of the Miaolingian Series. Stage 3 and 4 are recognised by acritarch assemblages of the *Skiagia ornata–Fimbriaglomerella membranacea* (Stage 3), *Heliosphaeridium notatum–Skiagia ciliosa* (Stage 3 and 4) and the *Volkovia dentifera–Liepaina plana* (Stage 4) zones (Fig. 1; Palacios et al., 2020).

In an approximately 40 m-thick siltstone- and mudstone-dominated sequence in the middle part of the member, located in the valley up from the shoreline at Breidvika (Fig. 1), comprehensive material of olenelloid and ellipsocephalid trilobites is found together with age-diagnostic acritarchs (Nikolaisen & Henningsmoen, 1990; Ebbestad et al., 2017; Palacios et al., 2020). Another trilobite-bearing mudstone occurs approximately 80 m further up-section in the valley, containing an ellipsocephalid species together with a linguliform brachiopod. These occur approximately 10 m below the first, rare occurrence of *Comasphaeridium longispinosum*, an acritarch indicating a close proximity to the Cambrian Series 2–Miaolingian Series boundary (Palacios et al., 2020). The Cambrian Series 2–Miaolingian Series boundary is seemingly without any significant sedimentation breaks, and the succession can be followed throughout the uppermost 70 m-thick parasequence of the Upper Member, which contains acritarchs diagnostic of the Wuliuan Stage at the base of the Miaolingian Series (Palacios et al., 2020). This uppermost parasequence consists of 7.5 m of basal, laminated, sand-, silt- and mudstone rich in trace fossils, overlain by a massive 63 m-thick quartzite with alternating pink and white colouring (Fig. 1D). An ellipsocephalid species is recognised in the lower part of this quartzite. Nielsen & Schovsbo (2015) considered the thick quartzite-dominated upper part of this member as lowstand deposits possibly related to the Hawke Bay regression event.

Material and methods

Two trace fossil-rich slabs described herein with the field sample No. D13–96, (shown in Fig. 1) consist of the larger TSGf 18356 (Fig. 2), and the smaller TSGf 18453 (Fig. 3). These were collected as float by M.H. that, based on lithology and outcrop proximity can be securely tied to a 1.5–2 m-thick, white-coloured band located 12–14 m in the uppermost parasequence of the Upper Member (Figs. 1D, 4). The slabs are both approximately 5 cm thick and consist of fine-grained sandstone with the base showing casts of ripples. The two slabs were clearly from the same bed; this part of the parasequence stands out by its pale colouration and the rich occurrence of large *Rusophycus* and *Cruziana*. From the same interval the impression of a single unidentified trilobite is reported here (Fig. 1C, D).

Trace fossils on the two slabs are dominated by *Halimedides annulatus, Bergaueria sucta*, *Palaeophycus imbricatus* and vertical burrow fragments with rare *Cruziana tenella* and *Cochlichnus*. The distribution of trace fossils on the two slabs is shown in Figs. 2 and 3.
Described material is kept in the palaeontological collection of the Arctic University Museum in Tromsø, prefix TSGf.

Description of trace fossils

Ichnotaxa on the two slabs are described in alphabetical order.

Ichnogenus *Bergaueria* Prantl, 1946

Bergaueria sucta Seilacher, 1990

Fig. 5

Material. – TSGf 18356 (5 specimens) and TSGf 18453 (5 specimens).

Description. – The traces consist of a combination of circular flat-based discs, and bulb-like structures 10 to 20 mm wide and extending a few millimetres above the bed sole. Variations in morphology include semi-circular arches (Fig. 5C, E) that may be laterally repeated producing arcuate complexes (Fig. 5F, G). The specimen in Fig 5A (TSGf 18356) comprises an especially well-preserved complex measuring ~30 × 30 mm, with each arch 19 mm in diameter. Specimen in Fig. 5D is somewhat worn, rounded and lacks details. Lateral repetition of the circular disc is distinctly indicated in Fig. 5F, extending 6 mm above the bed sole.

Remarks. – Seilacher (1990) erected *Bergaueria sucta* on the basis of a specimen from the Mickwitzia Sandstone Member of the File Haidar Formation, Sweden, and reported additional specimens from the Araba Formation of Sinai. *B. sucta* has also been reported from the Burj Formation of Jordan (Hofmann et al., 2012). These occurrences, as well as the one reported here, are all Cambrian Epoch 2 or early Miaolingian age. Additional specimens of *B. sucta* have since been reported from the Mickwitzia Sandstone Member (Jensen, 1997), but it still remains a rare form.

Bergaueria sucta differs from other species of *Bergaueria* in having a high width to depth ratio, a base that is flat or concave, rather than convex, and also in showing lateral displacement. Seilacher (1990, 2007) interpreted *B. sucta* as formed by the basal disc of an actinian-like animal (see Fig. 5B). Examples of *Bergaueria* more typical of the ichnogenus are also present in the Upper

Member of the Duolbagáisá Formation. Nikolaisen & Henningsmoen (1990, p. 76) mention large specimens of *Bergaueria* and material of this character was figured in McIlroy & Brasier (2017, Supplementary material). We have observed *Bergaueria perata* in the Upper Member.

Ichnogenus *Cochlichnus* Hitchcock, 1858

Cochlichnus isp.

Figs. 6D, 7C

Material. – TSGf 18356 (1 specimen).

Description and remarks. – Small, sinuously curved trace fossil, 1 mm wide, wavelength 3–5 mm and amplitude 1–2 mm (Figs. 6D, 7C). Although some irregularity can be seen in the sinuosity this trace fossil can be assigned to *Cochlichnus*.

Ichnogenus *Cruziana* d'Orbigny, 1842

Cruziana tenella (Linnarsson, 1871)

Fig. 6A–C

Material. – Two specimens on TSGf 18356. Additional specimens observed in loose material from the Upper Member of the Duolbagáisá Formation.

Description. – Small, bilobed trace fossils with prominent central grooves preserved in positive relief on the bed sole. Two specimens on TSGf 18356, are approximately 2 mm wide, and 6 and 3 mm long (Fig. 6A, B). A piece collected in float (TSGf 18454) from approximately the same stratigraphical level shows closely spaced horizontal repetition of short bilobed elements (Fig. 6C).

Remarks. – *Cruziana tenella* is a small bilobed trace fossil attributed to the activity of small arthropods. The ichnotaxon is rare in the material from the Digermulen Peninsula, but elsewhere commonly occurs in large numbers and with crossing paths. Transverse or oblique ridges on the lobes, reflecting the activity of appendages, are not seen in the present material. Such ridges are generally only visible in well-preserved specimens in fine-grained sediment. A particularly rich Cambrian material is known from the Mickwitzia Sandstone, File Haidar Formation, Sweden (Jensen, 1997; Kesidis et al., 2019). *C. tenella* on the slabs is short, approaching *Rusophycus* in length vs. width ratio, while those collected in float (Fig. 6C) are more extensively developed and similar to the material from the File Haidar Formation.

Ichnogenus *Halimedides* Lorenz von Liburnau, 1902

Halimedides annulata (Vyalov 1971)

Fig. 7

Material. – TSGf 18356 (approximately 220 specimens) & TSGf 18453 (approximately 150 specimens).

Description. – The horizontal strings are 2–3 mm wide with spherical to heart-shaped swellings, 7–8 mm wide, and 2–6 mm long, that are usually spaced 1–10 mm apart, in one specimen 40 mm apart (Fig. 7). Trace fossils are straight or slightly curved, in places disappearing into the bed sole, then reappearing; some are cut off by other traces. Preserved lengths vary between 10 and 240 mm, commonly between 50 and 100 mm long. Especially on TSGf 18356 (Fig. 7E, F) sections with swellings pass into sets of densely spaced ridges. Also, on

TSGf 18356 (Fig. 7D), in particular, strings with different types of swelling are seen. Several strings terminate at a swelling (Fig. 7D).

Taxonomic remarks. – This material belongs to a type of trace fossil that Buatois et al. (2017) categorised as “Horizontal burrows with serial chambers”. As the nature of the swellings remains uncertain, a more neutral term than chamber, such as swellings, could be appropriate. Ichnogenera in this category include *Fustiglyphus*, *Hormosiroidea*, *Rhabdoglyphus* and *Halimedides*. Buatois et al. (2017) listed additional ichnogenera that may belong to this category, but these differ from the material described here. Subspherical swellings fundamentally characterise *Hormosiroidea* and *Fustiglyphus*, whereas heart-shaped swellings characterise *Halimedides* and *Rhabdoglyphus*. The relationship and synonymies between these ichnogenera remain under discussion, but recently any differences have been considered best separated at ichnospecies rather than ichnogenus level (e.g., Uchman, 1998, 1999).
The Duolbagáisá Formation material adheres well to the diagnosis of *Fustiglyphus annulatus* Vyalov, 1971, of Stanley & Pickerill (1993, p. 61) “Unbranched *Fustiglyphus* bearing spherical-, hemispherical-, heart- or ring-shaped (either singly or paired) swellings. An individual specimen may be comprised entirely of one type of swelling or combinations of two or more”. Uchman (1999) advocated the combination *Halimedides annulata* (Vyalov, 1971) on account of *Fustiglyphus* Vyalov 1971, being a subjective junior synonym of *Halimedides*. Although the taxonomic status may still be open to modifications (cf., Gaillard & Olivero, 2009; Rodríguez-Tovar et al., 2019) we follow the currently most extended practice of *Halimedides annulatus* (Vyalov, 1971).

Temporal and spatial distribution of Halimedides. *Halimedides* has been most commonly reported from the Cretaceous but also from the Jurassic and

Cenozoic, all from deep-water settings (see Rodríguez-Tovar et al., 2019). Paleozoic occurrences are comparatively rare and have been typically reported as *Fustiglyphus*, with the exception of a record from the Ordovician of the Tarim Basin, China (Yang, 1994), from shallow-water deposits (see Stanley & Pickerill, 1993).

There is a moderately rich Ordovician record of *Halimedides*, whereas that of the Cambrian is poor (Table 1). Prior to the material reported here, the Cambrian record consisted of a single specimen reported by Jensen (1997) from the File Haidar Formation (Mickwitzia Sandstone Member; Cambrian Stage 3 or 4, see Nielsen & Schovsbo, 2011, 2015), and a short fragment reported as a possible *Fustiglyphus* by Bjerstedt & Erickson (1989) from the Furongian lower Theresa Formation, New York State. A possible further Cambrian occurrence is a specimen that Orłowski & Żylińska (2002, fig. 3E) reported as *Protovirgularia* isp., from the Ociesęki Formation of Poland, probably Cambrian Stage 4 on the basis of trilobites. The figured specimen is similar to the Duolbagáisá material but it is unclear if the swellings consist of U- or V-shaped pads of sediments as in *Protovirgularia* or spherical swellings as in *Halimedides*. From the same lithostratigraphical unit and area, *Arthraria* isp of Stachacz (2016, fig. 17D) also may be more closely comparable to *Protovirgularia* or *Halimedides*, rather than the dumb-bell shaped *Arthraria*.

The trace fossil-bearing horizon with *Halimedides* described here is constrained biostratigraphically to be of probable early Wuliuan age, approximately 509 Ma following Cohen et al. (2013, updated 2021) or 505 Ma following Sundberg et al. (2020), making this the oldest moderately rich material of this ichnogenus to date. Kolesnikov et al. (2015) considered a report of *Fustiglyphus annulatus* from the Ediacaran Basa Formation of the Urals (Becker, 2013) to be a pseudofossil, and its biogenicity was doubted also by Ivantsov & Zakrevskaya (2018).

Ethology. – The swellings in *Halimedides* have been interpreted as brood chambers (Stanley & Pickerill, 1993), reflections of peristalsis (Miller & Rehmer, 1982) or used for storage of material that served to attract micro-organisms that the producer then used as a food source (Gaillard & Olivero, 2009). This is also consistent with the agrichnial behaviour model by Seilacher (1977, 2007). The spacing and density of the swellings have further been proposed to indicate levels of bottom-water oxygenation in deep-water material (Gaillard & Olivero, 2009). A relationship with oxygen levels has been invoked for *Halimedides* associated with the early Jurassic Toarcian Event in northern Spain. Larger specimens with densely spaced swellings are correlated with weakly oxygenated facies, and smaller specimens with more sparsely spaced swellings are believed to be found in better oxygenated sediments (Lukeneder et al., 2012; Rodríguez-Tovar et al., 2019; Fernandez-Martínez et al., 2021). The Duolbagáisá Formation *Halimedides* are found with a moderately rich association of different types of traces, and we therefore assume the formation of the trace fossils took place in well-oxygenated water, with an unknown function of the swellings in *Halimedides*.

Five of the specimens of Duolbagáisá *Halimedides* show portions with imbricate ridges, one of these is wider than the central string (Fig. 7E, F). These are similar to structures formed by the activity of wedge-shaped palps of burrowing molluscs as seen in *Protovirgularia* (Seilacher & Seilacher, 1994; Seilacher, 2007; López Cabrera et al., 2019). Knaust (2022) on the other hand describes three ichnospecies of *Protovirgularia,* and suggests these were most likely produced by an arthropod or annelid. Gaillard & Olivero (2009) suggested that the *Halimedides* trace maker could have been a small infaunal crustacean, and small infaunal arthropods present an alternative interpretation for these ridges, and for the producer of the Duolbagáisá *Halimedides*.

Ichnogenus *Palaeophycus* Hall, 1847

Palaeophycus imbricatus (Torell, 1870)

Fig. 8

Material. – TSGf 18356 (20 specimens) & TSGf 18453 (13 specimens).

Description. – Straight or gently curving trace fossils preserved along base of bed with longitudinal more or less irregular ridges enclosing a shallow, poorly defined, central groove. The longest specimens measure 460 mm (TSGf 18356, Fig. 8A) and 400 mm (Fig. 8B). Additional, shorter specimens are scattered on the surfaces (Figs. 2, 3). Generally, the width of the traces is 4–6 mm.

Remarks. – These traces were formed by an animal burrowing close to the interface of sand and mud during which sand was pressed into the mud. Here, we follow Jensen (1997) in referring these trace fossils to *Palaeophycus imbricatus*. This type of trace fossil has also been named *Halopoa* but, for reasons outlined in Jensen (1997), this is not used here. For a contrasting view see Uchman (1998).

Vertical burrow fragments

Figs. 5A, D; 7C, E; 8A–C; 9

Material. – TSGf 18356 (61 specimens) & TSGf 18453 (8 specimens).

Description. – Fragmentary preserved cylindrical burrows with a vertical or oblique orientation (Fig. 9). The burrow termination is in the form of a rounded knob of varying appearance: concave, flat or irregular, extending a few millimetres from the bed sole (Figs. 5A, D & 9). Some burrows show lateral displacement (Fig. 9A), and are connected by horizontal parts with faint, longitudinal striations (Fig. 9C). TSGf 18356 shows five smaller specimens in a cluster that are preserved slightly more elevated above the bed sole, also exposing a distinct concave burrow termination (Fig. 9A–C). The base of some traces is surrounded by a flat collar.

Remarks. – These trace fossils are interpreted to represent only a minor portion of the entire morphology, which is mostly unknown and probably a heterogenous grouping. Some could be portions of a plug-shaped trace fossil such as typical forms of *Bergaueria*, but none of the specimens shows a clear basal portion. A single specimen shows a faintly preserved connection to a horizontal portion suggesting a U-shaped burrow (Fig. 9C), but it cannot be deduced that this was so for all the vertical traces.

Discussion

Within the siliciclastic Upper Member of the Duolbagáisá Formation, where skeletal fossils are known from only a few horizons, trace fossils provide the most diverse evidence for the presence of metazoans, documenting a wide range of behaviours. Trace fossils rarely permit the producer to be identified with any precision, and phylogenetically unrelated producers are known to produce morphologically indistinguishable traces. One exception to this rule is trace fossils produced by arthropods where morphologically informative 'finger-prints' can often be identified. Trilobites are known from the approximate middle part of the unit, with large holmiids having cephala wider than 7 cm identified as *Kjerulfia* n.sp., associated with *Elliptocephala* n. sp. (Ebbestad et al., 2017; see also Palacios et al., 2020, fig. 3). Large *Rusophycus* and *Cruziana* from the upper part of the member (Fig. 10A herein; McIlroy & Brasier, 2017, Supplementary figures) are evidence for the continued presence of large arthropods. *Cruziana tenella* documents the presence of smaller arthropods. Among the ichnotaxa on the two slabs described above, *Bergaueria sucta* was likely produced by a cnidarian (Fig. 5B).

From the early Cambrian section of the Upper Member of the Duolbagáisá Formation, *Psammichnites gigas* (Fig. 10B) and *Syringomorpha nilssoni* (Fig. 10C) are figured here for the first time. *Psammichnites gigas* was made by an animal moving horizontally through the sediment, with a meniscate structure suggesting manipulation of sediment. A sinusoidal furrow on the top of the trace fossil, not seen in the figured material, has been interpreted as formed by a snorkel-like organ keeping the animal in contact with the sediment surface (e.g., Seilacher, 2007). On the Digermulen Peninsula, the closely related *Psammichnites gigas arcuatus* (traditionally *Plagiogmus arcuatus, see* Mángano et al., 2022) is well represented in the Lower Member of the Duolbagáisá Formation (Banks, 1970; McIlroy & Brasier, 2017). *Syringomorpha nilssoni*, a vertically oriented spreite burrow formed by the progressive displacement of a J-shaped tube (Fig. 10B), is present through much of the Upper Member (McIlroy & Brasier, 2017). It does not show the type of producer-specific 'finger-prints' found in *Rusophycus* and *Cruziana*, and the only information of its producer is in the width of the causative burrow (1–2 mm). This ichnospecies does, however, have both a restricted stratigraphical range and a palaeogeographical distribution making it plausible that it was produced by one or a limited number of producers (Jensen et al., 2013). The producer likely was vermiform and a life-style as biofilm harvester has been suggested to explain its presence in sediments likely impoverished in organic material (Noffke et al., 2021).

The association of trace fossils from the Upper Member of the Duolbagáisá Formation shows similarity to the slightly older Mickwitzia Sandstone Member of southern Sweden. This is probably not only because of the similarity in the evolutionary stage in trace fossil development and broadly comparable environments, but also from similar trace producers.

Conclusions

The trace fossils described here from the Upper Member of the Duolbagáisá Formation, on the Digermulen Peninsula, Finnmark, northern Norway, expands our knowledge of Cambrian Series 2 to Miaolingian trace fossils in Baltica. This includes the first moderately rich Cambrian material of *Halimedides* and one of the earliest records globally of this ichnogenus. Several specimens of the rare *Bergaueria sucta* are recorded. *Syringomorpha nilssoni* is restricted to the early Cambrian part of the member.

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Figure captions

Figure 1. (A) outline of Scandinavia with the study area marked by a square on the northern tip of mainland Norway. Caledonides shaded. (B) geology of the Digermulen Peninsula showing location of the trace fossils described herein. (C) log of the 394 m-thick Upper Member of the Duolbagáisá Formation, overlain by the Kistedalen Formation. Acritarch zonation following Palacios et al. (2020), S–F corresponds to the Skiagia ornata–Fimbriaglomerella membranacea *Zone. (D) log of the approximately 70 m-thick uppermost parasequence of the Upper Member, of the Duolbagáisá Formation, the extension of which is indicated by a vertical line in (C). The base of the*

Miaolingian Series is found approximately 17 m stratigraphically below the uppermost parasequence on the basis of acritarchs.

Figure 2. (A) slab TSGf 18356. (B) line drawing of (A), showing distribution of more prominent trace fossils; ichnotaxa are colour coded. Position of illustrated specimens shown with figure number. Scale bars = 50 mm.

Figure 3. (A) slab TSGf 18453. (B) line drawing of (A), showing distribution of more prominent trace fossils; ichnotaxa are colour coded. Position of illustrated specimens shown with figure number. Scale bars = 50 mm.

Figure 4. Transition from the Upper Member of the Duolbagáisá Formation to the Kistedalen Formation in the Breidvika valley. The black arrow points to the site where the Halimedides*-bearing slabs were recovered. The white arrow shows the level at which this bed crops out. Location is marked by a red star in Figure 1B. The purple and white bar shows the extension of parasequence 9 and equals 70 metres; additionally, it indicates the alternation between the pink and white quartzite layers.*

Figure 5. Bergaueria sucta*. (A) specimen on TSGf 18356 showing rotational movement. Also seen is an unidentified truncated vertical trace fossil. (B) artistic reconstruction of trace maker. (C, F, G) specimens on TSGf 18453 exhibiting lateral movement. (D) truncated circular specimen and smaller unidentified truncated vertical trace fossil on TSGf 18356. (E) inclined form on TSGf 18453. Scale bars = 10 mm.*

Figure 6. Cruziana tenella *and* Cochlichnus*. (A, B) TSGf 18356, short* Cruziana tenella*, scale bars = 1 mm. (C)* Cruziana tenella *including portions showing repeated* Rusophycus *elements. Scale bar = 10 mm. TSGf 18454. D)* Cochlichnus *isp., scale bar = 10 mm. TSGf 18356.*

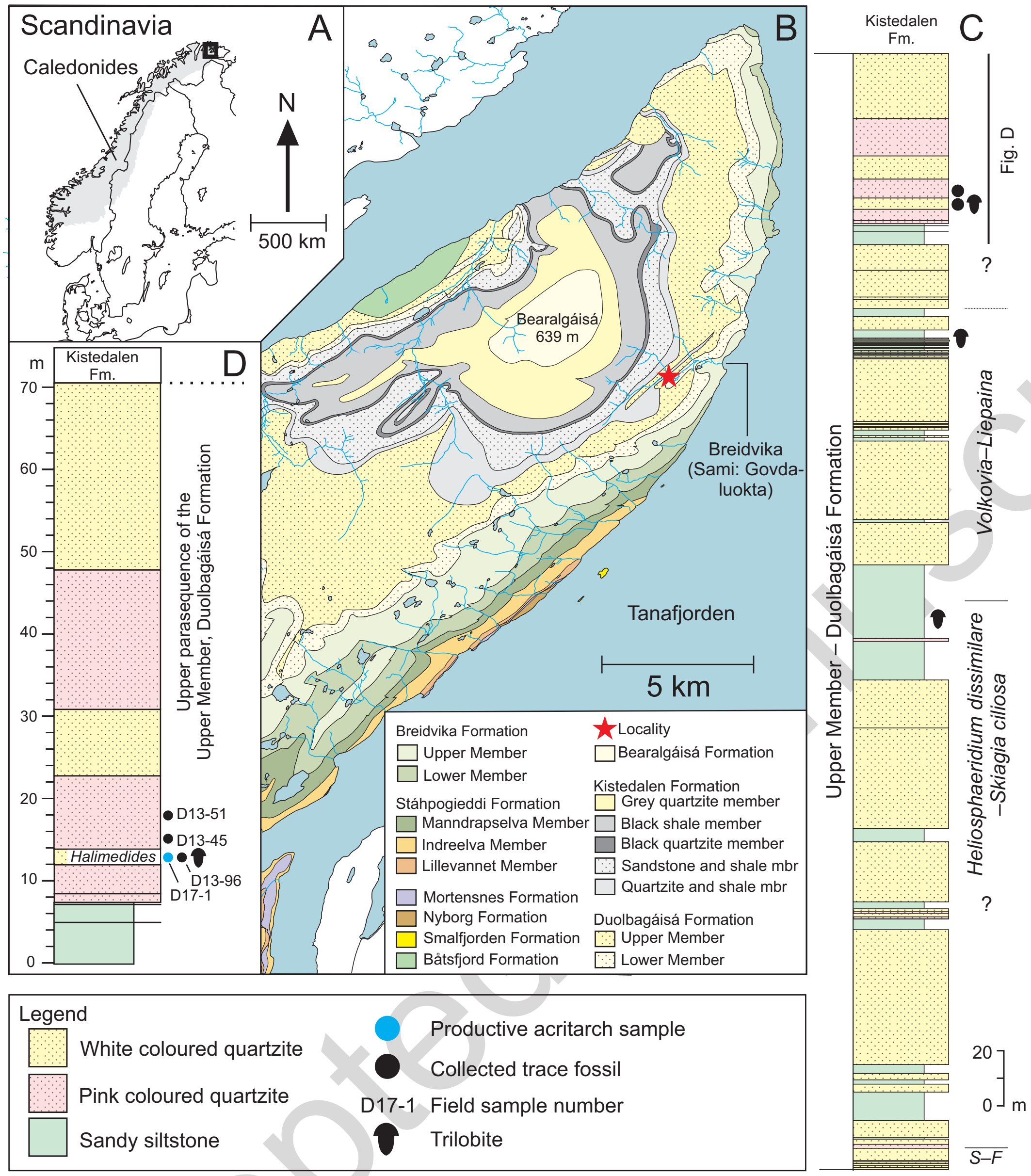
Figure 7. Halimedides annulatus*. (A) overview showing several overlapping specimens with heart-shaped swellings on TSGf 18356. (B-C) varying appearance of swellings on TSGf 18356, ranging from heart-shaped to hemispherical. (D) cluster of traces on TSGf 18453 terminating within the bed sole with distinct spherical swellings. (E) extended trace with marked ridges and heart-shaped swellings on TSGf 18356. (F) detail of (E). Scale bars = 10 mm.*

Figure 8. Palaeophycus imbricatus *on TSGf 18356. (A) slightly curved specimen terminating at the bed sole. (B, C) straight and curved specimens. Scale bars = 10 mm.*

Figure 9. Unidentified vertical trace fossils on TSGf 18356. (A, B) typical appearance showing horizontal fracture. Evidence for truncation is seen in (A). (C) specimen connected to horizontal portion. Scale bars = 10 mm.

Figure 10. Trace fossils from the Upper Member, Duolbagáisá Formation. (A) field photograph of Cruziana *inferred to originate from the same bed as* Halimedides*. Scale bar = 10 mm. (B)* Psammichnites gigas *from the middle part of the Upper Member. Scale bar = 50 mm. TSGf 18456. (C) field photograph of* Syringomorpha nilssoni *from the middle part of the Upper Member showing characteristic successive truncation along the lower part of the spreite. Scale bar = 10 mm.*

Figure 1



Scandinavia
A
Caledonides
N
500 km
B
Bearalgáisá
639 m
Breidvika
(Sami: Govda-
luokta)
Tanafjorden
5 km
Breidvika Formation
Upper Member
Lower Member
Stáhpogieddi Formation
Manndrapselva Member
Indreelva Member
Lillevannet Member
Mortensnes Formation
Nyborg Formation
Smalfjorden Formation
Båtsfjord Formation
Locality
Bearalgáisá Formation
Kistedalen Formation
Grey quartzite member
Black shale member
Black quartzite member
Sandstone and shale mbr
Quartzite and shale mbr
Duolbagáisá Formation
Upper Member
Lower Member
C
Kistedalen
Fm.
Fig. D
?
Volkovia–Liepaina
Upper Member – Duolbagáisá Formation
Heliosphaeridium dissimilare
–Skiagia ciliosa
20
0
m
S–F
D
m
Kistedalen
Fm.
70
60
50
40
30
20
10
0
Upper parasequence of the
Upper Member, Duolbagáisá Formation
Halimedides
D13-51
D13-45
D13-96
D17-1
Legend
White coloured quartzite
Pink coloured quartzite
Sandy siltstone
Productive acritarch sample
Collected trace fossil
D17-1
Field sample number
Trilobite

Figure 2

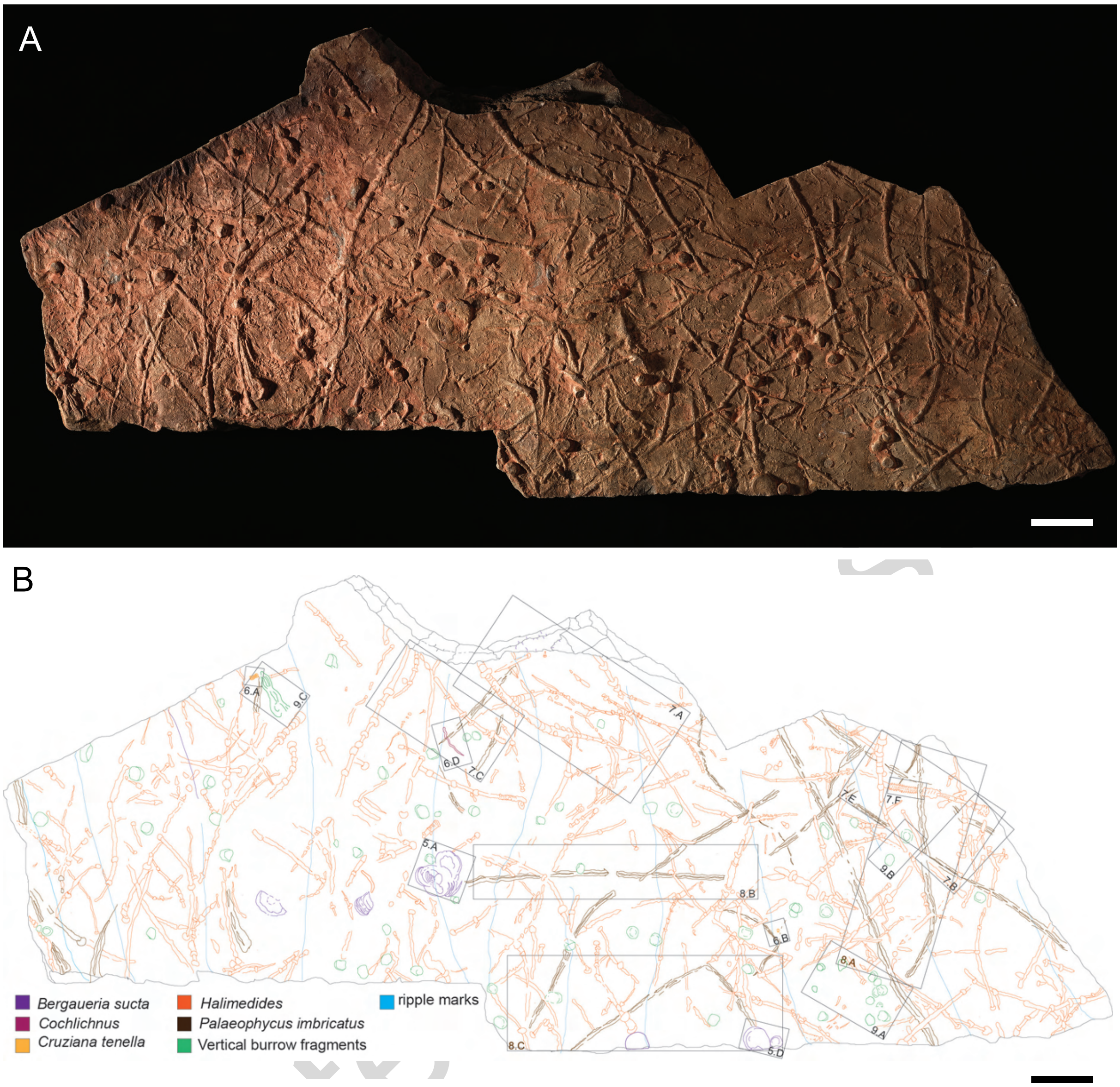

A
B
Bergaueria sucta
Cochlichnus
Cruziana tenella
Halimedides
Palaeophycus imbricatus
Vertical burrow fragments
ripple marks

Figure 3


A

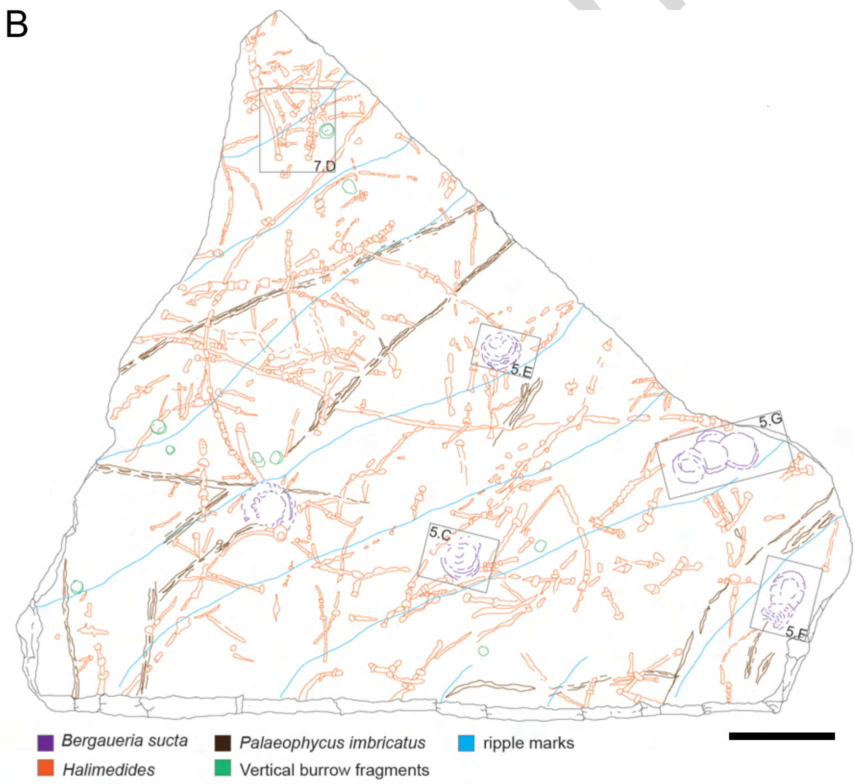

B
7.D
5.E
5.G
5.C
5.F
Bergaueria sucta
Palaeophycus imbricatus
ripple marks
Halimedides
Vertical burrow fragments

Figure 4

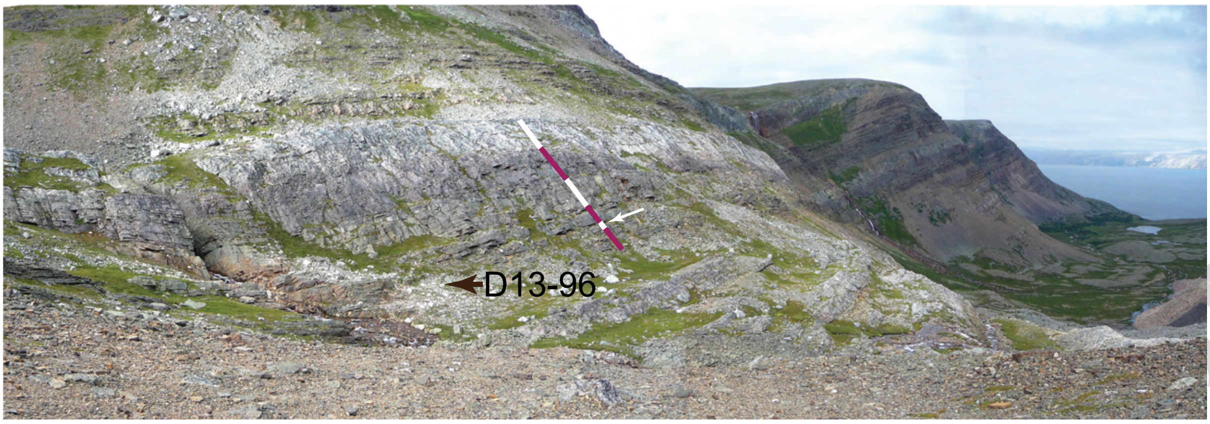


Figure 5

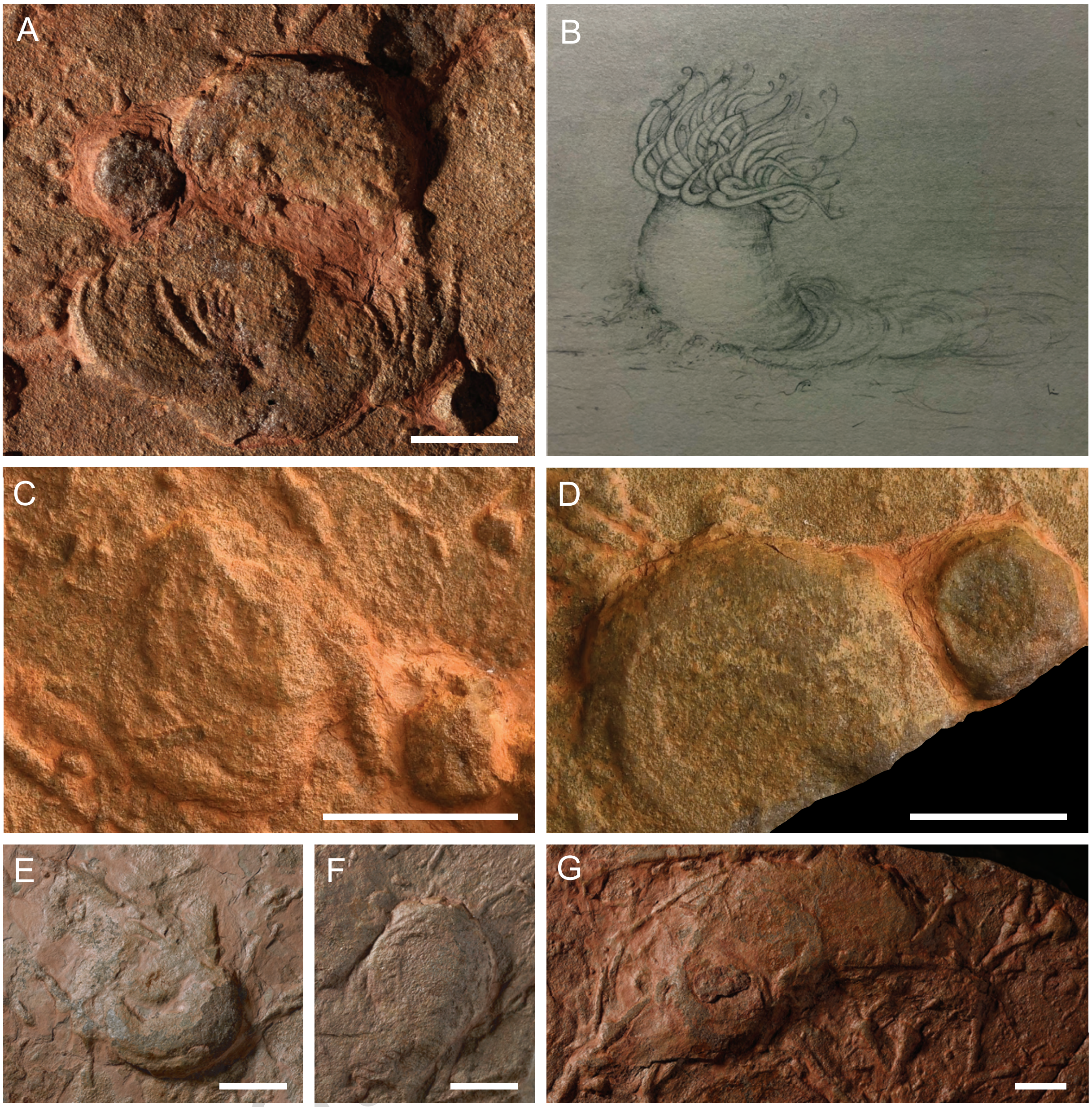


Figure 6

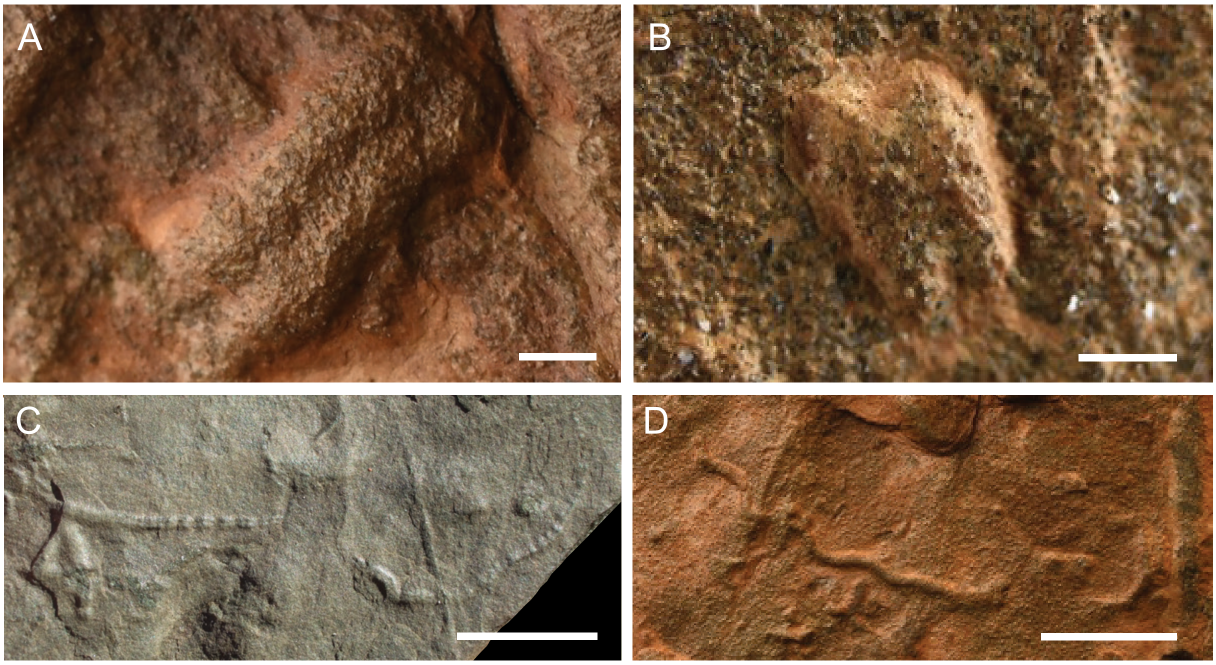


Figure 7

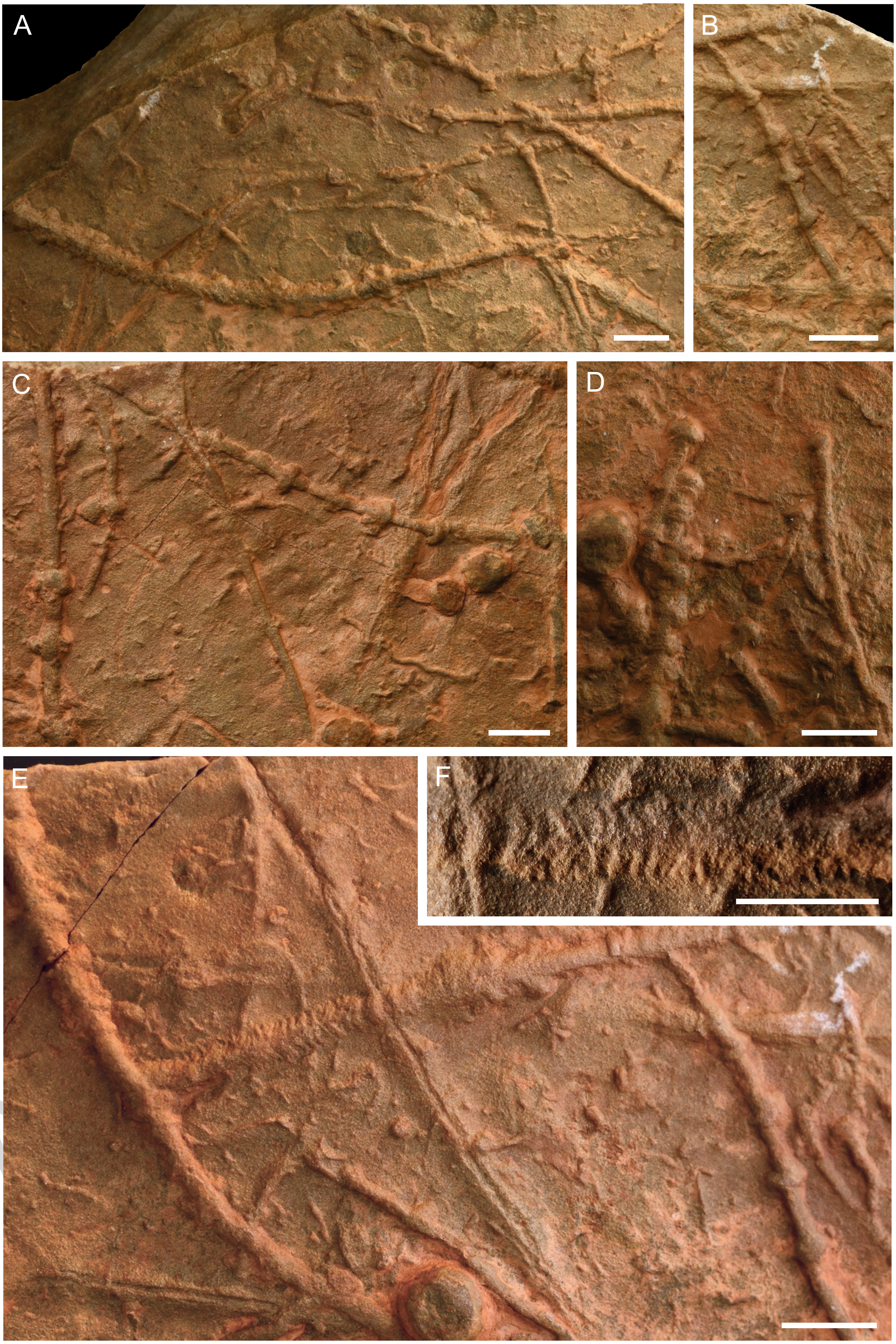


Figure 8

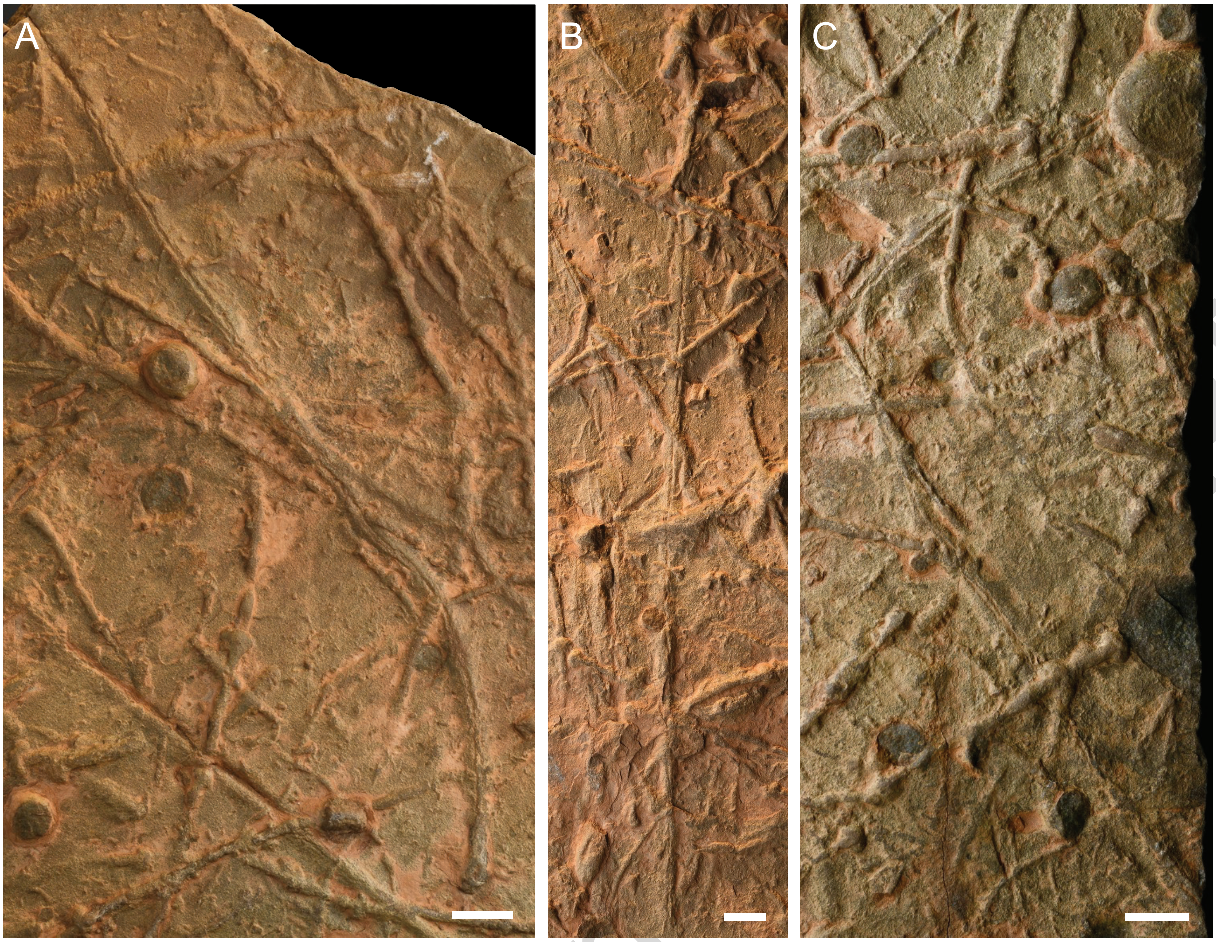
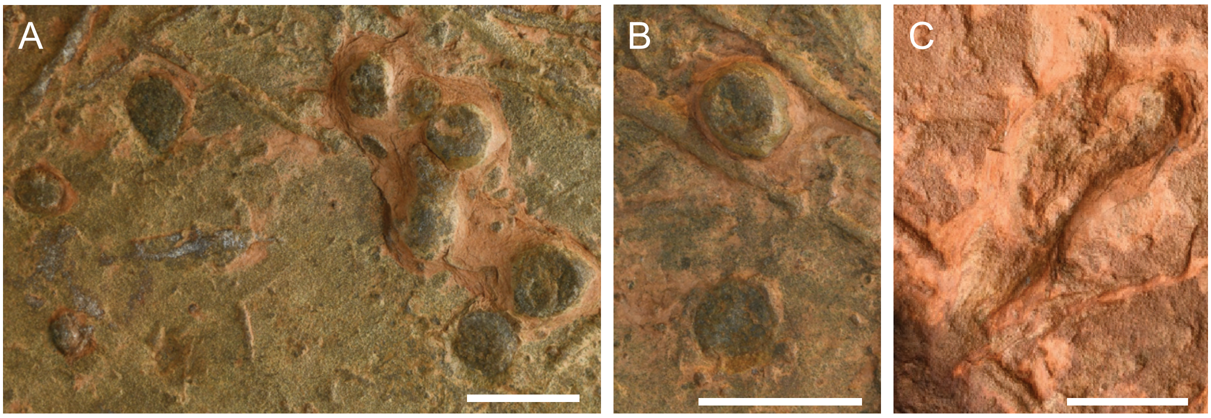


Figure 9



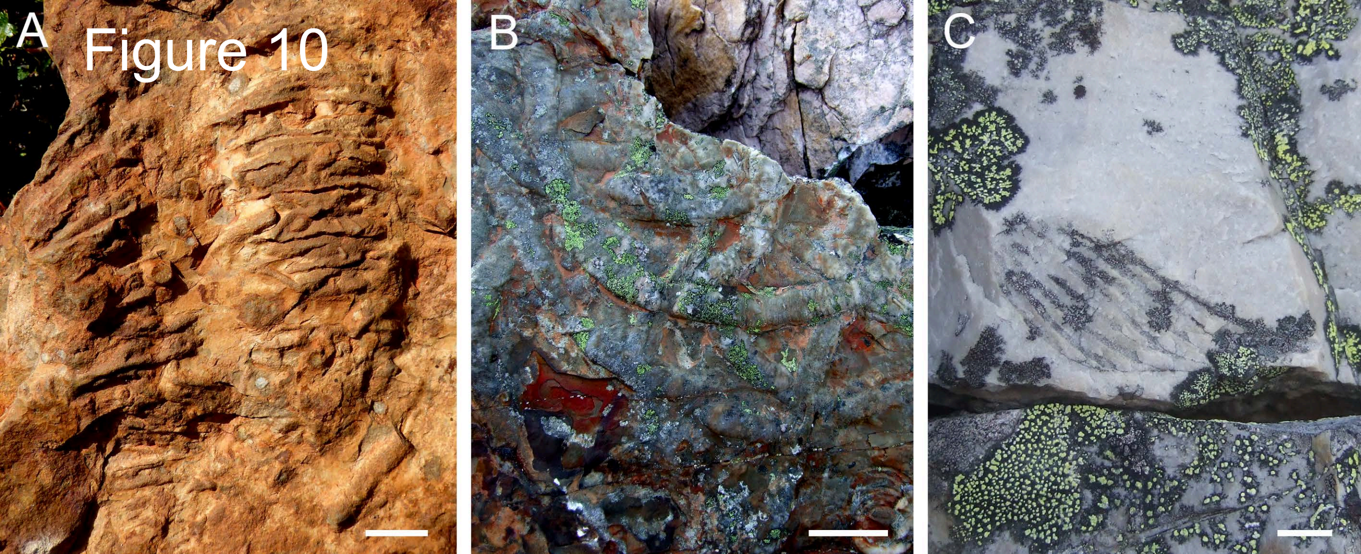

A
Figure 10
B
C

Table 1. Cambrian and Ordovician *Halimedides*

Original identification	Unit and geography	Chronostrat.	Primary reference	N	Dimensions (mm)	Comments
F. isp.	File Haidar Fm., Sweden	Cam. Stage 3-4	Jensen '97	1	St. 2, Sw. 3	
Protovirgularia isp.	Ocieseki Fm., Poland	Cam. Stage 4	Orłowski & Żylińska '02	1	St. 3, Sw. 9	Possible *Halimedides*
H. annulata	Duolbagáisá Fm, Norway	Miaol. (Wuliuan)	This report	370	St. 2-3, Sw. 7-8	
F. ?	Lower Theresa Fm., New York	Furongian	Bjerstedt & Erickson '89	1	St. 2, Sw. 4	
F. annulatus	Heituao Fm, Tarim Basin, China	L.-M. Ord.	Yang '94	?	St. 3.5-5, Sw. 6-10	Two figured specimens
F. annulatus	Georgian Bay Fm., Ontario	U. Ord.	Stanley & Pickerill '93	5	St. 3-4, Sw. 4-7	
F. annulatus	Trenton Group, Ontario	U. Ord.	Stanley & Pickerill '93	1	St. 1, Sw. 6-7	
F. isp.	Letna Fm, Czech Republic	U. Ord. (Caradoc)	Mikulas '98	1	St. 3, Sw. 6	
?*R. annulatus*	Kosov Fm., Czech Republic	U. Ord. (Hirnant.)	Mikulas '92	25	St. 6-12, Sw. 9, 14	Swellings from images
R. isp,	Arnheim Fm (a.o.), Ohio	U. Ord.	Osgood '70	10	St. 2-3, Sw. 5-6	Measures from figures

Abbreviations: F., *Fustiglyphus*; H., *Halimedides*; R., *Rhabdoglyphus*; St. String; Sw. Swelling