Upper Ordovician conodonts from Bornholm and possible migration routes in the Palaeotethys Ocean

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Upper Ordovician conodonts from the *Dicellograptus* Shale Formation on Bornholm are recorded from the base of the *Pleurograptus linearis* graptolite Zone in the Vasegaardian Stage of the Harjuan Series (Upper Ordovician in Balto-scandic chronostratigraphy). The conodont fauna includes *Hamarodus europaeus, Protopanderodus liripipus, Scabbardella altipes* and *Periodon grandis*. Additional uncommonly encountered elements are referred to *Eocarniodus gracilis*?, *Coelo-cerodontus*? sp. A, new genus A sp. A and gen. indet. et sp. indet. The faunal composition is indicative of cool deep water to temperate shallow open marine conditions. The *Hamarodus* conodont fauna of the *Pleurograptus linearis* graptolite Zone is separated from the *Dicellograptus clingani* graptolite Zone by a hiatus. This hiatus is recognised along the north-western margins of the Baltica, Avalonia and Gondwana palaeocontinents and it is called the Viru-Harju regressive event (VHRE).

Svend Stouge & Jan Audun Rasmussen. Geological Survey of Denmark and Green-land, Thoravej 8, DK-2400 Copenhagen NV, Denmark, September 25th, 1995.

Introduction

Diagenetic limestone nodules were collected from the *Dicellograptus* Shale Formation (Middle-Upper Ordovician) at Risebæk and Vasegård, south-western Bornholm (Fig. 1). One of these produced a small but characteristic assemblage of conodonts. The presence of conodonts in the *Dicellograptus* Shale Formation on Bornholm provides an opportunity for a direct comparison between graptolite zones (i.e. shaly facies) and conodont zones (shelly facies). The conodont fauna is recorded from a level near the Baltoscandian middle-upper Ordovician Series boundary (= Viru-Harju sensu Jaanusson 1960, 1963) and correlates with the basal Pusgillian Stage of the British Ashgill Series (sensu Fortey, Harper, Inghamn, Owen & Rushton 1995).

In this paper, the conodont fauna of the *Dicellograptus* Shale Formation is described. The appearance of the *Hamarodus* fauna in the Upper Ordovician of Europe is related to the transgressive signal following the distinct regressive hiatus across the series boundary.

Geological setting and stratigraphy

Bornholm is situated between the Teissyre-Tornquist Zone (TTZ) and the Sorgenfrei-Tornquist Zone (STZ) to the Southwest (also known as the Fennoscandian Border Zone) and the stable East European platform to the east-Northeast (Berthelsen 1992; Vejbæk, Stouge & Damtoft Poulsen 1994). Southwest of Bornholm, the Transeuropean fault (TEF) marks the northern limit of the Caledonian deformation front (Berthelsen 1988, 1992; Vejbæk et al. 1994). The Caledonian deformation front is interpreted by Katzung, Giese, Maletz, Servais & van Grootel (1995) to separate the strata that derived from the Avalonia continent from the Baltica sequence.

From the beginning of the Caradoc (Viru; Middle Ordovician) the platform began to subside to southwest of Bornholm (Vejbæk et al. 1994). The lithospheric flexure and foundering of the continental margin was associated with volcanic eruptions and numerous, and at times very thick, beds of K-Bentonites were deposited (Bergström & Nilsson 1974; Huff, Bergström & Kolata 1992; Bergström, Huff, Kolata & Bauert 1995). The foundering of the platform created well-

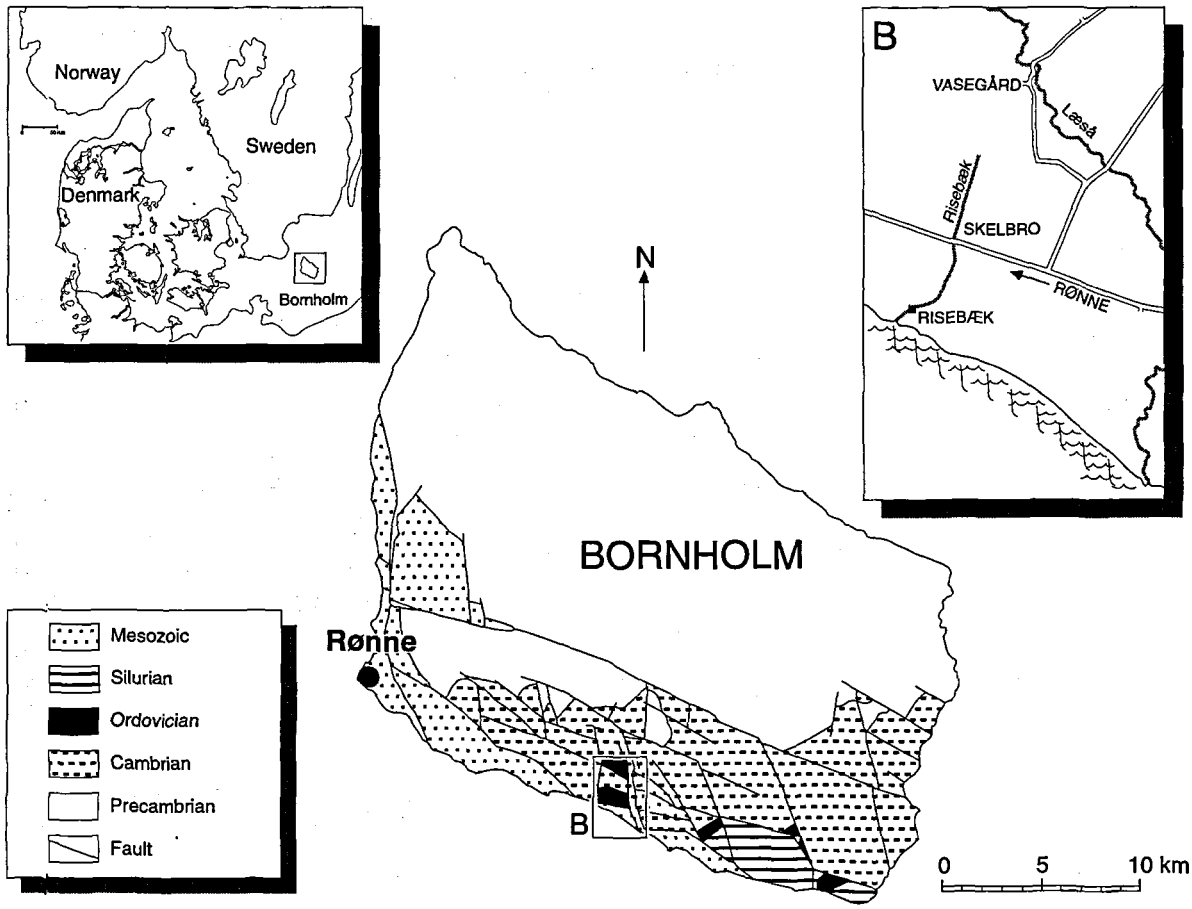


Fig. 1. Location map.

defined facies belts extending from marginal to distal deep shelf black shale deposits in deposition to forereef, reef and backreef environments. The forereef, reef and backreef facies distribution lasted into the Wenlock (Silurian) although it was interrupted by the short but distinct eustatic low at the end of the Ordovician (Hirnantian) due to global glaciation (Brenchley, P. J., Marshall, J. D., Carden, G. A. F., Robertson, D. B. R., Long, D. G. F., Meidla, T., Hints, L. & Anderson, T. F. 1994).

Ordovician stratigraphy of the Bornholm region

Palaeozoic deposits on Bornholm are exposed along the southwest coast and are preserved in small fault bounded areas (Figs 1-2). The Ordovician sedimentary deposits on Bornholm are characterised by shales and limestones interrupted by several distinctive hiati (Poulsen 1966; Stouge & Andsbjerg 1993; Vejbæk et al. 1994). The sequence begins with the graptolite bearing *Dictyonema* shale unit of the Alum Shale Group. The Upper Cambrian sediments are separated from the Lower Ordovician shales by a faunally barren interval (Poulsen 1966).

The Alum Shale Group is disconformably overlain by the Komstad Limestone Formation. The Komstad Limestone represents a lateral equivalent to the carbonates of the platform to the east and north. The unit is Volkov to Early Kundan (Middle to Late Arenig; Lower Ordovician) based on the fossil content (Poulsen 1966; Stouge 1975; Nielsen 1995).

On Bornholm, black shales of the *Dicellograptus* Shale Formation accumulated during the Middle to the early Late Ordovician and the fauna is characterised by graptolites and lingulate brachiopods (Poulsen 1966; Bjerreskov & Stouge 1985). The unit disconformably overlies the Komstad Limestone and Llanvirn-Llandeilo deposits are not present on Bornholm. The *Dicellograptus* Shale begins with a basal phosphatic conglomerate. Bentonite beds are present throughout the sequence but are especially well developed in the *Di-*

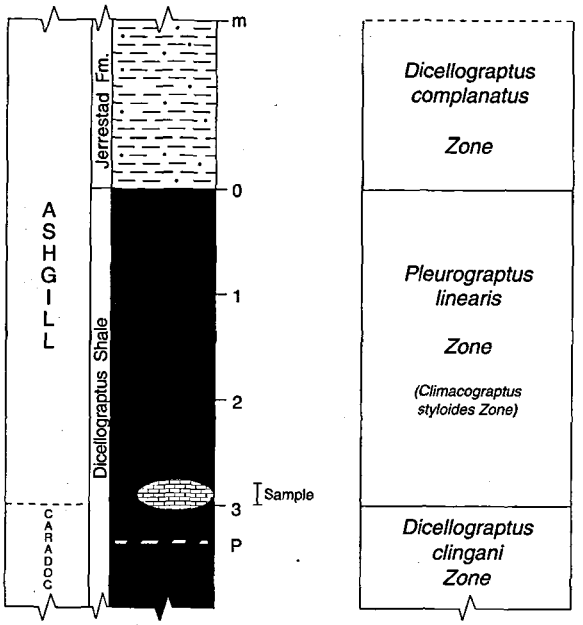


Fig. 2. Risebæk Section with position of sample. The graptolite zonation is compiled from Poulsen (1966). P = horizon with pyrite. The *Climacograptus styloides* Zone of Hadding (1915a, b) correlates with the *Pleurograptus linearis* graptolite Zone (Poulsen 1966).

plograptus multidens graptolite Zone in the lower part of the sequence (Gry 1948; Bergström & Nilsson 1974; Pedersen 1989; Pedersen & Klitten 1990).

A pyritic-phosporitic interval is situated between the *Dicellograptus clingani* and *Pleurograptus linearis* graptolite Zones (Fig. 2) and it represents a hiatus within the *Dicellograptus* Shale Formation (Poulsen 1966). The shales pass upwards into grey mudstones and siltstones of the Jerrestad and Tommarp Formations. The Ordovician sediments are overlain by a thick sequence of shales, calcareous shales and siltstones, and volcano-clastic sediments of Silurian age (Llandovery-Wenlock) (Bjerreskov 1975; Bjerreskov & Jørgensen 1983; Bjerreskov & Stouge 1985).

Material and method

The conodont fauna was extracted from black limestone lenses which are fine-grained and with a high organic content. Several samples of the same lithology have been investigated from the Risebæk and Vasegård localities (Fig. 1), but only one yielded conodonts which could be identified. This sample was collected from the *Dicellograptus* Shale Formation, (Middle-Upper Ordovician) exposed at the Risebæk "Waterfall".

The conodont-yielding sample weighted 1.3 kg. It was dissolved using nonbuffered acetic acid (10%). The acid was changed each second day and the insoluble residue was washed through a 63 mm sieve every time the acid was changed. The conodonts were picked without using the heavy liquid separation technique.

The conodont bearing sample was collected 3 m below the top of the *Dicellograptus* Shale Formation. This level is near, but above, the boundary between the *Dicellograptus clingani* and the *Pleurograptus linearis* graptolite Zones. The conodont elements have a CAI (Colour Alteration Index) value of 3.5 (Epstein, Epstein & Harris 1977) which corresponds to a Vitrinite reflectance value from 1.8 to 2.0 (=Wet Gas Floor) (Hoffknecht 1991) indicating that the sediments have been heated to 190–200° Celsius. Silty material is often attached to the specimens, but in many cases identification of the specimens to species level was possible. The conodont fauna is dominated by coniforms and only fragments representing more complex multielement apparatus have been recorded. The species and number of specimens are given in Table 1.

Locality

The Risebæk locality is situated near the southcoast and about 700 m south of the southern highway and Skelbro Quarry on Bornholm (grid ref. UTM coordinates VA 918991, Bornholm 1:25.000 topographic map) (Fig. 1). The exposed section (Fig. 2) includes approximately 4 m black shales with graptolites and lingulate brachiopods and are overlain by 3 m of light grey bioturbated mudstone with pyrite aggregates of the Jerrestad Formation (Upper Ordovician).

The Risebæk locality (Figs 1–2) was first described in the literature by the classic studies of Tullberg (1882) and Hadding (1915a, b) who described the graptolite

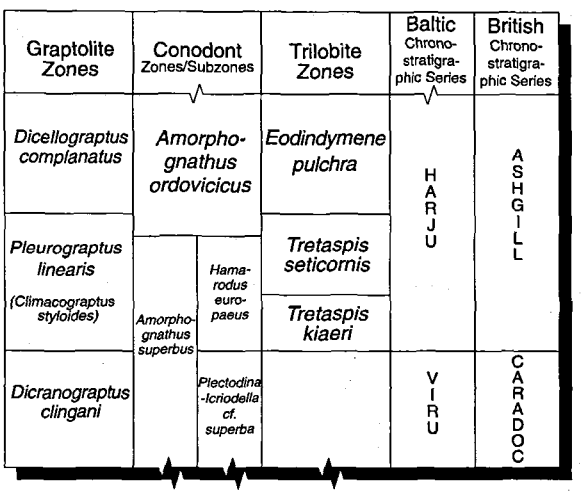


Fig. 3. Correlation of the *Hamarodus europaeus* fauna from Risebæk. Graptolite and trilobite zonal informations are from Poulsen (1966). Conodont zones and subzones are compiled from Bergström (1971) and Männik (1992).

Table 1. Number of conodonts from Risebæk, Bornholm

Conodont species	No. of specimens
Ansella nevadensis	1
Coelocerodontus? sp. A	6
Eocarniodus? *gracilis*?	4
Hamarodus europaeus	5
Periodon grandis	1
Protopanderodus liripipus	15
Scabbardella altipes	22
Genus indet A sp. A	6
Genus indet B sp. A	6
Total	66

fauna from the *Dicellograptus* Shale Formation. Tullberg (1882) reported *Dicellograptus clingani* and *Climacograptus styloides* from this locality. Beds at the same stratigraphical position in the nearby Vasegård section (Fig. 1) were included in the *Climacograptus styloides* Zone (Figs 2–3) (Hadding 1915; comprising the beds I_0–I_5 in his terminology). The zone was assigned to the Vasegaardian Stage of the Harju Series (Upper Ordovician) and the *Climacograptus sty-loides* Zone was correlated with the *Pleurograptus linearis* Zone of Great Britain (Jaanusson 1963) (Figs 2-3). The *Climacograptus styloides* fauna is well preserved on Bornholm, but the nominate species of the *Pleurograptus linearis* Zone has not been recovered (Bjerreskov & Stouge 1985). The overlying Jerrestad Formation comprises shelly fossils, mainly brachiopods and trilobites (Ravn 1899; Kielan 1959). The fauna is characteristic for the *Eodindymene pulchra* Zone; but the zonal fossil has not been found from Bornholm. The presence of *Dicellograptus complanatus* in the beds (Poulsen 1936; Skoglund 1963) suggests correlation with that zone (Poulsen 1966) (Fig. 3) and the Jerrestadian Stage (Jaanusson 1963).

Conodont biostratigraphy and correlation

Hamarodus europaeus is known from the *Amorphognathus superbus* conodont Zone and ranges into the *Amorphognathus ordovicicus* conodont Zone in Swedish sections (Bergström 1971; Sweet & Bergström 1984) and Norwegian sections (Hamar 1966). *Hamarodus europaeus* is associated with *Amorphognathus complicatus* Rhodes in Sweden and Norway. In Norway, *Hamarodus europaeus* is recorded from the uppermost part of the Solvang Formation (Owen, Bruton, Bockelie & Bocklie 1990) at Frognøy, Ringerike in Norway. The same beds belong to the *Tretaspis kiaeri* trilobite Zone (= 4b δ2 of Størmer 1953) which based on trilobites correlates with the Pusgillian Stage of the Ashgill Series in Great Britain (Owen 1980; Owen et al. 1990; Fortey et al. 1995). The Norwegian conodont fauna correlates with the upper part of the *Amorphognathus superbus* Zone (Bergström 1971) (Figs 3–4).

In the Estonian successions *Hamarodus europaeus* has been recorded from the Mõntu, Paekna and Saunja Formations (Viira 1974; Männik & Viira 1990; Männik 1992), which are referred to the Nabala Stage (F1a) of the Harju Series (Upper Ordovician) (Männil 1990; Männil & Meidla 1994). *Hamarodus europaeus* is the zonal index fossil for the *Hamarodus europaeus* conodont Interval-Subzone which is the upper interval of the *Amorphognathus superbus* conodont Zone in Estonia (Männik 1992).

Further to the south *Hamerodus europaeus* is known from the Mójcza Limestone in the Holy Cross Mountains, southern Poland (Dzik 1989, 1994). Here it appears within the upper *Amorphognathus superbus* Zone and ranges into the following *Amorphognathus ordovicicus* conodont Zone. This is the same stratigraphical position as in the Baltoscandian successions.

Outside the Scandinavian-Baltic-Polish region *Hamarodus europaeus* has been described from the Rawtheyan and Hirnantian Stages of the Ashgill Series (i.e. *Dicellograptus complanatus* graptolite Zone or *Amorphognathus ordovicicus* conodont Zone) in North England and North Wales (Rhodes 1955; Bergström 1971, 1990; Orchard 1980; Bergström & Orchard 1985). *Hamarodus europaeus* is recorded from the Abercwmeiddaw Beds in Bala (North Wales). In the North of England, *Hamarodus europaeus* has been recorded from the Mucronata Limestone in the Lake district, from the Cystoid Limestone of the Tayhes Inlier, the Keisley Limestone (Rhodes 1955) and Swindale Limestone in the Cross Fell Inlier and from the Westerdale Inlier of the Howgill Gell (Orchard 1980). At all these places, *Hamarodus europaeus* occurs within the *Amorphognathus ordovicicus* Zone and *Protopanderodus* cf. *liripipus* (? = *Protopanderodus insculptus*) and *Scabbardella altipes* are common associated species. Thus the first arrival of the *Hamarodus* fauna to Great Britain is younger than it is for the Scandinavian, Estonian or Polish successions.

In south Europe the *Hamarodus europaeus* fauna has been recorded from the "Tonflaser kalke" of the Carnic Alps of Austria and Italy (Serpagli 1967; Schönlaub 1969, 1979, 1980) and perhaps from the Northern Greywacke Zone in Austria (Flajs & Schönlaub 1976). The Urbana limestone and lateral equivalent units in Spain (Fuganti & Serpagli 1968; Carls 1975; Hammann, Robardet & Romano 1982; Sarmiento & Lopez 1993) are referred to the *Amorphognathus ordovicicus* Zone (Sarmiento & Lopez 1993). Ferretti & Serpagli (1991) preliminary reported on the presence of *Hamarodus europaeus* and *Scabbardella altipes* together with *Amorphognathus ordovicicus* from a limestone unit at the base of the Punta S´Argiola Member of the clastic dominated Dusmusnovas Formation on southeastern Sardinia (Leone, Hammann, Laske, Serpagli & Villas

1991). Knüpfer (1967) and Fuchs (1990) found *Hamarodus europaeus* associated with *Amorphognathus superbus* and *Amorphognathus ordovicicus* from a limestone unit in the top of the Schmiedefelder Formation in Thüringen (Thuringia) in Germany. This limestone is thin and it is underlain by iron oolites ("Oberer Erzhorizon") and quartzites.

Outside Europe, the *Hamarodus europaeus* fauna has been recorded from the Pagoda Limestone of the Yangtze Platform, south-central China and is incorporated in the *Hamarodus europaeus* Zone (An 1981, 1987; Chen 1983). The *Hamarodus europaeus* Zone of the Pagoda Limestone has been dated as Caradoc by An (1987), which is older than any of the known occurrences in Europe.

Contemporaneous conodont faunas from northern Libya, Africa (Bergström & Massa 1992) include *Scabbardella altipes* as the only species in common with the Bornholm fauna. Orchard (1980:12) mentioned the occurrence of *Hamarodus* sp. in the Elburz Mountains of Iran, where it is present in the upper half of the *Amorphognathus superbus* Zone (earlier referred to the *Amorphognathus ordovicicus* Zone by Whittington & Orchard 1977).

Hamarodus cf. *europaeus* from the Grog Brook Group of the Metapedia Belt in northwestern New Brunswick, eastern Canada (Nowlan 1983) occurs together with *Amorphognathus ordovicicus, Periodon* and *Protopanderodus*. This fauna is mixed with taxa belonging to the North American continent; the Canadian fauna is the youngest *Hamarodus* bearing fauna known so far (Nowlan 1983).

Periodon grandis is known mainly from outside Europe. In North America it ranges from the late Mohawkian *Phragmodus undatus* Chronozone to the lower part of the early Cincinnatian *Oulodus velicuspis* Zone (Sweet 1984, 1995). This interval covers the *Baltoniodus alobatus* Subzone of the *Amorphognathus tvaerensis* conodont Zone and the *Amorphognathus superbus* conodont Zone (Sweet 1984; Bergström 1990). Earlier, Bergström (1978) reported the species from the *Amorphognathus ordovicicus* Zone in the Maravillas Formation in Texas.

The conclusion of this overview is that the conodont faunal association found on Bornholm existed in the upper part of the *Amorphognathus superbus* Zone and extended into the base of the *Amorphognathus ordovicicus* Zone. The conodont fauna is equivalent to the *Pleurograptus linearis* graptolite Zone, which in turn corresponds to the *Tretaspis kaieri* trilobite Zone. The conodont fauna is contained in the Vasegaardian and the Nabala Stages of the Harju Series in the Baltoscandian chronosystem. In the British chronostratigraphical terminology, the fauna corresponds – at least in part – to the Pusgillian Stage of the Ashgill Series in Great Britain (Fig. 3).

Hamarodus is known from younger stages in the Ashgill (Cautleyan to Hirnantian) and the fauna disappears at the end of the Ordovician Period. It probably became a victim of the faunal extinction event that occurred at the Ordovician-Silurian system boundary (e.g. Barnes & Bergström 1988).

Conodont biofacies

The conodont fauna from Bornholm is dominated by *Scabbardella altipes* (Table 1). The presence of this species together with *Hamarodus europaeus* and *Protopanderodus liripipus* suggests that the Bornholm fauna is contained within the *Hamarodus europaeus-Dapsilodus mutatus-Scabbardella altipes* (HDS) Biofacies (Sweet & Bergström 1984) within the North Atlantic conodont province. This biofacies has been identified from several places including Dalarna, Sweden, from the Ringerike district, southern Norway, from southern Sardinia, Italy and several localities in Spain and Iran.

The fauna of the HDS Biofacies has been obtained from a variety of lithologies which suggest that the faunal assemblage was indifferent to the bottom conditions and occupied a deep shelf to marginal settings. The distribution of the fauna when compared with the oceanographic current distribution (Wilde 1991) suggests that the temperate-boreal water mass was the preferred habitat for this association. *Periodon* and *Protopanderodus* are characteristic of deep shelf to slope deposits along continental margins and oceanic volcanic island arcs in the Ordovician (Stouge 1984; Rasmussen & Stouge 1995).

Significance of the hiatus at the Viru-Harju Series boundary

The hiatus between the *Dicellograptus clingani* and *Pleurograptus linearis* graptolite Zones on Bornholm (Poulsen 1966) is contemporaneous with the hiatus recorded from Scania (Jaanusson 1963) (Fig. 4). Moreover the pre-Fjäcka Shale (= *Pleurograptus linearis* graptolite Zone) surface on top of the reefal Kullsberg Limestone (Caradoc) in Dalarna, Sweden (Jux & Manze 1979) occupies the same time range. Björlykke (1982) indicated, and Williams & Bruton (1983) demonstrated, the presence of a hiatus covering much of the upper *Dicellograptus clingani* Zone within black shaly facies in the Oslo Region, Norway (Fig. 4). In Estonia, discontinuity surfaces in carbonate facies (Saadre 1993) represent a period of nondeposition and mark the same event on the East European platform. The hiatus, or the equivalent conformable deposits in the distal facies, can be recognized in Poland as a lithological change (e.g. Podhalanska 1980; Stouge & Andsbjerg 1993) (Fig. 4).

Evidence for a sea-level drop at the Caradoc-Ashgill Series boundary is present on other continents includ-

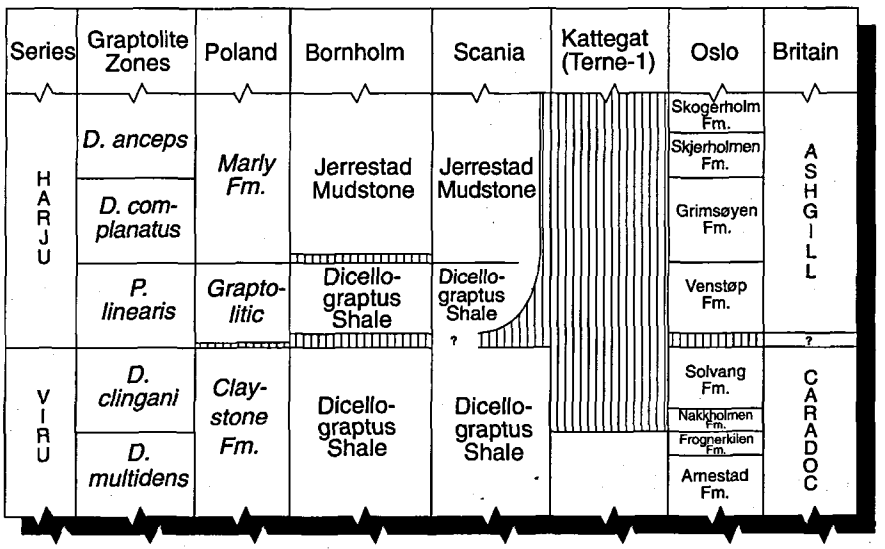


Fig. 4. Correlation and magnitude of the hiatus across the Viru-Harju Series Boundary in Scandinavia.

ing east Avalonia (Dean 1958, 1977; Fortey 1984; Woodcock 1989) and Gondwana (Fortey 1984; Hammann 1992; Chen 1991).

Whether the VHRE hiatus was eustatic or tectonic controlled is uncertain. The VHRE did, however, have an impact on the Baltica, Avalonia and Gondwana palaeocontinents that surrounded the Prototethys Ocean (sensu Scotese & McKerrow 1990, 1991) on the southern hemisphere. Evidence for the VHRE has not been recorded from other continents outside the Palaeotethys Ocean and it may have been restricted to this palaeo-ocean. The record of the *Hamarodus* fauna (except for the single known occurrence in east Canada) suggests that the fauna was mainly restricted to the Palaeotethys Ocean in late Caradoc-early Ashgill (Fig. 5).

In summary, the *Hamarodus europaeus* fauna from the *Dicellograptus* Shale of Bornholm correlates with

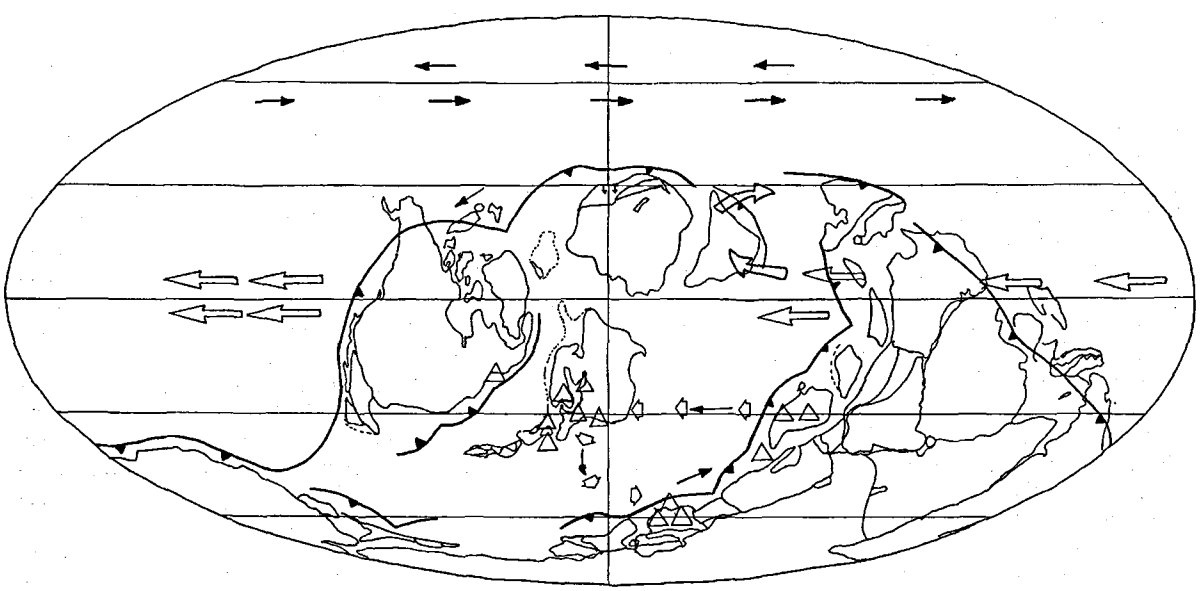


Fig. 5. Distribution of *Hamarodus* fauna in Upper Ordovician. Black arrows: Temperate to cold ocean currents. Large open arrows: Warm, equatorial ocean currents. Small open arrows: Suggested *Hamerodus* migration route. Open triangles: Documented occurrences of *Hamerodus*. The palaeogeographic map is modified from Scotese & McKerrow (1991). Oceanic current circulation is from Wilde (1991).

the *Pleurograptus linearis* Zone of the Baltoscandian Harju Series and the Pusgillian Stage of the British Ashgill Series. The fauna is characteristic of the temperate to boreal waters of the North Atlantic faunal Province as it is well documented from localities in northern Europe.

A significant regressive event occurred at the Viru-Harju Series boundary which can also be traced on the Baltica, Avalonia and Gondwana palaeocontinents. The appearance of *Hamarodus europaeus* on the Baltica platform in north Europe coincides with the transgression which occurred after the Viru-Harju regressive event (= VHRE). The first appearance of *Hamarodus* onto the Baltica continent suggests that the species is useful as a marker for the base of the Harju and Ashgill Series on that palaeocontinent.

The *Hamarodus* fauna was restricted to the southern hemisphere from the Middle to Upper Ordovician. It was mainly present within the Palaeotethys Ocean (or Rheic Ocean of some authors) in late Caradoc and Ashgill times.

Systematic descriptions

All the illustrated material is deposited in the collection of Geological Museum, Copenhagen (prefix MGUH).

Genus *Ansella* Fåhræus & Hunter, 1985
Type species. – *Belodella jemtlandica* Löfgren, 1978

Ansella nevadensis (Ethington & Schumacher, 1969)
Pl. 1, Fig. 16

Synonymy
1969 *Oistodus nevadensis* n. sp. – Ethington & Schumacher, pp. 467-468, Pl. 68, Figs 1–4; Text-fig. 5C.
1969 *Oepikodus copenhagensis* n. sp. – Ethington & Schumacher, p. 564, Pl. 68, Figs 5, 9; Text-fig. 4L.
1978 *Belodella nevadensis* (Ethington & Schumacher) – Bergström, Pl. 79, Figs 9–10.
1985 *Ansella nevadensis* (Ethington & Schumacher) – Fåhræus & Hunter, pp. 1175–1176, Pl. 1, Figs 7, 10; Pl. 2, Figs 13–14; Text-fig. 2.
1990 *Ansella nevadensis* (Ethington & Schumacher) – Bergström, p. 25, Pl. 1, Figs 11–14.

Remarks. – The Bornholm material consists of one alate Sa element (Table 1). The element bears relatively coarse denticles and the upper margin of the base is convex, which is typical for *Ansella nevadensis.*

Material. – 1 Sa element.
Repository. – MGUH 23987.

Genus *Coelocerodontus* Ethington, 1959
Type Species. – *Coelocerodontus trigonius* Ethington, 1959

Coelocerodontus? sp. A
Pl. 1, Figs 14–15

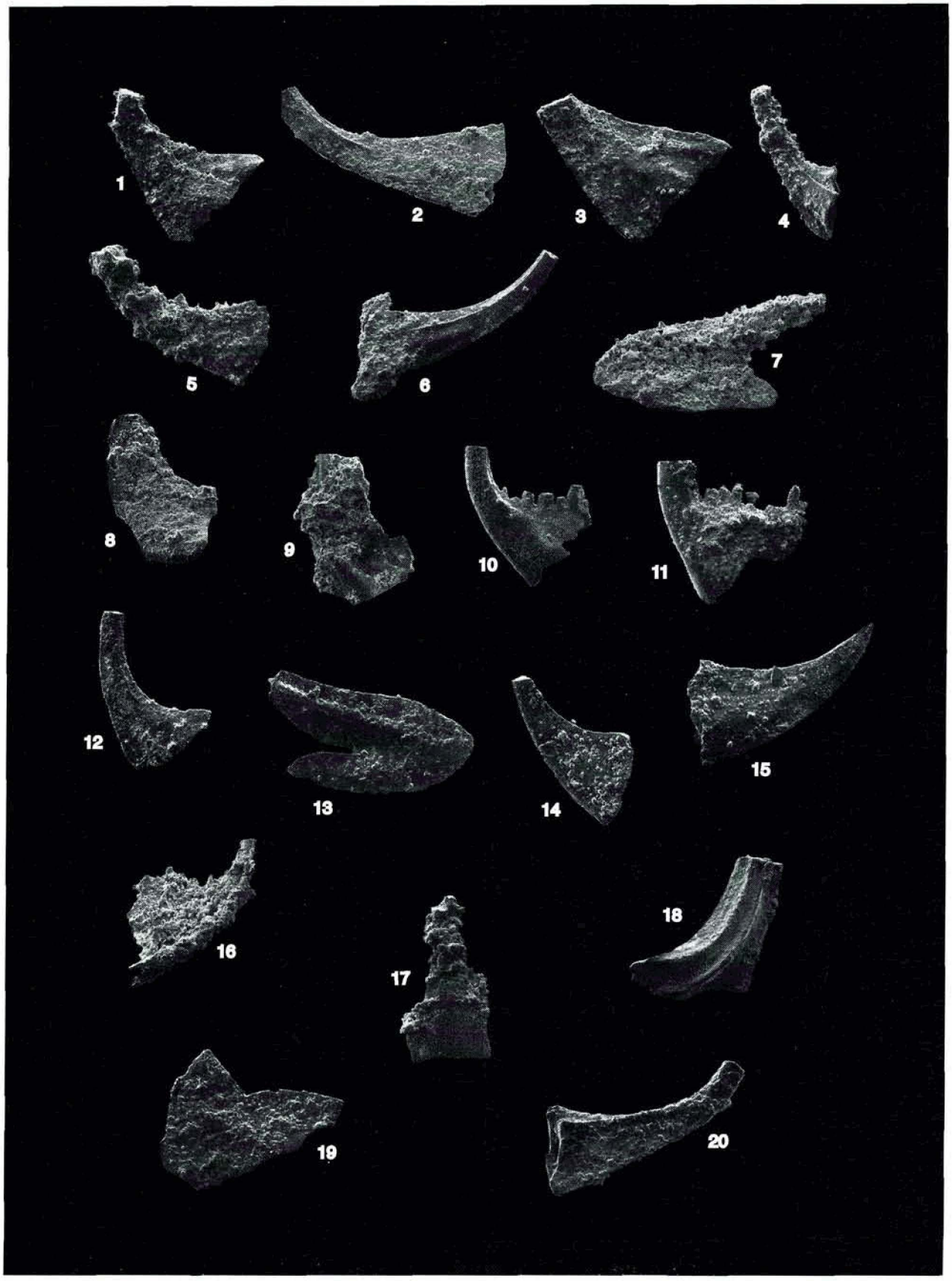
Synonymy
?1979 *Coelocerodontus*? *lacrimosus* n.sp. – Kennedy, Barnes & Uyeno, pp. 543-544, Pl. 1, fig. 23 (only), non Fig. 20.

Remarks. – The Bornholm specimens resemble the holotype of *Coelocerodontus*? *lacrimosus* depicted by Kennedy et al. (1979, Pl. 1: 23), but the Bornholm specimens differ by having a flattened outer lateral surface. One specimen figured by Kennedy et al. (1979, Pl. 1: 20) is probably a drepanodontiform element of the genus *Drepanoistodus* rather than being part of *Coelocerodontus.* Nowlan (1983) suggested that the *C.*? *lacrimosus* specimens were elemental parts of the *Scabbardella* apparatus. The very deep basal cavity, however, excludes the Bornholm specimens from being part of *Scabbardella.*

Material. – 6 specimens.
Repository. – MUGH 23988 – MGUH 23989.

Genus *Eocarniodus* Orchard, 1980?
Type species.– *Prioniodus gracilis* Rhodes, 1955
Remarks. – McCracken (1987) questioned the generic name.

Plate 1. Figs 1–6 *Scabbardella altipes* ssp. A Orchard 1980. Fig. 1. Distacontiform element, ×100, MGUH 23997. Fig. 2. "distacodontiform" element, ×270, MGUH 23998. Fig. 3. Acondontiform element, type 1. ×140, MGUH 23999. Fig. 4. Acondontiform element, type 2. ×100. MGUH 24000. Fig. 5. Drepanodontiform element. ×140, MGUH 24001. Fig. 6. Acodontiform element, type 2. ×100, MGUH 24002. Figs 7, 12–13. New Genus A sp. A Fig. 7. Oistodontiform elemen,. ×200, MGUH 24003. Fig. 12. Drepanodontiform, ×200, MGUH 24004. Fig. 13. Oistodontiform element, ×240, MGUH 24005. Figs 8–11 *Hamarodus europaeus* (Serpagli 1967). Fig. 8. P element, ×60, MGUH 23991. Fig. 9. P element?, ×60, MGUH 23992. Fig. 10. Sc element, ×180, MGUH 23993. Fig. 11. Sc element, ×150, MGUH 23994. Figs 14–15. *Coelocerodontus*? sp. A. Fig. 14. Shortbased element, ×200, MGUH 23988. Fig. 15. Longbased element, ×60, MGUH 23989. Fig. 16. *Ansella nevadensis* (Ethington & Schumacher 1969). Alate Sa element, ×220, MGUH 23987. Fig. 17. *Eocarniodus? gracilis* (Rhodes 1955)? ×140, MGUH 23990. Fig. 18. *Protopanderodus liripipus* Kennedy, Barnes & Uyeno 1979. Acontiodontiform element, ×60, MGUH 23996. Fig. 19. *Periodon grandis* (Ethington 1959). M element, ×210, MGUH 23995. Fig. 20. Gen.et sp. indet. B. ×210, MGUH 24006.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Eocarniodus? gracilis (Rhodes, 1955)?
Pl. 1, Fig. 17

Synonomy
?1955 *Prioniodus gracilis* n.sp. – Rhodes, p. 136, Pl. 8, Figs 5–6.
?1980 *Eocarniodus gracilis* (Rhodes) – Orchard, p. 20, Pl. 2, Figs ?13, 14, ?15, 18-21, 24–26, ?27, 28, 30, ?31, 33, 34, ?36, 38.
?1991 *Eocarniodus gracilis* (Rhodes) – Leone, Hammann, Laske, Serpagli & Villas, Pl. 3, Fig. 8.

Remarks. – The Bornholm specimens are fragmented and cannot be safely identified at the species level; they are, however, identical to those depicted by Orchard (1980). This species has been fully described by Orchard (1980).

Material. – 4 specimens.
Repository. – MGUH 23990.

Genus *Hamarodus* Viira, 1974
Type species. – *Distomodus europaeus* Serpagli, 1967.

Hamarodus europaeus (Serpagli, 1967)
Pl. 1, Figs 8, ?9, 10, 11
Synonymy
1955 *Cordylodus elongatus* n.sp. – Rhodes, p. 135, Pl. 7, Figs 5–6.
1955 *Oistodus* sp. – Rhodes, p. 126, Pl. 10, fig 9, Figs 13, 20.
1966 N. genus and n.sp. – Hamar, p. 77, Pl. 3, Figs 8-10; Text-fig 5: 5a-b.
1967 *Distomodus europaeus* n.sp. – Serpagli, p. 64, Pl. 14, Figs 1–6.
1974 *Hamarodus europaeus* (Serpagli) – Viira, p. 81, Pl. 13, Figs 22-25, (misnamed *H. norvegicus* on Pl. 13); Text-fig 106.
1974 *Hamarodus estonicus* gen. et sp. nov. – Viira, p. 88, Pl. 13, Figs 26-27 (misnamed *H. europaeus* on Pl. 13); Text-fig 107.
1976 *Hamarodus europaeus* (Serpagli) – Dzik, p. 436, Figs a–g.
1978 *Hamarodus europaeus* (Serpagli) – Dzik, Text-fig 2.
1980 *Hamarodus europaeus* (Serpagli) – Orchard, p. 21, Pl. 4, Figs 22, 25, 29–31.
1985 *Hamarodus europaeus* (Serpagli 1967) – Bergström & Orchard, Pl. 2.5, Figs 4, 7, 12.
1990 *Hamarodus europaeus* (Serpagli 1967) – Fuchs, p. 208, Pl. 6, Fig 2 (cum syn 1967)
1990 *Hamarodus europaeus* (Serpagli) – Männik & Viira, p. 118, Pl. 17 – conodonts, Fig 3.
1991 *Hamarodus europaeus* (Serpagli) – Ferretti & Serpagli, Pl. 2, Figs 1–6.
1991 *Hamarodus europaeus* (Serpagli, 1967) – Leone, Hammann, Laske, Serpagli & Villas, Pl. 3, Figs 9–13.
?1983 *Hamarodus europaeus* (Serpagli, 1967) – Nowlan, pp. 664–665, Pl. 2, Figs 1–12.
?1994 *Hamarodus brevirameus* (Walliser, 1964) – Dzik, pp.111–112, Pl. 24, Figs 14–19; Text-fig 31a.

Remarks. – The sexi- or septimembrate *Hamarodus* apparatus comprises angulate P elements, ramiform S elements and geniculate, coniform M elements (Dzik 1976, 1989, 1994; Orchard 1980; Sweet 1988). The Bornholm specimens comprise P, S and possibly M elements.

Fuchs (1990) revised the elements described by Knüpfer (1967) and agreed with the apparatus reconstruction presented by Dzik (1989) for *Hamarodus*. This reconstruction is different from the interpretation given earlier by Sweet & Bergström (1984). Thus some of the elements which Sweet & Bergström (1984) originally referred to the *Hamarodus* apparatus became part of the multielement genus *Sagittodontus* Knüpfer (Dzik 1989; Fuchs 1990) instead. We follow the information presented by Fuchs (1990).

Dzik (1994) placed *Neoprioniodus brevirameus* Walliser, 1964 in synonomy with *Distomodus europaeus* Serpagli, 1967. This interpretation is not followed here awaiting for further documentation. It is, however, likely that more than one species of *Hamarodus* should be recognized (see below and Nowlan 1983).

Hamarodus cf. *H. europaeus* (Serpagli, 1967) *sensu* Nowlan, 1983 differs from the Bornholm material in the development of lamellar cavities. We concur with Nowlan (1983) that the Canadian specimens probably represent another species of the genus *Hamarodus* (Serpagli).

Material. – 2 Pa, 2S and 1M element.
Repository. – MGUH 23991 – 23994.

Genus *Periodon* Hadding, 1913
Type species. – *Periodon aculeatus* Hadding, 1913.

Periodon grandis Ethington, 1959
Pl. 1, Fig. 19

Synonomy
1959 *Loxognathus grandis* n. sp. – Ethington, p. 281, Pl. 40, Fig. 6.
1966 *Periodon grandis* (Ethington) – Bergström & Sweet, pp. 363–365, Pl. 30, Figs. 1–8.
1979 *Periodon* cf. *aculeatus* Hadding – Kennedy, Barnes & Uyeno, pp. 544–546, Pl. 1, Fig. 8 (only).
1989 *Periodon grandis* (Ethington, 1959) – McCracken & Nowlan, p. 1889, Pl. 3, Figs 7–9.

Remarks. – On Bornholm the species is represented

by a M element. The element has two anterior denticles. The M element figured by Kennedy et al. (1979, Pl. 1: 8) and obtained from the *Amorphognathus tvaerensis – Baltoniodus alobatus* Subzone (Caradoc) is very similar to this specimen.

Material. – 1 M element.
Repository. – MGUH 23995.

Genus *Protopanderodus* Lindström, 1971
Type species. – *Acontiodus rectus* Lindström, 1955.

Protopanderodus liripipus Kennedy, Barnes & Uyeno, 1979
Pl. 1, Fig. 18

Synonomy
1979 *Protopanderodus liripipus* n. sp. – Kennedy, Barnes & Uyeno, pp. 546–550, Pl. 1, Figs 9–19.
1988 *Protopanderodus liripipus* Kennedy, Barnes & Uyeno – Nowlan & McCracken in Nowlan McCracken & Chatterton, p. 29, Pl. 11, Figs 18, 20.
1989 *Protopanderodus liripipus* Kennedy, Barnes & Uyeno – McCracken, pp. 18-20, Pl. 3, Figs 15–16, 18, 20–25; Text-fig. 3G-J.
1989 *Protopanderodus liripipus* Kennedy, Barnes and Uyeno – McCracken & Nowlan, Pl. 4, Fig. 1.
?1980 *Protopanderodus* cf. *liripipus* Kennedy, Barnes and Uyeno – Orchard, p. 24, Pl. 4, Figs 27, 33.

Remarks. – Elements of *Prototopanderodus liripipus* were first described by Kennedy et al. (1979) and the complete apparatus for the species was presented by McCracken (1989). The specimens depicted by Orchard (1980) are broken. The general outline of the elements, however, suggests that the elements from the Cystoid and Mucronata Limestones should be referred to *Protopanderodus insculptus* (Branson & Mehl) instead.

Material. – 2 scandodiform and 13 acontiodontiform elements.
Repository. – MGUH 23996.

Genus *Scabbardella* Orchard, 1980
Type species. – *Drepanodus altipes* Henningsmoen, 1948.

Scabbardella altipes (Henningsmoen)
Pl. 1, Figs 1–6

1948 *Drepanodus altipes* n. sp. Henningsmoen, p. 420, Pl. 25, Fig. 14 (acostate drepanodontiform element).
1980 *Scabbardella altipes* n. ssp. A – Orchard, pp. 25–26, Pl. 5, Figs. 4–5, 7–8, 12, 28, 35 (cum syn.).
1989 *Scabbardella altipes* (Henningsmoen 1948) – Fuchs, Fig. 3: 1–5.
1989 *Scabbardella altipes* (Henningsmoen) – Rasmussen & Stouge, Fig. 3: M–Q.
1990 *Scabbardella altipes* (Henningsmoen) – Bergström, Pl. 4, Fig. 14.
1990 *Scabbardella altipes* (Henningsmoen 1948) – Fuchs, p. 210, Pl. 5, Figs 9, 11–12; Pl. 6, Figs 5–10; Pl. 7, Figs 8–14.
1991 *Scabbardella altipes* (Henningsmoen, 1948), morphotype A – Ferretti & Serpagli, Pl. 2, Fig. 13.
1991 *Scabbardella altipes* (Henningsmoen, 1948), morphotype B – Ferretti & Serpagli, Pl. 2, Figs 12, 14.
1991 *Scabbardella altipes* (Henningsmoen, 1948) – Leone, Hammann, Laske, Serpagli & Villas, Pl. 3, Figs 14–15.
1992 *Scabbardella altipes* (Henningsmoen, 1948) – Bergström & Massa, p. 1339–1340, Pl. 1, Figs 1, 3–4.

Remarks. – The multielemental composition of this species consists of six morphotypes (two drepanodontiforms, two acodontiforms and two distacodontiforms) (Orchard 1980). Orchard (1980) identified two subspecies, where *S. altipes* subsp. A has moderately curved elements without extended base. *S. altipes* subsp. B is characterized by elements with strongly recurved acodontiforms and with bases that extended to posterior and antero-basal directions.

The elements from Bornholm are identical with *S. altipes* ssp. A sensu Orchard, 1980 which is *Scalpellodus altipes* sensu stricto. Most probably two species of *Scabbardella* should be distinguished instead of two subspecies.

Material. – 22 specimens.
Repository. – MGUH 23997 – 24002.

New genus A sp. A
Pl. 1, Figs 7, 12–13

Synonomy
1988 *Paroistodus*? sp. A – Nowlan & McCracken, pp. 24–26, Pl. 9, Figs 1–22.
1989 *Paroistodus*? sp. A – Nowlan & McCracken in Nowlan et al. 1988 – McCracken & Nowlan, p. 1889, Pl. 3, Figs 1–6.

Remarks. – The elements of New genus A sp. A were tentatively referred to the multielement genus *Paroistodus* Lindström, 1971 by Nowlan & McCracken (1988). These authors discussed several possibilities for the generic assignment of the elements without making conclusive decisions. We concur with Nowlan & McCracken (1988) that the elements are part of a

distinct taxon and we informally refer the elements to New genus A sp. A rather than to *Paroistodus* Lindström, 1971.

The apparatus comprises acodontiform (two morphotypes), distacodontiform (two morphotypes) and oistodontiform elements. The simple cone elements include acodontiform and oistodontiform elements only. The acodontiform element from Bornholm is the a-1 element in the Nowlan & McCracken (1988, Pl. 9: 5–6) terminology; it differs by having a deeper base. The oistodontiform element is identical with that of *Paroistodus*? sp. A of Nowlan & McCracken in Nowlan et al. (1988).

Material. – 6 specimens.
Repository. – MGUH 24003 – 24005.

Genus et species indet. A
Pl. 1, Fig. 20

Remarks. – Genus et species indet. A comprises simple cones with 0–2 prominent costae and a very deep basal cavity. Some specimens resemble *Walliserodus amplissimus* (Serpagli 1967), but the basal part of the elements is more slender.

Material. – 6 specimens.
Repository. – MGUH 24006.

Dansk Sammendrag

En undersøgelse af kalkstennoduler fra Dicellograptusskiferen ved Risebæk på Bornholm resulterede i et fund af en karakteristisk conodontfauna. Conodontfaunaen omfatter arterne *Hamarodus europaeus, Periodon grandis, Protopanderodus liripipus* samt *Scabbardella altipes*. Conodontfaunaen blev fundet i den Øvre Ordoviciske *Pleurograptus linearis* graptolitzone (Harju/Ashgill Serie).

P. linearis Zonen er på Bornholm adskilt fra den ældre *Dicellograptus clingani* graptolitzone af en hiatus, der er udbredt over hele Skandinavien, de østbaltiske lande samt Polen og kendes under navnet Viru-Harju regressionen (VHRE). Hiatusen kan også erkendes fra Tyskland, Spanien, Sardinien og Nordafrika.

Conodontfaunaens udbredelse viser, at faunaen havde sin oprindelse i sydlige Kina. Den migrerede til Skandinavien i løbet af sen-mellem Ordovicium og immigrerede til Skandinavien i sen Ordovicium og senere til England og Wales. Spredningen af faunaen blev sandsynligvis styret af fremherskende palæohavstrømme indenfor det sydlige tempererede-arktiske ocean (Palæotethys). *Hamarodus* faunaen uddøde ved overgangen fra Ordovicium til Silur, men opnåede at blive udbredt over hele Palæotethys oceanområdet, der var afgrænset af Avalonia, Baltica og Gondwana palæokontinenterne.

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