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Silurian agglutinated foraminifera from the Dingle Peninsula, Ireland

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KEY WORDS - Foraminifera, Monothalamana, Tubothalamana, Ludlow, Eurytholia bohemica*, paleogeography.*

*ABSTRACT - An assemblage of primitive agglutinated foraminifera is reported for the first time from Silurian limestones from the Dingle Peninsula, Ireland. The assemblage is dominated by tubothalamids (*Rectoammodiscus *and rare* Sansabaina*), with less abundant monothalamids (*Psammosiphonella *and* Psammosphaera*). At the species level, the agglutinated foraminiferal assemblage is identical to those described previously from the Silurian of North America but is of lower diversity. The foraminiferal assemblage has limited potential for stratigraphic correlation as long-ranging taxa are present. The co-occurring conodont fauna enables an assignment to the early Ludlow.*

RIASSUNTO - [Foraminiferi agglutinanti nel Siluriano della Penisola di Dingle, Irlanda] - *Viene qui descritta per la prima volta una associazione di foraminiferi agglutinanti all'interno di calcari siluriani della Penisola di Dingle, Contea di Kerry, Irlanda sud-occidentale. La collezione è stata rinvenuta nel residuo di campioni trattati per la preparazione di conodonti. I foraminiferi sono dominati da tubotalamidi (*Rectoammodiscus *e rari* Sansabaina*), mentre più rari sono i monotalamidi (*Psammosiphonella *e* Psammosphaera*). A livello specifico l'associazione presente in Irlanda è identica a quella descritta in precedenza nel Siluriano del Nord America, anche se presenta minore diversità. Tutte le specie rinvenute hanno una lunga distribuzione stratigrafica, e quindi ricoprono un significato limitato per correlazioni stratigrafiche. La fauna a conodonti ritrovata nei campioni ha permesso una attribuzione dei foraminiferi agglutinanti alla parte iniziale del Ludlow.*

INTRODUCTION

The fossil record of agglutinated foraminifera dates back to the earliest Cambrian, with some reports extending further back to the Ediacarian (Gaucher & Sprechmann, 1999; McIlroy et al., 2001; Kaminski et al., 2010), or possibly even to the Cryogenian (Bosak et al., 2012). The mean standing diversity of agglutinated foraminifera during the early Phanerozoic grew slowly from the Cambrian to the Ordovician, reaching a stable value (close to 50 genera) in the mid-Silurian, and remained fairly constant up to the Triassic (Kaminski et al., 2010). Foraminifera are usually rare in lower Paleozoic rocks and are mostly reported from acid residue of samples studied for non-calcareous microfossils.

A synthesis of the Silurian foraminifera in the British Isles was given by Kircher & Brasier (1989). According to this study, some morphologically simple agglutinated foraminifera were first recognized by Ireland (1958, 1967) in western England. Mabillard & Aldridge (1982) described and illustrated this Llandovery to Wenlock fauna. Wenlockian foraminifera were also reported by Aldridge et al. (1979, 1981) from the Welsh Basin. Kircher & Brasier (1989) noted that these British Silurian assemblages appear to be facies-related, being more abundant in carbonate-rich paleoenvironments. As far as we know, there are no published reports of agglutinated foraminiferal assemblages from the Silurian of the Irish Republic. Rare associations have been reported from higher latitudes in the peri-Gondwana area (e.g., Langer, 1969; Gnoli & Serpagli, 1984).

In an attempt to document and correlate time-specific facies (sensu Brett et al., 2012; Ferretti et al., 2012a, b) across the Iapetus Ocean during the Silurian, our attention has focused on Silurian calcareous occurrences in Ireland, exposed in the Dingle Peninsula, County Kerry, south-western Ireland. The locality is already known in the literature for its peculiar shelly fauna (i.e., brachiopods and trilobites: M'Coy, 1846; Bassett et al., 1976; Siveter, 1989) and the recovery of a silicified enigmatic microfossil (Ferretti et al., 1993). In order to improve the biostratigraphic resolution based on conodonts and in an attempt to provide three-dimensional specimens illustrating the nature of the problematic organism, samples of limestone were etched in dilute formic acid. A small collection of agglutinated foraminifera was recovered in the acid residue. The purpose of the present paper is to describe, illustrate, and assess the significance of this foraminiferal fauna.

GEOLOGICAL SETTING

Silurian rocks in Ireland were deposited on the flanks of and within the contracting Iapetus Ocean between Laurentia and Avalonia. The great majority of outcrops

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are of basinal facies - typically shales and greywackes (Fig. 1). Holland (2009) described these sediments and their generally graptolitic faunas. Shallow water facies are restricted to the west and southwest of the country. In the west, a late Llandovery transgression resulted in the deposition of fossiliferous shallow water, calcareous siltstones and sandstones of Telychian age. The shelly faunas, dominated by brachiopods, are generally preserved as moulds. Only in a few places are the rocks sufficiently calcareous to be disaggregated by leaching in acetic or formic acid. Aldridge et al. (1996) recovered conodonts and thelodonts from one such brachiopod-rich sandstone in the Kilbride Formation at Coolin Lough, County Galway (Fig. 1). Similarly, Aldridge (1980) recovered conodonts from silty limestone in the Telychian-aged Uggool Limestone Member of the Cloonnamna Formation in the Charlestown inlier, County Roscommon (Fig. 1). In addition, silty limestone has been reported by Graham et al. (1989) from the Bouris Formation at Croagh Patrick, County Mayo (Fig. 1), which is probably of Llandovery age, although there are no records of conodonts from this formation.

In contrast to the west of Ireland (Counties Galway, Mayo and Roscommon), the shallow water facies of the Silurian of the Dingle Peninsula, County Kerry (Figs 1-2), are of Wenlock and Ludlow age. The commonest marine facies are calcareous siltstones and sandstones with abundant shelly faunas, predominantly brachiopods. In the Dunquin inlier at the western end of the Dingle Peninsula (Fig. 2), there have been no successful attempts to disaggregate the calcareous rocks by acid leaching. However, in the Annascaul inlier (Fig. 2), described by Parkin (1976), the Wenlock (Homerian) to Ludlow-aged Ballynane Formation (Pracht, 1996) consists of siltstones, containing thin bands and nodular masses of limestone, and fine-grained volcaniclastics (Ferretti & Holland, 1994).

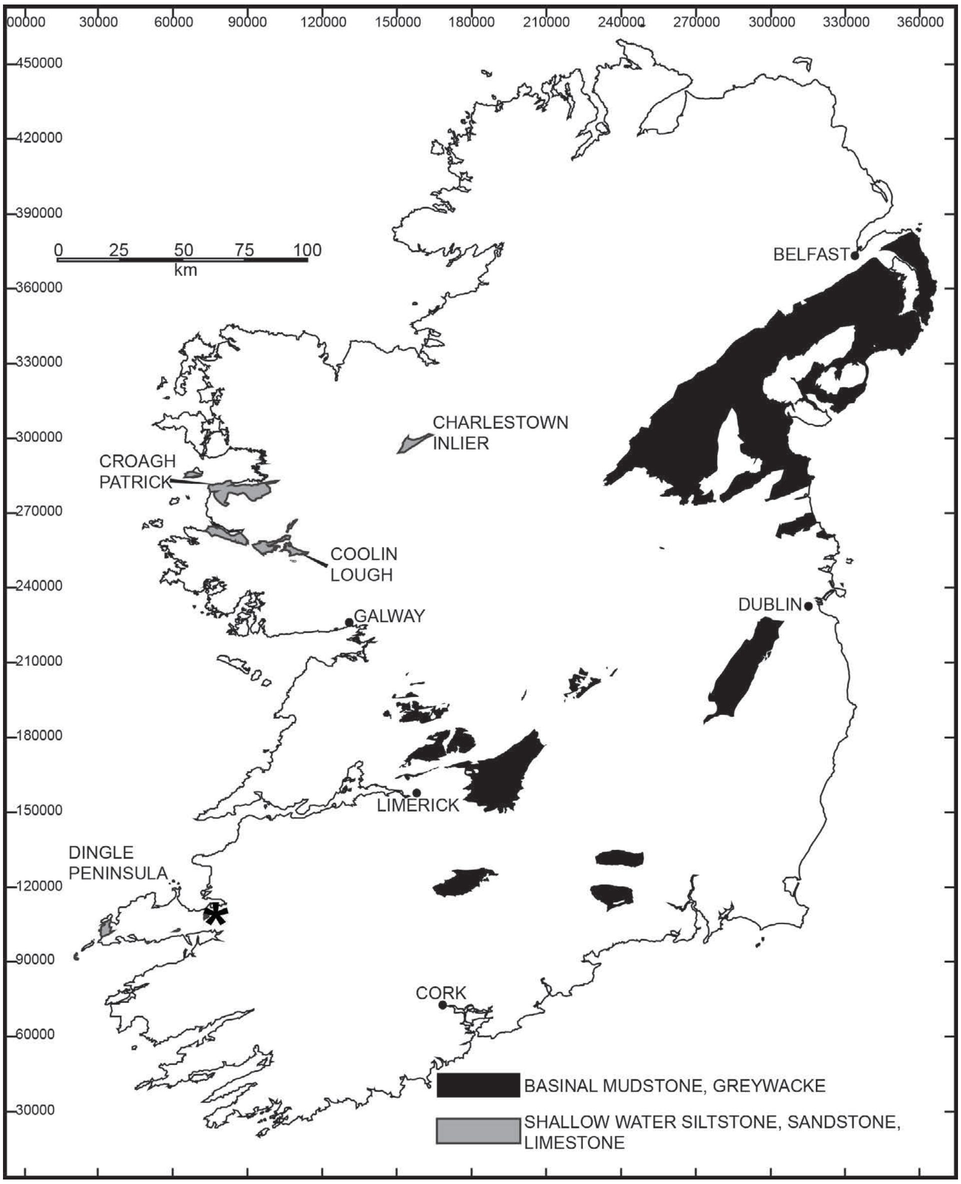


Fig. 1 - Distribution of outcrop/suboutcrop of Silurian rocks of basinal and shallow water shelf facies in Ireland. Locality yielding foraminifera and conodonts on the Dingle Peninsula is marked by an asterisk. The Irish National Grid is shown on the margins of the map.

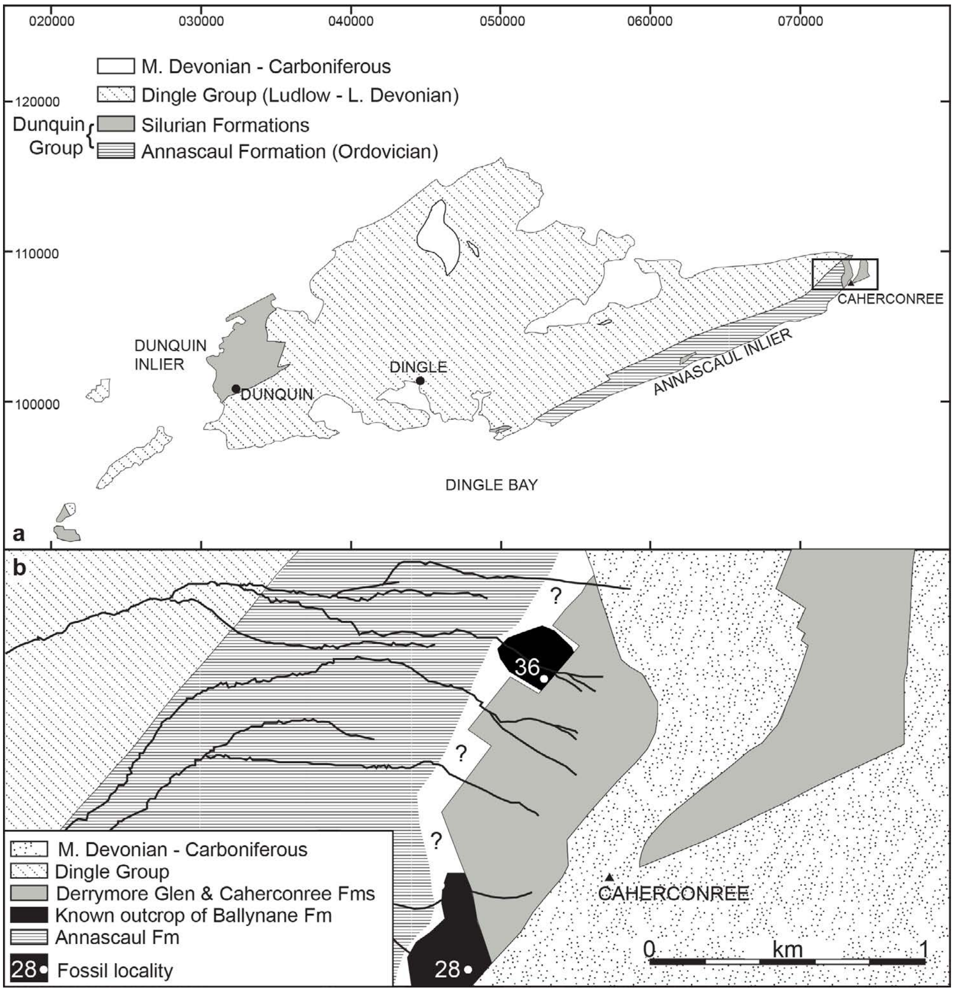


Fig. 2 - Geology of the Dingle Peninsula. a) Geological map of the Dingle Peninsula showing the distribution of Lower Paleozoic rocks, the location of Caherconree and the Irish 10 km National Grid, adapted from Pracht (1996, fig. 3). Inset box shows the location of Fig. 2b. b) Geology of the region around Caherconree, showing the outcrops of the Ballynane Formation with fossil localities referred to in the text, adapted from Parkin (1976).

The younger Caherconree and Derrymore Glen Formations (Fig. 2) are of Ludlow age and do not contain limestone.

The limestones in the Ballynane Formation occur in two small exposures (localities 28 and 36 of Parkin), separated by one kilometre of unexposed ground (Fig. 2b). The limestones were the source of a rich trilobite fauna dominated by odontopleurids described by Siveter (1989) and conodonts reported by Aldridge (1980). Aldridge (1980), on conodont evidence, had suggested that Locality 28 might be of Wenlock age and Locality 36 of Ludlow age. According to Siveter (1989), trilobite data would indicate a 'mid/late Wenlock to earliest Ludlow' age for Locality 36.

Parkin's Locality 36, the one from which our material was collected, consists of 3 m of small grey carbonate nodules, generally 5-6 cm but up to 20 cm in size, embedded in finer-grained matrix. The abundant fauna recovered is almost exclusively represented by benthic organisms, dominated by disarticulated trilobites representing a thanatocoenosis (Siveter, 1989) and crinoidal fragments, and rarer brachiopods and bryozoans. Trilobites and brachiopods are present as well in the silty matrix. Trilobite-crinoidal silty wackestone to packstone (Fig. 3a-b), with local brachiopod concentrations, represents the dominant microfacies, associated with minor occurrence of fossiliferous mudstone (Fig. 3c). These brachiopod-trilobite-crinoidal communites of shallow and well-ventilated water might have represented periodical episodes of colonisation of the bottom intercalated with volcanic events and redepositions in deeper-waters (Ferretti & Holland, 1994) (Fig. 4).

Limestones from Parkin's Locality 36 were also the source of two genera of partially silicified microfossils of uncertain affinity, *Regnellia* and *Sandvikina* Lauritzen, 1974, recognised in thin sections by Ferretti et al. (1993).

THE DINGLE FAUNAL ASSEMBLAGE

Material and methods

In order to fulfil our aims, 3.244 kg of material were processed in diluted formic acid with the standard technique used for conodont preparation, and the > 100 μm residue was hand picked under a Zeiss binocular microscope, yelding a sparse conodont collection and the agglutinated foraminifera described in this paper. Some

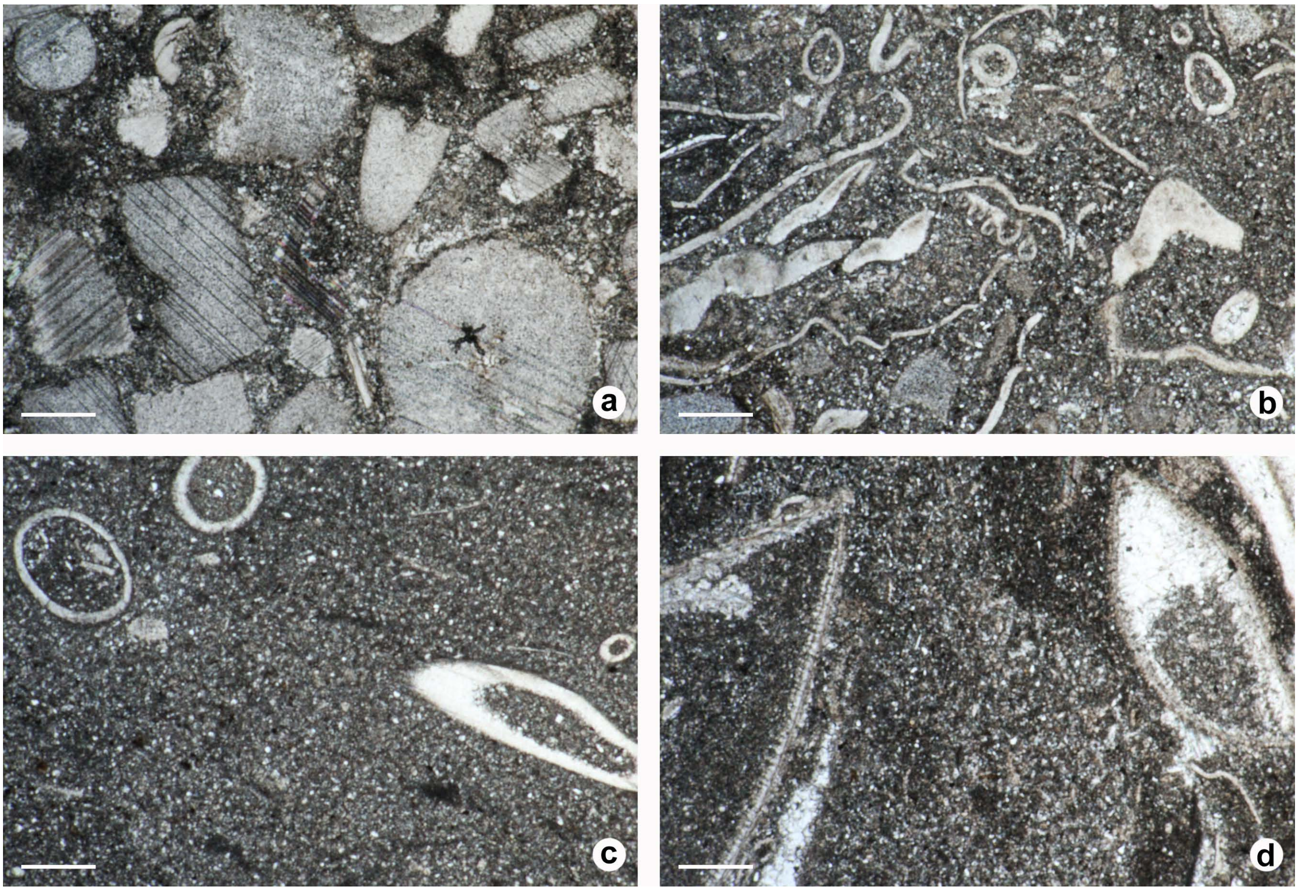


Fig. 3 - Main microfacies types recognized in the Dingle material under investigation. a) Echinoderm packstone; sample TCD.12556. b) Trilobite packstone; sample TCD.12157. c) Trilobite mudstone; sample TCD.12371. d) Brachiopod wackestone; sample TCD.12036. Scale bar corresponds to 500 µm.

zircon grains were recovered as well. Specimens were mounted on aluminium stubs previously covered with carbon-conductive adhesive tape. Au-coated and non-coated elements were observed with an Environmental Scanning Electron Microscope FEI ESEM-Quanta 200, equipped with an Oxford EDX INCA 300 X-ray energy dispersive spectrometer system at the Centro Interdipartimentale Grandi Strumenti CIGS, Università degli Studi di Modena e Reggio Emilia, Modena, Italy. Specimens of foraminifera were photographed using a Nikkon-1500 photomicroscope at KFUPM.

Illustrated specimens are deposited in the collections of the Trinity College of Dublin (TCD), Ireland, under repository numbers TCD.60901-60933.

Biostratigraphic assignment

The conodont specimens (Fig. 5) exhibit a Colour Alteration Index (CAI; cf. Epstein et al., 1977) of about 5, indicating a heating of 300-480°C. The fauna is dominated by representatives of *Kockelella ortus absidata* Barrick & Klapper, 1976 (Fig. 5a), *Kockelella variabilis variabilis* Walliser, 1957 (Fig. 5b-d), *Panderodus recurvatus* (Rhodes, 1953) (Fig. 5e) and *Dapsilodus obliquicostatus* (Branson & Mehl, 1933) (Fig. 5f-g). *Kockelella ortus absidata* appears in the Homerian and continues into the Gorstian (Corradini & Ferretti, 2009; Corradini et al., 2009; Corriga et al., 2009), but the co-occurrence of *Kockelella variabilis variabilis* suggests an early Ludlow (Gorstian-earliest Ludfordian) age for the investigated material.

Minor biota

A ring-like phosphatic element, comparable in size and shape to those recently described from slightly younger levels in the Czech Republic by Ferretti et al. (2013), was also found (Fig. 5h). Two enigmatic plates attributed to *Eurytholia bohemica* Ferretti, Serpagli & Štorch, 2006 and already reported from the Silurian-Early Devonian of the Czech Republic (Ferretti et al., 2006) and the Silurian of the Austrian Carnic Alps (Ferretti & Serpagli, 2008; Brett et al., 2009) have been recorded as well (Fig. 5i-j). *Eurytholia* had been originally described from the Middle-Late Ordovician of several sites of the Iapetus Ocean (United Kingdom, Sweden, Estonia and Alabama) and attributed to a problematic scleritome, ovoid in outline, with plates inserted in soft tissue and distributed in sub-longitudinal rows for protection (Sutton et al., 2001). Unluckily, the sparse occurrence and poor state of preservation of the Irish material do not allow to add any information on the nature of this problematic organism.

The foraminiferal assemblage

The agglutinated foraminiferal assemblage recovered from the Silurian limestones of the Dingle Peninsula is dominated by the tubothalamid genus *Rectoammodiscus*, and contains a smaller proportion of monothalamid genera (*Psammosiphonella*, *Psammosphaera*). The assemblage displays low diversity compared with other assemblages described from the British Isles (Kircher & Brasier, 1989). At the species level, *Psammosiphonella parallela* (Dunn, 1942), *P. rugosa* (Ireland, 1939), *Psammosphaera cava* Moreman, 1930 and *Sansabaina curva* (Moreman, 1930) have been described from the central-northern USA (Mississippi basin, Kansas, Oklahoma, Wisconsin: see Moreman, 1930; Ireland, 1939, 1966; Dunn, 1942; Watkins et al., 1999). *Rectoammodiscus diai* (Culver, 1994) had apparently a wider geographic distribution, including not only the central USA (Oklahoma, Kansas: see Moreman, 1930; Ireland, 1939, 1966) but also the Welsh Borderlands (Kircher & Brasier, 1989) and Senegal (Culver, 1994). Overall, the assemblage displays closest affinity with the assemblages described from the Silurian limestones of North America, but is of lower diversity. All the species recovered are long-ranging, and therefore the foraminiferal assemblage has limited potential for stratigraphic correlation.

Under ESEM analysis, silicon is the most abundant element detected in the spectra run on several areas of the foraminifera, associated with patchy occurrences of iron, aluminium and magnesium. Pyrite grains are also present on the surface of some specimens.

SYSTEMATIC PALEONTOLOGY

The systematics of the agglutinated foraminifera used herein follows the classification of Kaminski (2014). Species identifications are based on the studies of early Paleozoic foraminifera by Moreman (1930), Ireland (1939, 1966), Dunn (1942), Kircher & Brasier (1989), Culver (1994) and Watkins et al. (1999). The essential synonymy is given below.

Class Foraminifera d'Orbigny, 1826
Subclass Monothalamana Pawlowski, Holzmann & Tyszka, 2013
Suborder Astrorhizina Lankester, 1885
Superfamily Astrorhizoidea Brady, 1881
Family Rhabdamminidae Brady, 1884
Subfamily Bathysiphoninae Avnimelech, 1952

Genus *Psammosiphonella* Avnimelech, 1952
Type species *Bathysiphon arenacea* Cushman, 1927

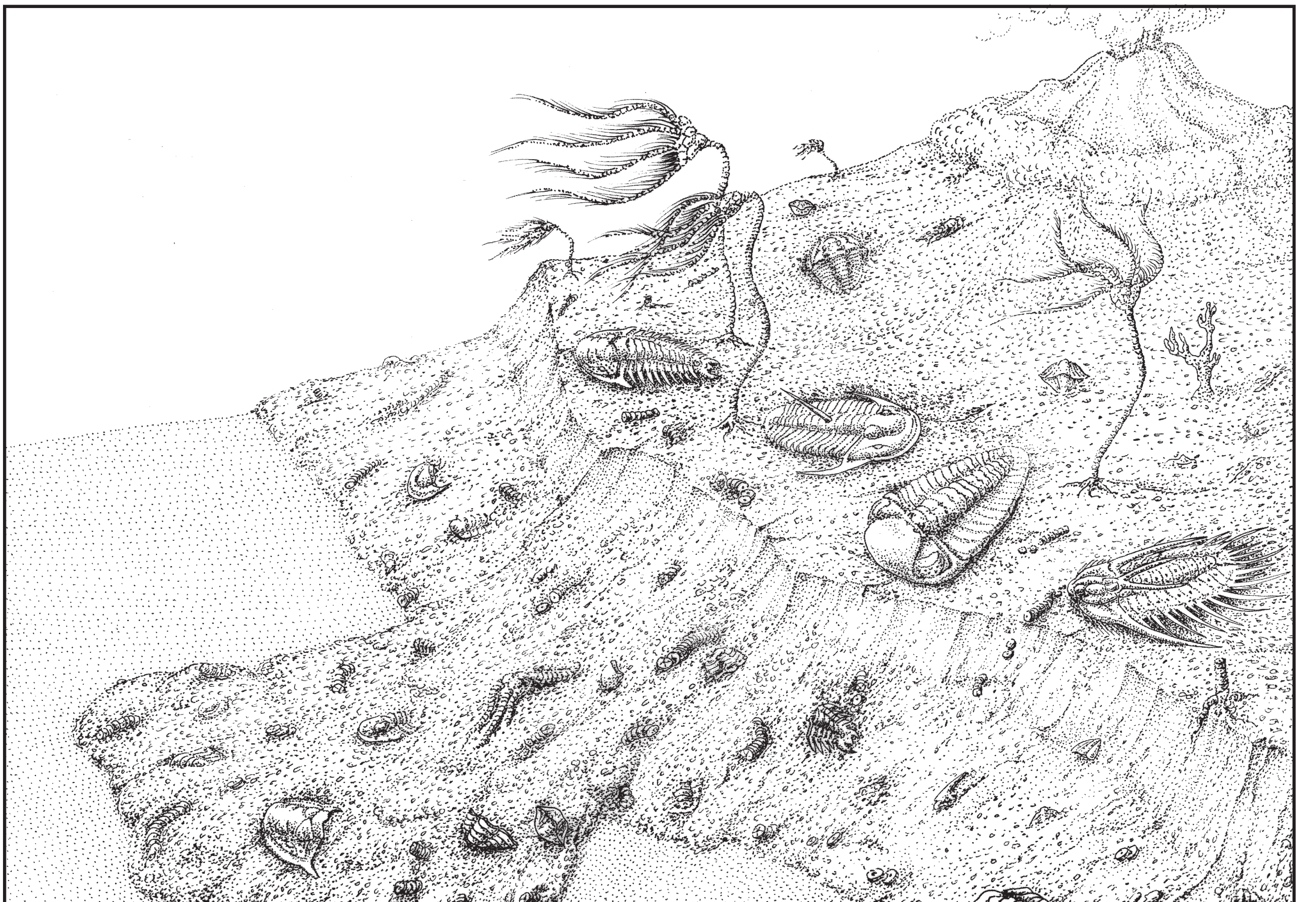


Fig. 4 - Depositional environment of the investigated limestone from Locality 36 as reconstructed by Ferretti & Holland (1994). Shallow benthic faunal trilobite-crinoidal-brachiopod communities developed close to volcanic elevations under the influence of volcanic episodes. Drawing by Giancarlo Leonardi (refigured after Ferretti & Holland, 1994).

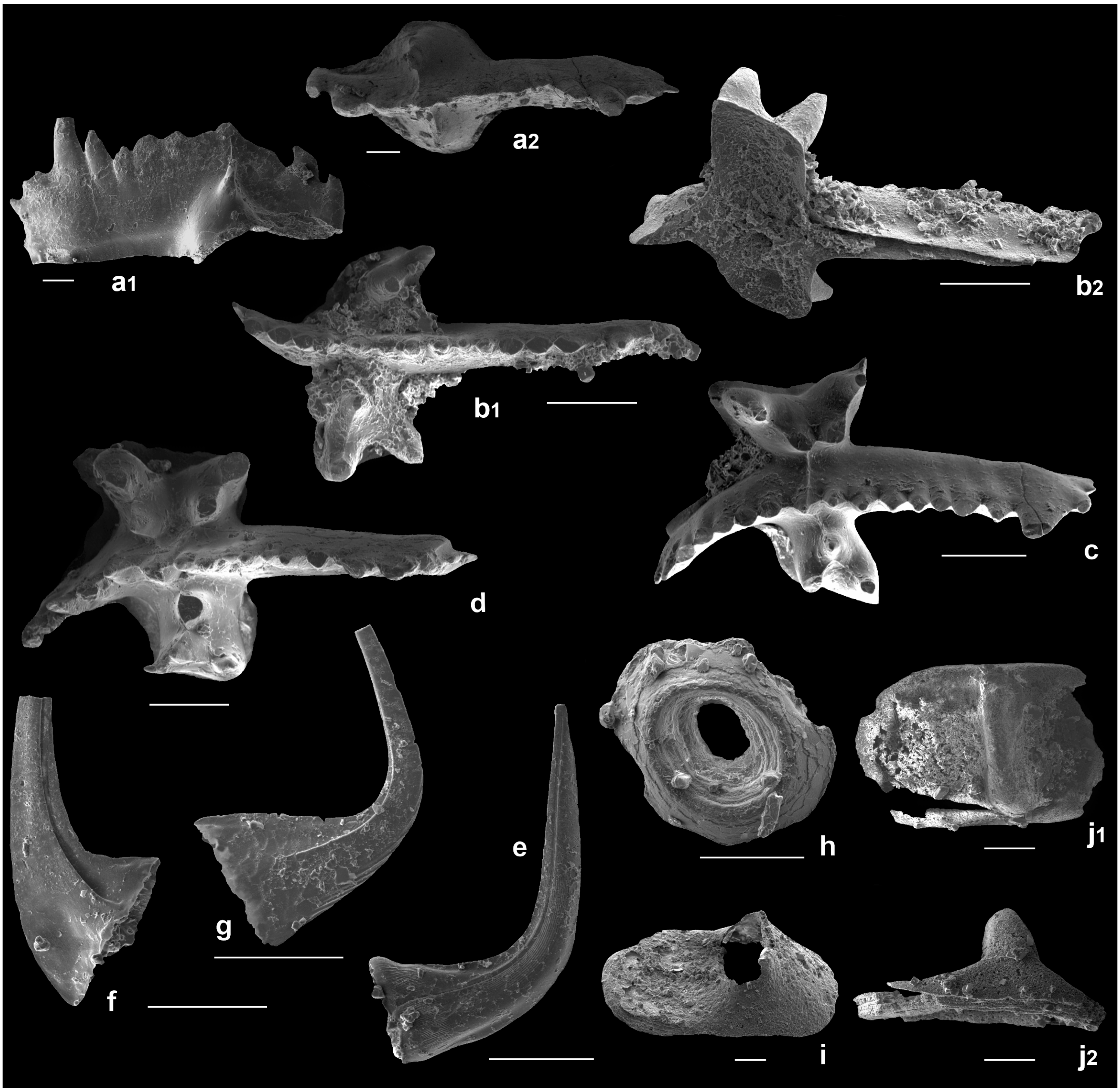


Fig. 5 - Main conodonts (a-g) and enigmatic phosphatic ring (h) and plates (i-j) recovered in the Dingle material. a) *Kockelella ortus absidata* Barrick & Klapper, 1976. Lateral (a1) and upper (a2) views of Pa element TCD.60901. b-d) *Kockelella variabilis variabilis* Walliser, 1957. Upper (b1) and lower-lateral (b2) views of Pa element TCD.60902 and upper (c-d) views respectively of Pa elements TCD.60903 and TCD.60904. e) *Panderodus recurvatus* (Rhodes, 1953). Lateral view of element TCD.60905. f-g) *Dapsilodus obliquicostatus* (Branson & Mehl, 1933). Lateral views respectively of elements TCD.60906 and TCD.60907. h) Upper view of problematic phosphatic ring, specimen TCD.60908. i-j) *Eurytholia bohemica* Ferretti, Serpagli & Štorch, 2006. Upper-lateral view (i) of specimen TCD.60909a and upper (j1) and lateral (j2) views of specimen TCD.60909b. Scale bar corresponds to 200 µm.

EXPLANATION OF PLATE 1

Agglutinated foraminifera from the Silurian (Ludlow) of the Dingle Peninsula, Ireland. Monothalamana (Rhabdamminidae and Psammosphaeridae) and Tubothalamana (Hippocrepinidae).

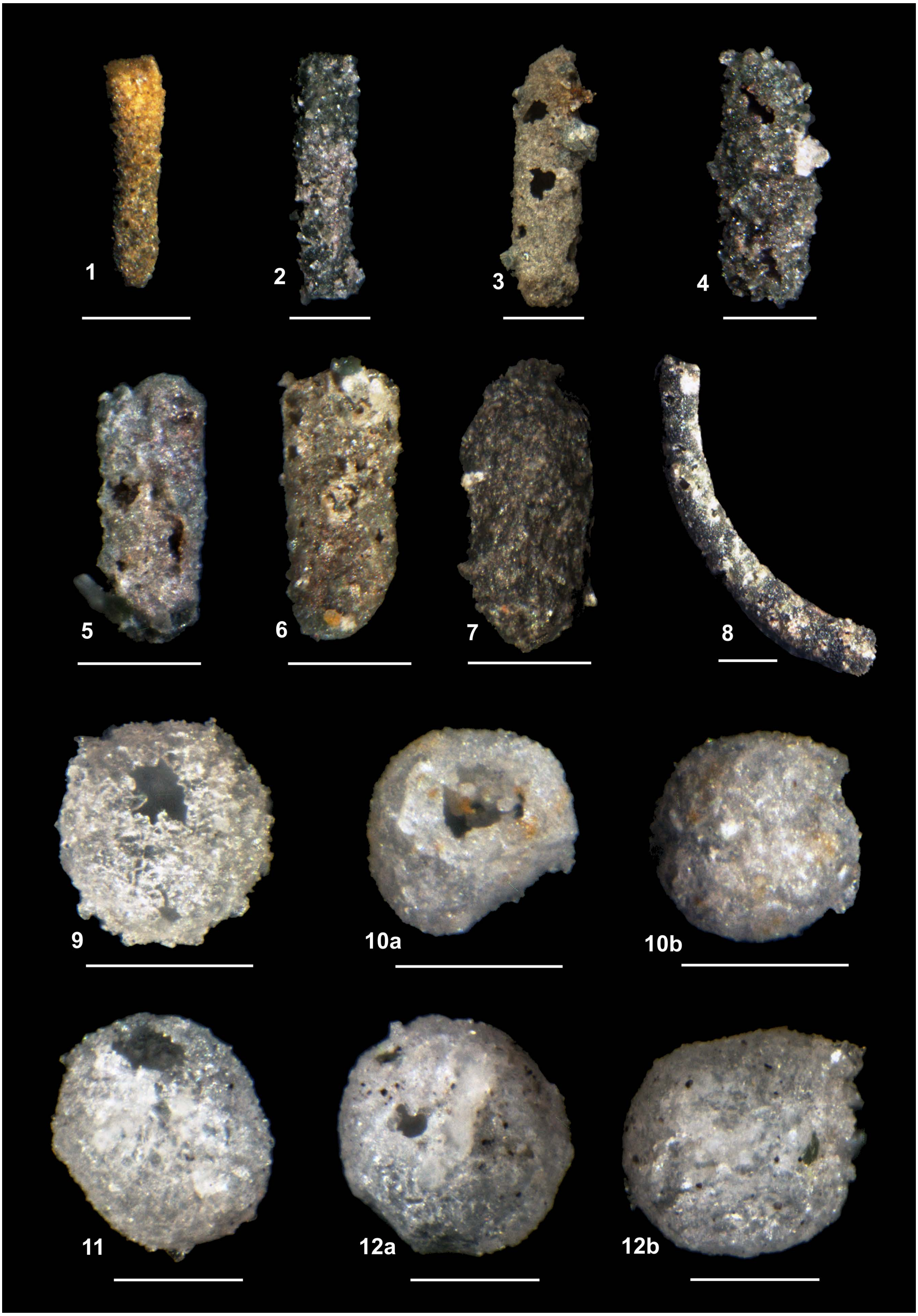
Figs 1-2 - *Psammosiphonella parallela* (Dunn, 1942). Specimens TCD.60910-60911.

Figs 3-7 - *Psammosiphonella rugosa* (Ireland, 1939). Specimens TCD.60912-60916.

Fig. 8 - *Sansabaina curva* (Moreman, 1930). Specimen TCD.60917.

Figs 9-12 - *Psammosphaera cava* Moreman, 1930. 9: specimen TCD.60918; 10: specimen TCD.60919; 11: specimen TCD.60920; 12: specimen TCD.60921.

All specimens from Parkin's Locality 36. Scale bar corresponds to 200 µm.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Psammosiphonella parallela (Dunn, 1942)
(Pl. 1, figs 1-2)

1942 *Bathysiphon parallelus* Dunn, p. 322, Pl. 6, fig. 8.
1966 *Psammosiphonella parallela* (Dunn); Ireland, p. 223, Pl. 1, fig. 5.

Material - Two specimens.

Remarks - A small thin-walled straight tube with parallel sides. Our specimens are similar to those illustrated by Ireland (1966).

Stratigraphic range - Silurian.

Geographic distribution - Dunn (1942) and Ireland (1966) reported this species from the Silurian of the central United States.

Psammosiphonella rugosa (Ireland, 1939)
(Pl. 1, figs 3-7)

1939 *Bathysiphon rugosus* Ireland, p. 192, Pl. A, figs 2-3.
1952 *Psammosiphonella rugosa* (Ireland); Avnimelech, p. 65.
1966 *Bathysiphon rugosus* Ireland; Ireland, p. 224, Pl. 1, figs 6-7.

Material - Six specimens.

Remarks - A large tube with a rough surface as a result of occasional coarser agglutinated grains.

Stratigraphic range - Silurian.

Geographic distribution - Ireland (1939, 1966) reported this species from the central United States.

Suborder Saccamminina Lankester, 1885
Superfamily Psammosphaeroidea Haeckel, 1894
Family Psammosphaeridae Haeckel, 1894
Subfamily Psammosphaerinae Haeckel, 1894

Genus *Psammosphaera* Schulze, 1875
Type species *Psammosphaera fusca* Schulze, 1875

Psammosphaera cava Moreman, 1930
(Pl. 1, figs 9-12)

1930 *Psammosphaera cava* Moreman, p. 48, Pl. 6, fig. 12.
1966 *Psammosphaera cava* Moreman; Ireland, p. 225, Pl. 1, fig. 16.
1999 *Psammosphaera cava* Moreman; Watkins, Walsh & Kuglitsch, p. 543, fig. 5: 8-9.

Material - Ten specimens.

Remarks - Our specimens compare well with the material illustrated by Watkins et al. (1999).

Stratigraphic range - Upper Ordovician (Mound, 1968) to Lower Carboniferous (Conkin & Conkin, 1982).

Geographic distribution - First described from the Silurian of Oklahoma (USA) by Moreman (1930); it has also been reported from the Silurian of England (Mabillard & Aldridge, 1982), Sardinia (Gnoli & Serpagli, 1984), Australia (Bell et al., 2000), the Lower-Middle Devonian of the Czech Republic (Holcova, 2004), and the Upper Devonian of central Poland (Olempska, 1983).

Subclass Tubothalamana Pawlowski, Holzmann & Tyszka, 2013
Order Ammodiscida Mikhalevich, 1980
Suborder Hippocrepinina Saidova, 1981
Family Hippocrepinidae Rhumbler, 1895
Subfamily Jaculellinae Mikhalevich, 1995

Genus *Sansabaina* Loeblich & Tappan, 1984
Type species *Hyperammina elegantissima* Plummer, 1945

Sansabaina curva (Moreman, 1930)
(Pl. 1, fig. 8)

1930 *Bathysiphon curvus* Moreman, p. 45, Pl. 5, figs 9-10.
1999 *Hyperammina curva* (Moreman); Watkins, Walsh & Kuglitsch, fig. 4: 1-3.

Material - One specimen.

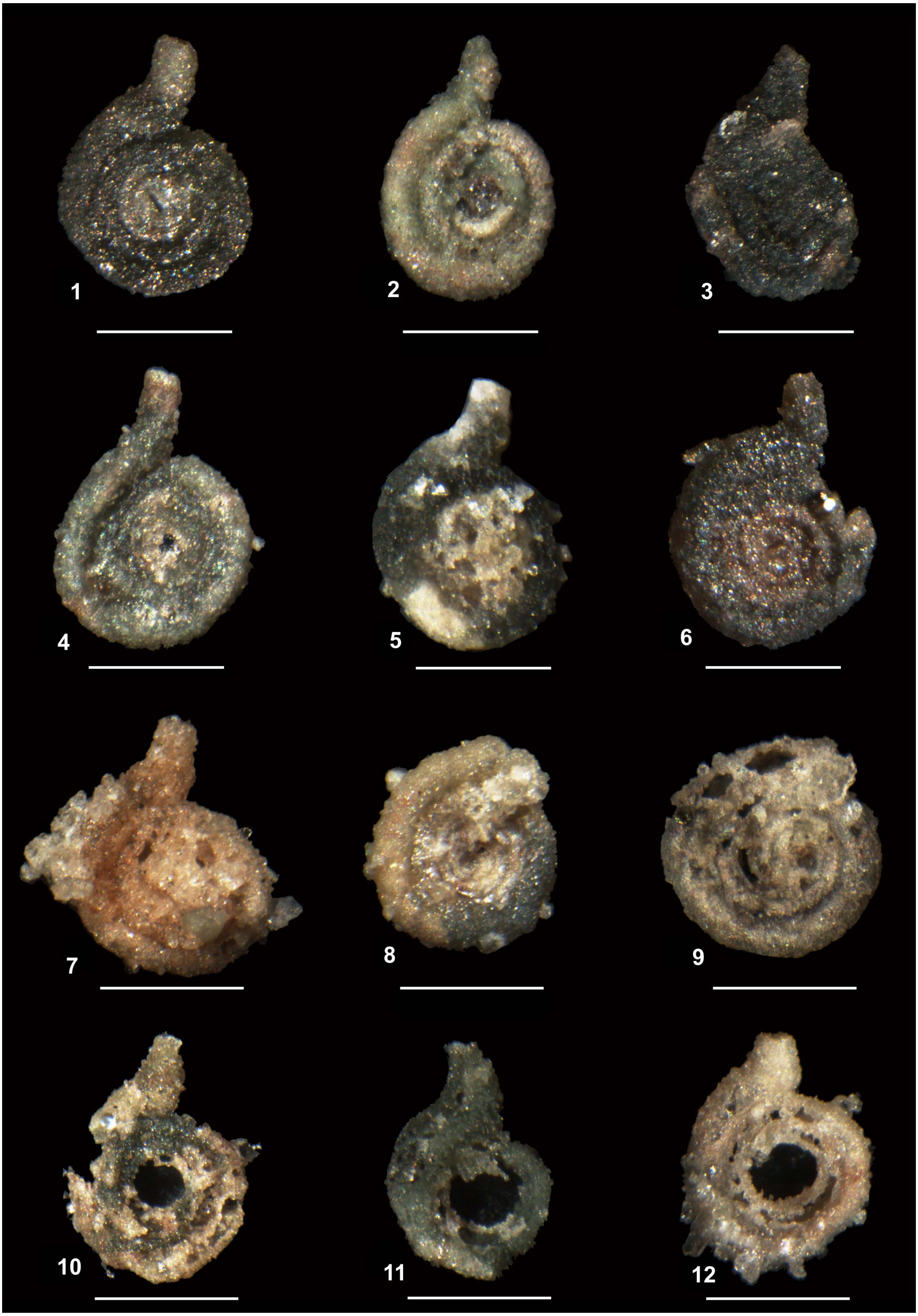
Remarks - A single specimen, gently tapered, broken at both ends. This species has been transferred to the genus *Hyperammina* by later authors (e.g., Watkins et al., 1999). However, we move it to the genus *Sansabaina* Loeblich & Tappan, 1984 because of its arched test and lack of a distinct proloculus, which is missing in most illustrated specimens. The genus *Hyperammina* (type species *H. elongata* Brady, 1897) possesses a large elongated proloculus, while *Sansabaina* is reported to have a proloculus that may be recognizable as a distinct chamber in the megalospheric generation, but in the microspheric generation the test may taper gradually to a point (Loeblich & Tappan, 1984). This fact would explain the lack of a visible proloculus in most specimens of *Bathysiphon curvus* Moreman, 1930. *Sansabaina elegantissima* (Plummer, 1945) is known from the Upper Carboniferous (Pennsylvanian) Mineral Wells Formation at San Saba, Texas (Plummer, 1945). Transferring *Bathysiphon curvus*

EXPLANATION OF PLATE 2

Agglutinated foraminifera from the Silurian (Ludlow) of the Dingle Peninsula, Ireland. Tubothalamana (Ammodiscidae).

Figs 1-12 - *Rectoammodiscus diai* (Culver, 1994). Specimens TCD.60922-60933.

All specimens from Parkin's Locality 36. Scale bar corresponds to 200 μm.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to this genus therefore extends its known stratigraphic range to the early Ludlow.

Stratigraphic range - Silurian.

Geographic distribution - Reported from the Silurian of the central United States by Moreman (1930), Ireland (1966) and Watkins et al. (1999). A specimen identified as *Hyperammina leptalea* by Bell et al. (2000, fig. 5E) from the Lower Silurian of New South Wales, Australia, may belong in this species.

Suborder Ammodiscina Mikhalevich, 1980
Superfamily Ammodiscoidea Reuss, 1862
Family Ammodiscidae Reuss, 1862
Subfamily Ammodiscinae Reuss, 1862

Genus *Rectoammodiscus* Reitlinger, 1993
Type species *Involutina longexsertus* Gutschick & Treckman, 1959

Rectoammodiscus diai (Culver, 1994)
(Pl. 2, figs 1-12)

1994 *Ammodiscus diai* Culver, p. 197, Pl. 1, figs 5-9 (with synonyms).

Material - Twenty-six specimens.

Remarks - Common in the studied material. The tubular chamber changes direction and uncoils abruptly in the plane of coiling. This is the generic characteristic of the genus *Rectoammodiscus*. Culver (1994) reported the species from the Lower Cambrian of West Africa, and included specimens identified as *Ammodiscus exsertus* Cushman, 1910 by Moreman (1930), Ireland (1939, 1966), and Kircher & Brasier (1989).

Stratigraphic range - Lower Cambrian to Silurian (Culver et al., 1994).

Geographic distribution - Culver (1994) reported the species from the Lower Cambrian of West Africa, and included specimens from North America and the United Kingdom identified as *Ammodiscus exsertus* Cushman, 1910 by Moreman (1930), Ireland (1939, 1966), and Kircher & Brasier (1989). *Ammodiscus* cf. *exsertus* was reported in the Silurian of the Carnic Alps (Langer, 1969).

PALEOGEOGRAPHIC SIGNIFICANCE OF THE IRISH FORAMINIFERAL FAUNA

Ireland occupied a key position in the Silurian, being located at the Iapetus suture zone merging terranes associated with Laurentia, Baltica and Avalonia and still under the influence of the supercontinent of Gondwana. Such a complicated geohistory is reflected in the actual configuration of Ireland, deriving from the fusion of several terranes already existing in the Ordovician (e.g., Ferretti et al., 2014).

Shelly faunas had already provided significant information on the faunal affinity of the area. The original brachiopod material reported from the Dingle Peninsula by M'Coy (1846) has correspondence with the type Wenlock and Ludlow successions of the Welsh Borderland, with the majority of species common to both areas (Bassett et al., 1989). Two endemic brachiopods were later described from the Wenlock by Bassett et al. (1989).

The trilobite material described by Siveter (1989) from two localities in the Annascaul inlier documented sixteen species, five of which were new, belonging to thirteen genera and eight families. According to these authors, the fauna is cosmopolitan at a generic level, but clear affinities with the Welsh Borderland (in particular), Bohemia, and Scandinavia emerge at the specific level.

The Silurian foraminiferal faunas from the British Isles, according to Kircher & Brasier (1989), is poorly known, except for a quite rich assemblage described by Mabillard & Aldridge (1982) from Shropshire (Llandovery-Wenlock). Here thousands of specimens are reported, with a dominance of *Ammodiscus exsertus* Cushman (= *Rectoammodiscus diai*) and *Hyperammina* spp. (possibly including *Sansabaina*); *Psammosphaera cava* is also locally common. However, as stated above, the faunal composition of the foraminiferal material investigated in this paper perfectly matches, at a specific level, the assemblages reported at several localities in the central United States that were parts of Laurentia during Silurian times. These conclusions appear to confirm data derived from paleomagnetic analysis of Homerian (upper Wenlock) sediments from the Dingle Peninsula (Mac Niocaill, 2000) that indicate how the ocean between Laurentia and Avalonia had narrowed to below the limits of paleomagnetic resolution already by Wenlock time.

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