Ordovician sponges (Porifera) and other silicifications from Baltica in Neogene and Pleistocene fluvial deposits of the Netherlands and northern Germany

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Received 22 August 2008, accepted 21 October 2008

Abstract. Fluvial deposits of Miocene to Early Pleistocene age in Germany and the Netherlands were laid down in the delta of the Eridanos River System, but the exact provenance of this material continues to be a subject of discussion. The aim of the present study is twofold. Firstly, a comparison of Ordovician sponges in these deposits with those from northern Estonia and the St Petersburg region (Russia) demonstrates that these erratics originated from the drainage area of the Pra Neva, a tributary of the Eridanos. Secondly, the importance of Late Ordovician silicified boulders, which yield forms of preservation that are unknown in comparable fossils, preserved in situ, is outlined. Some recommendations for future studies are made.

Key words: Baltica, Eridanos River, erratics, Ordovician, Porifera, silicifications.

INTRODUCTION

Baltoscandia contributed considerably as a source area to the formation of late Cenozoic sediments in northern Germany and the Netherlands. The composition and provenance of clastics in glacial deposits of Late Pleistocene age have been described in numerous studies. This has led to the erroneous view that all clastics from Baltoscandia should be considered to have been transported by glaciers. However, fluvial erratics, originating from the Baltic Shield, occur over an area which extends from Poland to far into the present North Sea, in deposits of Miocene to Early Pleistocene age. These strata were deposited by the Eridanos River System, which drained the Baltic Shield between Late Oligocene and Early Pleistocene times (Overeem et al. 2001). The drainage area of this immense river system extended from the Gulf of Bothnia and Lapland in the north to large portions of mainland Sweden in the west, and to Finland, the Gulf of Finland, the Baltic States, and the Neva River area up to the White Sea in the east (Fig. 1).

Erratics from these deposits differ from glacial strata in many aspects, such as rock types and preservation of existing fossils. The provenance and ways of transport of the erratics have been discussed for over a century. Advances in the geology of Baltoscandia and the Eridanos River System, as well as renewed studies of erratic fossils in recent publications, have led to the present study, whose purpose is twofold. The most important goal is the attempt to locate probable source areas of sedimentary erratics as collected in the Netherlands and northern Germany. The other aim is to emphasize the uncommon preservation of some of the fossils, which

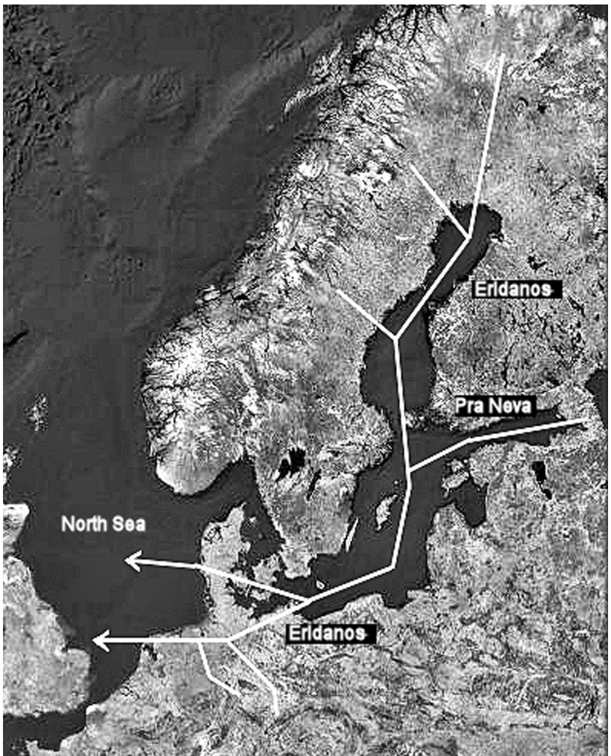

Fig. 1. Drainage area and delta of the Eridanos River System, which existed from Miocene to Early Pleistocene times.

may contribute to our knowledge of coeval Ordovician fossils from Baltic strata.

Fluvial erratics comprise boulders of Cambrian to Devonian age. Cambrian erratics consist of sandstones and quartzites, which are not considered further. The same goes for Silurian and Devonian erratics, which are extremely rare in or even absent from the fluvial deposits. Thus, in this study only Ordovician erratics will be discussed.

In succession, four groups of material will be described briefly, followed by a synopsis of papers dealing with these categories. The next items are the development of the Eridanos River System and the stratigraphical setting of its deposits. Erratic sponges and those from strata in Estonia and the St Petersburg area (Russia) will be compared in relation to possible areas of provenance of the former, followed by some conclusions and recommendations.

METHODS AND MATERIAL

Most of the material discussed herein has been collected from sand and gravel pits in the Twente district, in the eastern part of the Netherlands, and adjacent German territory. Other major deposits are found in the Isle of Sylt (former sand pits), the Lausitz area (former lignite pits) in Germany, and boulder ridges along the coast of Gotland (Sweden), as rendered in Fig. 2. Boulders recorded from Sawidowice (former Sadewitz), Poland, such as by Roemer (1861), are glacially transported (Meyer 1998) and therefore not discussed in the present study.

In broad outline, the fluvially transported clastics can be subdivided into four sets of different stratigraphical age, according to the regional Baltic (Estonian) stage of the Ordovician System (Fig. 3). However, being erratics, they will also be considered in the Neogene System of Germany and the Netherlands, according to the age of the deposits in which they occur. Table 1 illustrates the relationship between the composition of each group, its geographical occurrence, as well as the age of the deposit. The stratigraphical age, being Late Ordovician (Haljala and Pirgu stages, respectively), was obtained by comparison with literature data (e.g. Rõõmusoks 1970; Neben & Krueger 1971, 1973, 1979), as well as by palynomorphs isolated from a series of samples dissolved in hydrofluorid acid (HF) (Z. Smeenk, Laboratory of Palaeobotany and Palynology, Utrecht University, pers. comm. 1997, 1998, 2000).

Unless indicated otherwise, all specimens figured in this paper are in the Rhebergen Collection that will be donated to the National Museum of Natural History, Leiden (the Netherlands).

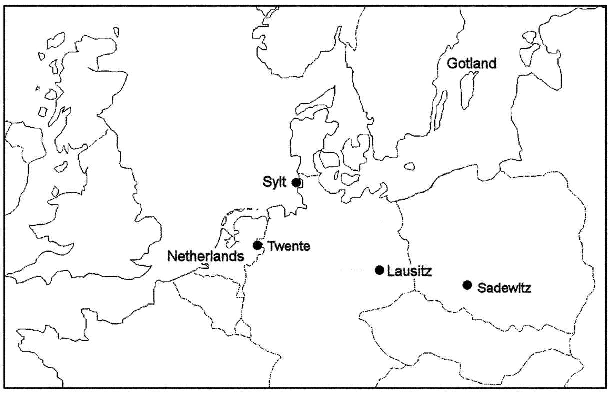

Fig. 2. Map of northern Europe with the geographical position of areas from where most of the material discussed in this study originates.

Without exception, all erratic clastics are silicified. The process of silicification must have occurred already in the Baltic. Possibly, carbonate boulders were transported as well, but these were dissolved during or after transport. Four groups of clastics can be distinguished.

1. **The Haljala group** comprises several types of silicified, usually yellowish-grey, porous, deeply weathered, brick-like limestones. The rock is a leached carbonate, in which the matrix is silicified, and all fossils are dissolved and preserved as casts. As a result, many fossils show details that are uncommon in or absent from similar rocks (Spjeldnaes & Nitecki 1990b, p. 7). These boulders are derived from rocks of Late Ordovician age; most of them are coeval to the Estonian Haljala Stage (comprising the Idavere (C_{III}) and Jõhvi substages (D_I)). Only a few boulders are of Late Kukruse (C_{II}) and Early Keila age (D_{II}). Generally, the rock is not stratified. Often one side is flat, while the facing is strongly undulose (Fig. 4). Usually fossils occur disorderly in nests, and occasionally are distributed irregularly. This rock type seems to have been formed by mud flows. Boulders of another type are more or less flat and slightly stratified, often comprising large gastropods. These boulders are of Jõhvi age (D_I). Flat, relatively coarse-grained boulders form a third type. They represent hardgrounds, showing extensive burrows.

The faunal assemblages resemble those from Estonia, as listed by Rõõmusoks (1970). The commonest trilobite taxa are *Chasmops marginata* Schmidt, 1881, *Otarion* sp. *sensu* Zenker, 1833, *Illaenus jewensis* Holm, 1886, and *Atractocybeloides berneri* Krueger, 1991. Flora is well represented,

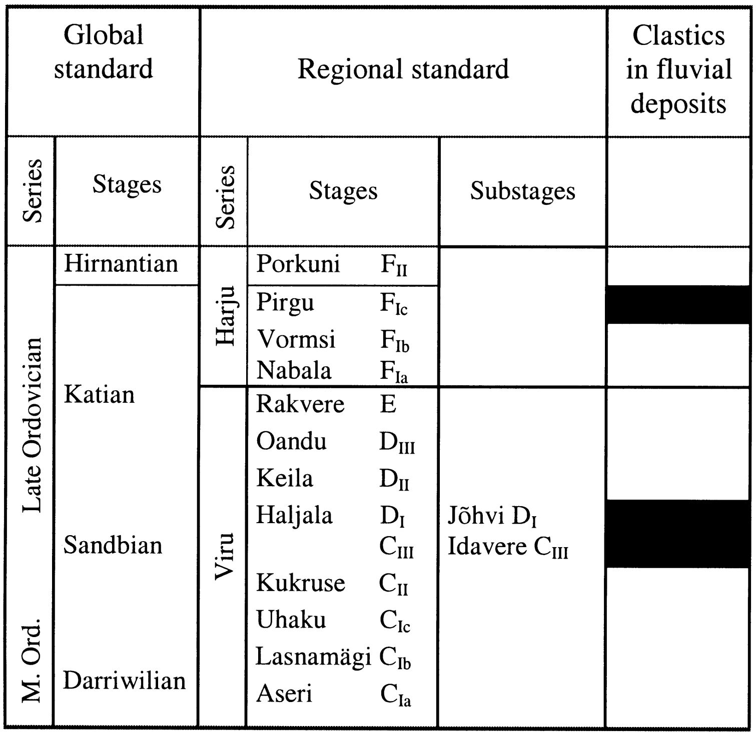

Fig. 3. The Ordovician stratigraphy of Estonia, as far as relevant to the present study, with indication of the age of major groups of clastics occurring in fluvial deposits in Germany and the Netherlands. M. Ord., Middle Ordovician.

Table 1. Groups of clastics related to their geographical distribution and age of deposition

Groups of clastics	Geographical distribution and age of deposition			
	Gotland, Late Pleistocene	The Netherlands, Early Pleistocene	Sylt (N Germany), Pliocene	Lausitz (E Germany), Miocene
Pirgu cherts and mudstones	+++	++	+	–
Haljala limestones	++*	+++	+	–
'Brown' sponges	++	+++	++	–
'Lavender blue' silicifications	–	+	+++	+++
'Blue' sponges	–	+	+++	++

+++ very common, ++ common, + relatively rare, – absent or very rare, * not as fluvial but as glacial erratic.

with *Apidium krausei* (Kiesow, 1893) as the commonest algal species, in decreasing order of frequency, followed by *Coelosphaeridium sphaericum* (Kjerulf, 1865) (according to Spjeldnaes & Nitecki (1990a, p. 7), *C. cyclocrinophilum* Roemer, 1885 is a junior, invalid synonym), *Mastopora concava* Eichwald, 1861, *Vermiporella fragilis* Stolley, 1893, and *Cyclocrinites porosus* Stolley, 1896. Two rare species are *Mastopora odini* Stolley, 1898 and *Hoeegonites kringla* Nitecki & Spjeldnaes, 1989. Figure 5 illustrates some of these algae. A co-occurrence of astylospongiid sponges and algae has been observed occasionally, such as *Caryospongia juglans* (Quenstedt, 1878) and *Coelosphaeridium sphaericum* in a boulder from Sylt, now in the Von Hacht Collection (Archiv für Geschiebekunde, Hamburg University).

Rock fragments from the Haljala group are relatively common in Lower Pleistocene deposits in the Netherlands and adjacent German territory, but rare in Pliocene deposits of northern Germany, and rare or absent in the Miocene deposits in eastern Germany. On Gotland they occur rather commonly among the beach pebbles as Sandöflint, unweathered glacial erratics (geschiebes) (Schallreuter 1983, p. 165).

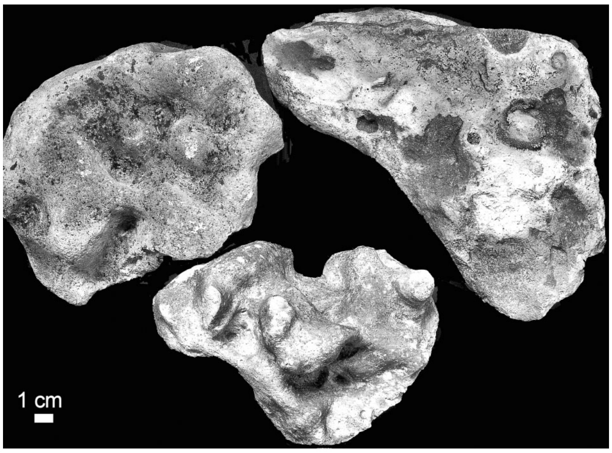

Fig. 4. Samples of erratic boulders of 'yellowish-grey' silicified limestones of Haljala age. Note the undulose surface, which is characteristic of the most frequent type of rock in this group. Boulders in this group average 12 cm in diameter. Erratics from Wilsum, western Germany.

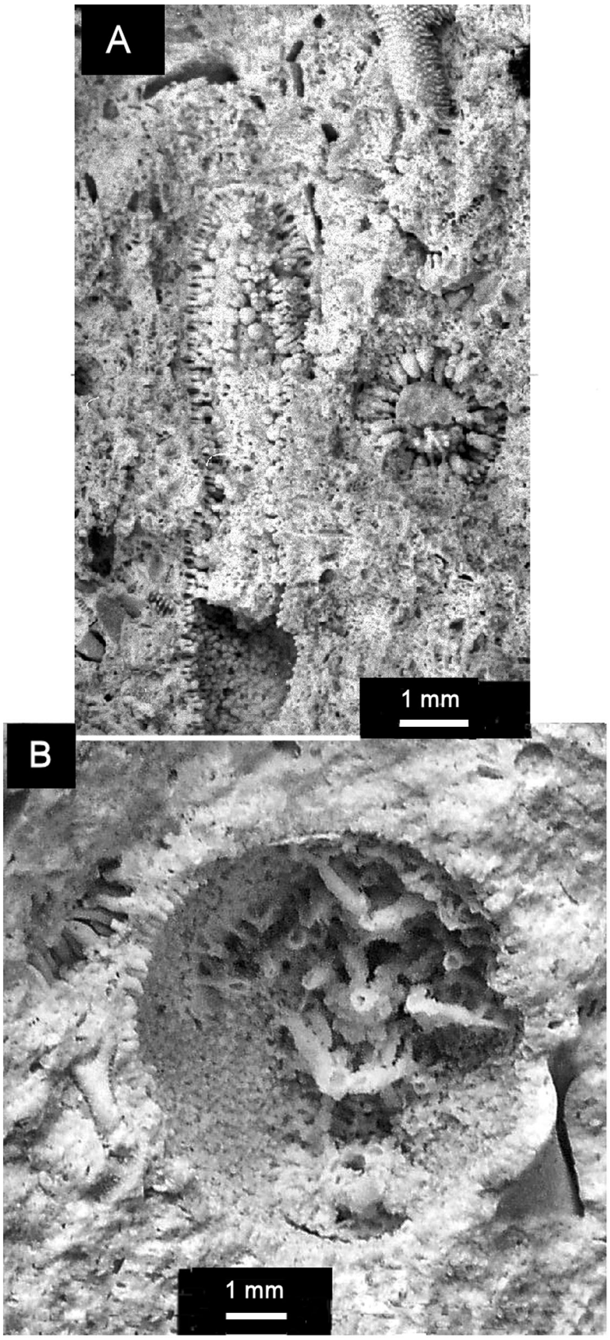

Fig. 5. Examples of algae in erratic boulders of the Haljala group. (A) *Hoeegonites kringla* Nitecki & Spjeldnaes, 1989. One specimen in cross section, another in side view. (B) *Apidium krausei* (Kiesow, 1893), with preservation of part of the internal structure of laterals. Erratics from Wilsum, western Germany. Rhebergen Collection; A: Ue 14.618; B: Ue 14.192.

2. Boulders from the **Pirgu group** comprise several rock types. The commonest are boulders of chert. Obviously, these boulders are fragments of larger blocks, as they reveal series of pressure marks. In addition, one of the sides usually has a white crust of argillaceous limestone. Second in frequency are white-grey boulders of slightly stratified mudstones, which are identical to the crust of the cherts and usually highly fossiliferous (Fig. 6). Bryozoans, trilobites, and brachiopods predominate. The most characteristic trilobites are *Erratencrinurus kiaeri* Owen, 1981, *Ascetopeltis bockeliei* Owen, 1981, and *Harpidella* sp. *sensu* M'Coy, 1849. Unidentified, articulated, cylindrical algae occur more frequently than *Apidium rotundum* Høeg, 1932 and the rare *A. sororis* Stolley, 1896. Other boulders are markedly stratified, but are intensely silicified so that they are chert-like when split. So far differences in flora and fauna with the former type have not been observed. Quite distinct are coarse-grained boulders, often with *Palaeoporella* sp. *sensu* Stolley, 1893 and/or *Dimorphosiphon rectangulare* Høeg, 1927. Occasionally, silicified orchocladinid and/or sphaeroclonidid sponge bodies occur in these boulders (see below). The Pirgu clastics are common in the Netherlands and in Gotland, less common in northern Germany, and rare or absent in Miocene deposits in eastern Germany.
3. **The 'lavender-blue' group** comprises a range of silicification types, varying from bluish-grey to black, from porous to cherty, and from non-fossiliferous to richly fossiliferous. The name for these silicifications was originally coined by Meyn (1874). Occasionally, fossils are unrecognizable as a result of intensive diagenetic modification. As a consequence, it is not possible to obtain their age by palynomorphs.

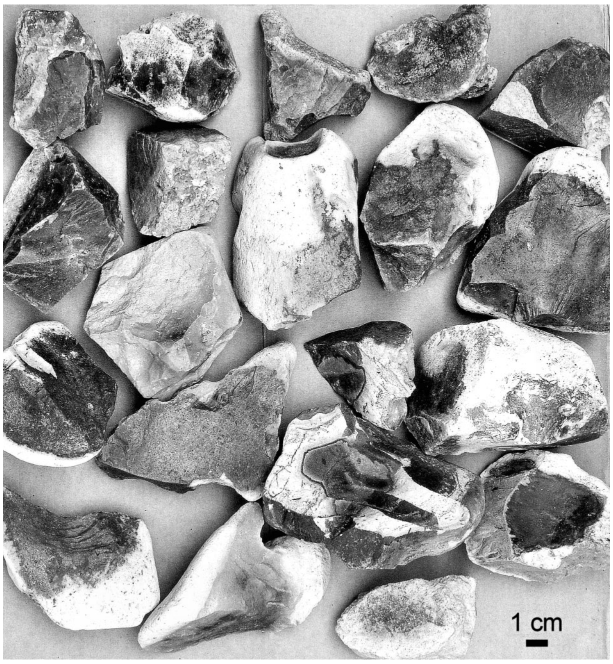

Fig. 6. Samples of erratic boulders of chert of Pirgu age (Öjlemyr flint). Note that one of the sides has a white crust, representing the surface of the original nodule. Boulders in this group average 8 cm in diameter. Erratics from Wilsum, western Germany.

Cavities in the rock may be filled with quartz crystals, botrydoidal aggregates of chalcedony, or finely laminated agates. These features are characteristic of both the 'lavender-blue' silicifications and the 'lavender-blue' isolated fossils discussed below. Within the framework of the present study, this subject is too complex to be discussed in detail. The stratigraphical range is more extensive than that of groups discussed above. The older portion of this group corresponds to the Upper Kukruse to Keila and, possibly, Lower Oandu stages. The younger part consists of clastics from the Nabala, Vormsi, Pirgu, and Porkuni stages. To my knowledge, clastics from the Rakvere Stage do not occur in the fluvial deposits.

The most typical representatives are algae, asaphid trilobites, *Brachytomaria baltica* Verneuil, 1845 and *Incuhinzia syltensis* Schallreuter, 1990. The last-named is a problematicum of Late Ordovician age, which occurs exclusively in 'lavender-blue' chert. An assignment to bryozoans cannot be ruled out. Algae are represented predominantly by *Cyclocrinites* spp. *sensu* Eichwald, 1840. *Coelosphaeridium* and *Mastopora concava* are relatively rare, and *Apidium krausei* is absent.

These silicifications predominate in Miocene and Pliocene deposits of eastern and northern Germany, are relatively rare in Lower Pleistocene deposits in the Netherlands, and seem to be absent in Upper Pleistocene deposits in Gotland. Their diagenetic modifications, as well as the composition of the fossil assemblages, provide evidence that they originated from other strata and other areas than the Haljala and Pirgu associations discussed above. In addition, many specimens have polished surfaces, on which percussion marks have been covered by patina or desert varnish, indicating transport during two or more stages.

4. **Isolated sponges, stromatoporoids, and tabulates** form an important group of Palaeozoic fossils in the fluvial deposits. Some show features of silicification, which are similar to those in the 'lavender-blue' assemblage, and are thus considered to have originated from the same areas. Although most stromatoporoids and tabulates are of Late Ordovician age, Silurian representatives occur as well, albeit rarely. A complicating factor is that unsilicified tabulates and stromatoporoids frequently occur also in till deposits laid down by Late Pleistocene glaciers. Locally, they may be mixed with fluvially transported sediments. Within the framework of the present study, they are less meaningful and are thus not considered further, as are trepostomate bryozoans.

Figure 2 illustrates the major areas that yield(ed) erratic sponges: Gotland, Twente (the Netherlands), the Isle of Sylt (northern Germany), and the Lausitz area (eastern Germany). Each of these assemblages differs from the others with respect to taxa represented (Von Hacht & Rhebergen 1997). In addition, a numerical approach, to distinguish taxa according to frequency of occurrence, has provided more data than a mere listing of species would have done. Thus, it was possible to link the composition of distinct assemblages to their palaeoecological environment, which gave each of these assemblages a kind of identity (Rhebergen & Von Hacht 1996). Figure 7 gives an impression of erratic sponges from Twente.

In the Late Pleistocene erratics assemblage from Gotland, astylospongiids are slightly commoner (45%) than anthaspidellids (42%). In the Pliocene erratics assemblage from Sylt, consisting mainly of 'blue' sponges, anthaspidellids predominate (51%) over astylospongiids, representing only 24%. Even more extreme are differences in the Miocene erratics assemblage from the Lausitz area: anthaspidellids comprise 63% and astylospongiids 20% of the assemblage. In the Early Pleistocene erratics

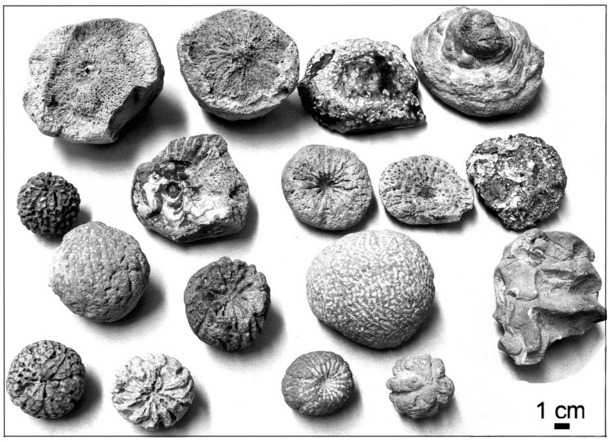

Fig. 7. Sponges collected from fluvial deposits in the Dutch–German border area, figured here as illustration of isolated silicifications. Specimens from the Rhebergen Collection.

assemblage from the Netherlands, the numbers of anthaspidellids and astylospongiids are about equal (both about 44%) and thus this assemblage occupies an intermediate position between those from Gotland and Sylt/Lausitz.

PREVIOUS STUDIES ON FLUVIAL CLASTICS

Since the nineteenth century Ordovician erratics from the Baltic area have been discussed frequently in the literature, in particular their provenance. Although authors have recognized close similarities to rock types in Fennoscandia, they also noted differences and concluded that the source area(s) of part of these erratic clastics could not be established. The general opinion was, and is, that they are relics of Ordovician strata that have been eroded completely.

The ‘yellowish-grey’ boulders, mentioned above as the Haljala group, are similar to but not identical with those described from Germany. Silicified erratic boulders and, usually more or less rectangular, siliceous Ordovician limestone boulders in the Berlin area were referred to as ‘Backsteinkalk’, after the characterization of ‘certain brick stones’ by Klöden (1834). Subsequently, this term was used in a more general sense for silicified Ordovician erratics. Numerous fossils collected from these boulders were illustrated by Neben & Krueger (1971, 1973, 1979). Schallreuter (1969, 1984, 1998) described an extensive association of ostracodes, many of them representing new taxa, and also discussed the provenance of the ‘Backsteinkalk’, indicating them to be from areas within the triangle northern Gotland–south of the Åland archipelago–Stockholm. In his opinion, silicification was caused mainly by overlying bentonite layers. However, the ‘Backsteinkalk’ boulders from northern Germany were transported glacially, in Late Pleistocene times, which distinguish them from the fluvial material discussed in the present study.

Meyn (1874) described silicifications from the Isle of Sylt as ‘lavender-blue hornstone’. It is beyond the scope of the present paper to list all views and studies, by German authors mainly, on the geographical and chronostratigraphical distribution. Generally, their studies concentrated on the origin of deposits of quartz sand and associated ‘lavender-blue’ silicifications. More recent studies (e.g. Ahrens & Lotsch 1976; Von Bülow 1969, 2000a; Krueger 1990, 1994) contain extensive lists of references. Numerous fossils from Pliocene deposits in Sylt have been described and illustrated by a number of authors (see Von Hacht 1985, 1987, 1990). Anderson (1957) and Rhebergen (1985) discussed the provenance and transport of fluvial erratics in the Netherlands.

Wiman (1901) was the first who used the name Öjlemyrkalk (Öjlemyr limestone), when describing erratic boulders of chert from Öjle Myr (Gotland). He considered them as of Porkuni age. Thorslund & Westergard (1938) questioned this age and took into consideration the Lyckholm age (F_I). Schallreuter (1984, 1998) restricted the age on the Pirgu Stage (F_{Ic}) and recorded numerous new ostracode taxa, as well as an extensive microfauna. Eiserhardt (1992) published on palynomorphs from boulders in Gotland, and compared this association with those from identical boulders in Sylt, as well as from Wilsum in the Dutch–German border area.

With view of the numerous papers on isolated silicified fossils, in this study I confine myself to sponges. Thus, papers on tabulate and coral assemblages from the fluvial deposits in the Netherlands (Huisman 1974, 1975), as well as those from Sylt (Huisman 1987) are not considered further. The same goes for as yet unidentified, Ordovician calcified sponges from black carbonate bedrock in the Oslo region (Spjeldnaes, pers. comm. 1999).

Rauff (1893, 1894) examined the erratic sponge assemblages, and his *Palaeospongiologie* is still the standard for sponge studies. In his description of new sponge taxa Van Kempen (1978) suggested a provenance from basins in the Baltic. Von Hacht (1985, 1990) described erratic sponges from the Isle of Sylt, while Von Hacht & Rhebergen (1997) compared the sponge assemblages from northern Germany, the Netherlands, the Lausitz area, and Gotland. They proposed the Barents Sea as a possible source area for the ‘lavender-blue’ sponges. Rhebergen & Von Hacht (1996) published the results of an extensive inventory of erratic sponges distinguished on the basis of assemblage and possible provenance. They also described the composition of the erratic sponge assemblage from Gotland (Rhebergen &

Von Hacht 2000). Rhebergen et al. (2001) summarized all these data in a monographic treatment of erratic Ordovician sponges.

It has now become clear that our knowledge of this subject is still fragmentary. Views on source areas are highly diverse, especially since glacial and fluvial ways of transport have not been distinguished consistently.

STRATIGRAPHICAL SETTING OF FLUVIAL DEPOSITS IN GERMANY AND THE NETHERLANDS

Since the Early Miocene, and possibly already during Late Oligocene times, an immense river system, now known as the Eridanos River System, drained the Baltic and transported huge masses of clastics. According to Suuroja (2007, p. 59), a complex of deposits, up to 1.5 km thick, over an area of about 100 000 km^2, formed the Eridanos Delta. Its development is illustrated in Fig. 8. Initially, the Eridanos built its delta southwards into the Polish–German Basin. In the Lausitz area, in eastern Germany, these deposits interfinger with Miocene lignite strata. These 'Seeser Sande' (Krueger 1990, 1994) comprise quartz sands, pebbles, and boulders. For the present study only the Ordovician 'lavender-blue' silicifications and 'blue' sponges are of interest.

During Miocene and Pliocene times the delta moved westwards, gradually filling in the basin. Many of these deposits were subsequently removed by erosion afterwards and only local relics, such as in the Vejle area in eastern Jutland (Denmark) (Dreyer Jörgensen 1944; Ahrens & Lotsch 1976), and the 'Loosener Sande' (Von Bülow 2000a, 2000b) are preserved. Delta deposits of Late Pliocene age are preserved in the Isle of Sylt and yielded until recently numerous sponges, tabulates, and stromatoporoids and huge quantities of 'lavender-blue' silicifications.

During the Early Pleistocene the course of the Eridanos changed considerably as a result of tectonic uplift of the Polish–German Basin, possibly influenced by isostasy in the Baltic Shield. The main direction

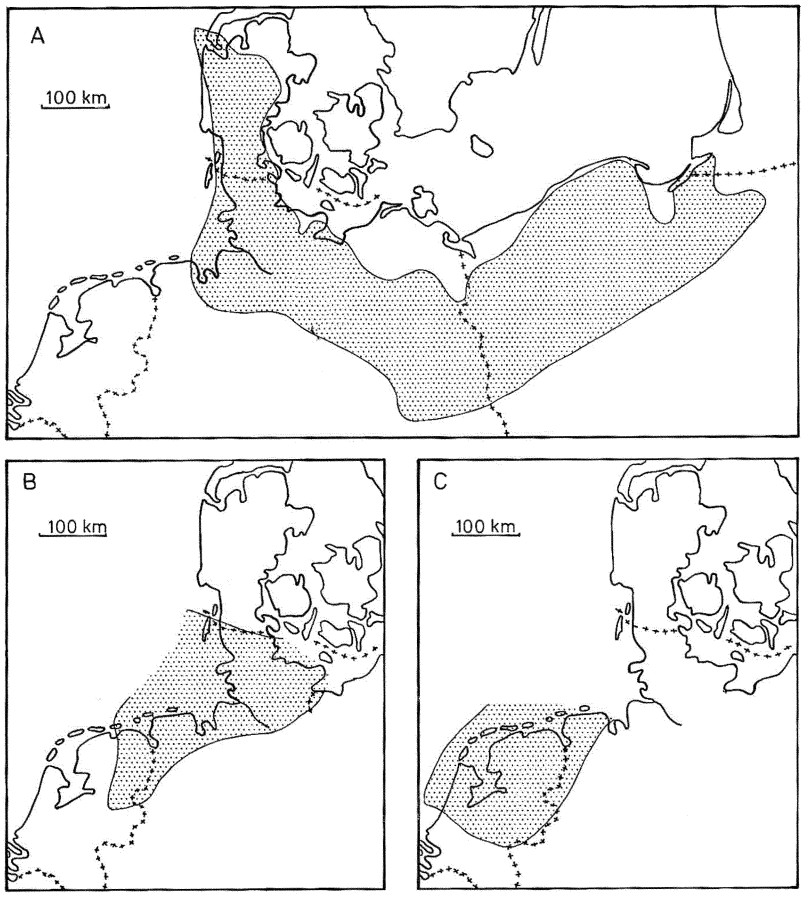

Fig. 8. Geographical extent of Eridanos River sediments. (A) Miocene deposits; (B) Pliocene to Late Tiglian deposits; (C) Younger Early Pleistocene deposits. Reproduction of fig. 3 in Bijlsma (1981).

of the lower reaches changed from NE–SW to west, parallelling the German Mittelgebirge (Zagwijn 1975; De Mulder et al. 2003). Tributaries of the Eridanos, such as the Pre Elbe, Pre Saale, and Pre Weser, contributed a substantial component from the south, which was intermixed with clastics from eroding Miocene fluvial deposits from the east. Thus, in the Pleistocene deposits in the Netherlands 'lavender-blue' silicifications form a minor component and occur mainly as reworked relics. Ordovician silicified limestones and cherts, referred above to the Haljala and Pirgu groups, were transported by the Eridanos from the northeast and became the predominant Ordovician rock type in Lower Pleistocene deposits, which are assigned to the Appelscha Formation in the Netherlands (Zagwijn 1975; De Mulder et al. 2003). About 800 000 years ago, Pleistocene glaciers and tectonics terminated the Eridanos River system.

Bijlsma (1981) studied the gravel composition of fluvial deposits and introduced the term 'Baltic Gravel Assemblage' (BGA). The graphic in Fig. 9 (modified after Bijlsma's fig. 2) combines the geographical and chronostratigraphical development of the Eridanos delta. It also shows the connection of 'lavender-blue' silicifications with Miocene and Pliocene deposits, as well as the connection of 'yellowish-grey' silicified limestone and chert with Pleistocene deposits.

On the one hand, the fossil association in the 'lavender-blue' group shows similarities to that from the 'yellowish-grey' limestone, but on the other hand, differences are so marked that they are to be regarded as distinct associations. This circumstance has been demonstrated on the basis of differences in cyclocrinitid algae (see above), but the same holds true for other groups as well, such as trilobites and brachiopods, at least at the genus or species level. The trilobite genus *Atractocybeloides* Krueger, 1991 can be given as an illustration: *A. berneri* Krueger, 1991 is restricted to the 'yellowish-grey' limestone, but the coeval, closely related *A. vonhachti* Krueger, 1991 is known only from 'lavender-blue' silicifications. These and other examples indicate different source areas for coeval clastics. For the 'yellowish-grey' limestone a provenance near Estonia is probable, considering the similarities of fossils in erratics to associations from Estonian strata (Rõõmusoks 1970). Concerning the provenance of the 'lavender-blue' group, Stolley (1929, p. 84) considered the "North Baltic and Finnish-Baltic East" as a possible region of origin of the material. Schallreuter (1984) and Krueger (1990, 1994) assumed Finland, Lapland and/or the Gulf of Bothnia to be the most probable source areas. That may apply to part of the silicifications, but cannot be upheld for erratic sponges. Their occurrence is limited, in essence, solely to the Estonian–St Petersburg area. Thus, only sponges may function as a key group in establishing the provenance of these distinct associations and therefore, will be discussed more thoroughly below.

SPONGES IN FLUVIAL DEPOSITS FROM BALTIC STRATA

So far, in northern and eastern Germany, the Netherlands, and in Gotland about 60 000 erratic sponges have been collected, most of them of Pirgu age, and relatively few of Haljala to Keila age (Krueger 1990). This number is in stark contrast with the ca 500 specimens housed in museums in Estonia and St Petersburg, collected from Haljala strata. The contrast becomes even clearer when the remaining reports concerning Fennoscandia are summarized.

Rõõmusoks (1970) listed some sponge taxa from Estonia, both as erratics, and collected in situ. Confirmation of his data was obtained recently by a study of the sponge collections at the Geological

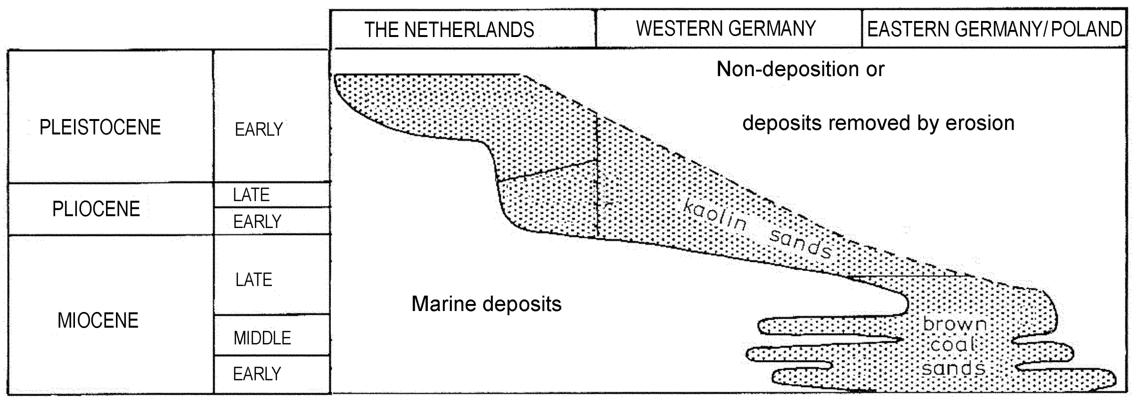

Fig. 9. Stratigraphical correlation of the deposits of the Eridanos River System in a schematic cross-section from the German–Polish Basin to the present North Sea. Modified after fig. 2 in Bijlsma (1981).

Museum of the University of Tartu and the Museum of the Institute of Geology at Tallinn University of Technology (TUT). There are only four records of sponges from mainland Sweden: two specimens of the cosmopolitan *Hindia sphaeroidalis* Duncan, 1879, from the Siljan District, Dalarne, Sweden (pers. comm. H. Leipnitz, Uelzen 1992 and J. Hagström, Swedish Museum of Natural History, Stockholm 2007, respectively), one specimen of *Pyritonema subulare* Roemer, 1861 (Paulsen 2007), and two erratics near Gävle, Sweden (Wiman 1901). Neither from Öland (C. Franzén, Swedish Museum of Natural History, pers. comm. 1999, 2005) nor from Finland (A. Uutela, Finnish Museum of National History, Helsinki, pers. comm. 1995, 2008) have more sponges been recorded, neither as erratics, nor in situ; thus, they are indeed restricted to Estonia and the St Petersburg area.

Although the number of sponge taxa from Estonian and Russian strata, as well as the number of specimens, contrasts markedly with the varied assemblages of erratic sponges in Germany and the Netherlands, these collections are an important starting-point for further studies. Therefore, a brief overview of their composition is useful.

The collections in Tallinn and Tartu are small but varied, containing about 100 specimens. Heteractinids are represented by five specimens of *Astraeospongium patina* Roemer, 1861 from the Volkhov to Kunda stages (B_{II} and B_{III}, respectively), and Idavere Substage (C_{III}) (Rhebergen 2007a). *Pyritonema subulare* Roemer, 1861 is the sole hexactinellid. Among astylospongiids, *Carpospongia* is the predominating genus. Other taxa are *Hindia sphaeroidalis* and one specimen of *Calycocoelia typicalis* Bassler, 1927. About 50% of the collections consisted of two anthaspidellid taxa. The genus *Aulocopella* includes *A. cepa* (Roemer, 1861), *A. dactylos* Rigby & Bayer, 1971, and, probably, *A. hemisphaericum* (Roemer, 1861) (Fig. 10). About 20 specimens are large, flat, discus-like sponge bodies, on average 120 mm across and 35 mm in height, labelled *Aulocopium discus* or *Aulocopium* sp. (Fig. 11). Roemer (1861) based his description of *Aulocopium discus* on the single specimen known at that time, originating from Kukruse (Estonia). It is now in the Museum für Naturkunde, Berlin. However, Rauff (1895, pl. 19, fig. 1) rejected this name and assigned the specimen to *Aulocopium aurantium* Oswald, 1847, regarding the discus as the base of a sponge body, of which the upper part had become detached. Yet, as there are about 20 nearly identical specimens, it is unlikely that only upper parts would have been lost. Therefore, the identification as *Aulocopium aurantium* should be reconsidered. Possibly, Roemer's *Aulocopium discus* will appear to be a valid taxon after all. The recent find of the astylospongiid *Syltrochos pyramidoidalis* Von Hacht, 1981 at Ristna Cliff (Keila Stage, D_{II}), during an excursion of the 7th Baltic Stratigraphical Conference, is the first record of this species, which so far had only been identified from fluvial deposits in Germany and, rarely, in the Netherlands (Fig. 12).

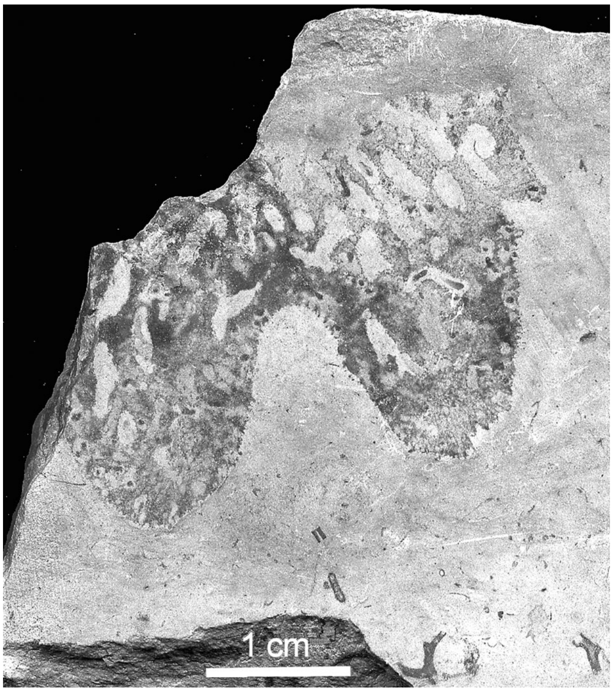

Fig. 10. *Aulocopella dactylos* Rigby & Bayer, 1971. One of the rare anthaspidellid specimens from Estonian strata. Pärnu core, depth 264.1 m, Pirgu Stage. Institute of Geology TUT, Tallinn, coll. No. GIT 413-73.

Additional data were gathered by studying sponges at the Geological Institute (CNIGR, VSEGEI) in St Petersburg, collected recently from the Shundorovo Formation (Upper Ordovician, C_{IV}) in the St Petersburg area (Iskyul & Fedkovets 2008). This formation corresponds approximately to the North Estonian Vasavera Formation, which is the upper part of the Idavere Regional Substage (Haljala Stage) (Iskyul & Fedkovets 2008). The CNIGR museum collections contain a few sponges in the Asatkin Collection, inclusive of the holotype of *Carpospongia pogrebowi* Asatkin, 1949 (Fig. 13). To my knowledge, papers by Asatkin have never been referred to in western Europe or the USA. Asatkin's species, as well as the assemblage noted above, will be the subject of a future paper.

In comparison with sponge assemblages from fluvial deposits, the Shundorovo assemblage is unusual, in at least two respects: (1) near-absence of anthaspidellids (2%), which will be discussed below, and (2) notable predominance of astylospongiids (80%). In addition, the

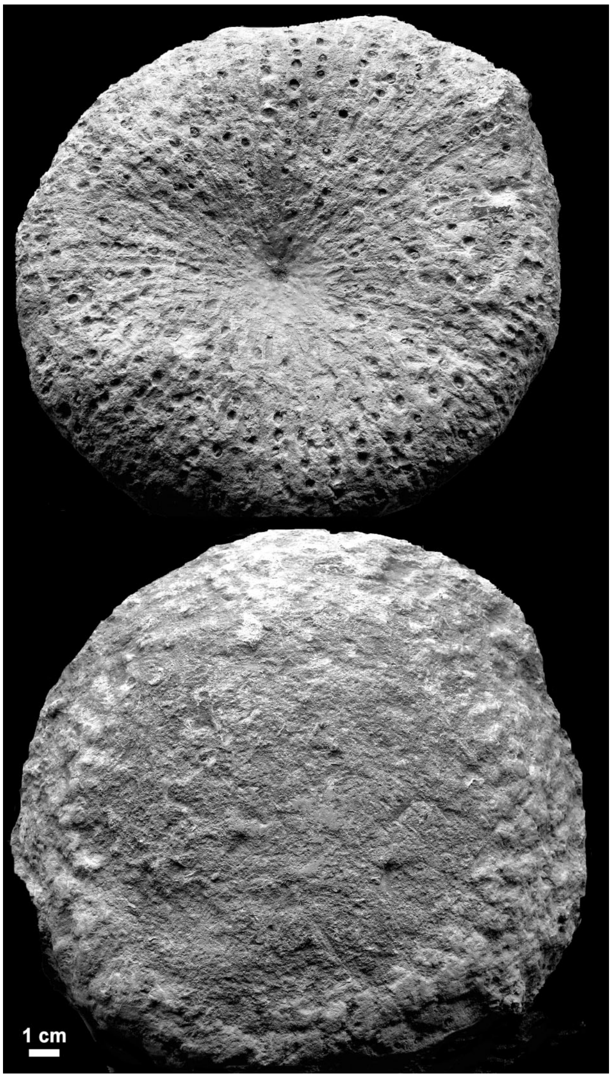

Fig. 11. *Aulocopium discus* Roemer, 1861. Specimen without further data in the Särghaua field station of the Institute of Geology TUT. In accordance with similar specimens in the Institute of Geology TUT and in the Museum of the University of Tartu, its age is probably the Idavere Substage.

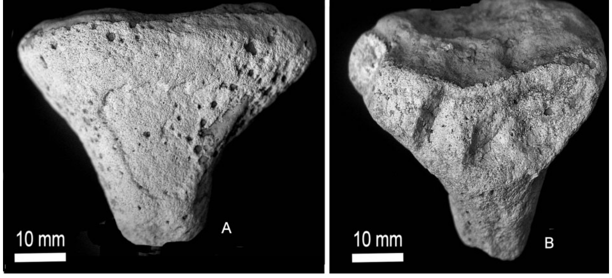

Fig. 12. *Syltrochos pyramidoidalis* Von Hacht, 1981 is the first record of the unusual astylospongiid species. (A) Side view; (B) oblique top view. Ristna cliff, Estonia. Keila Stage. After publication the specimen will be donated to the Institute of Geology TUT, Tallinn, coll. No. GIT 413-93.

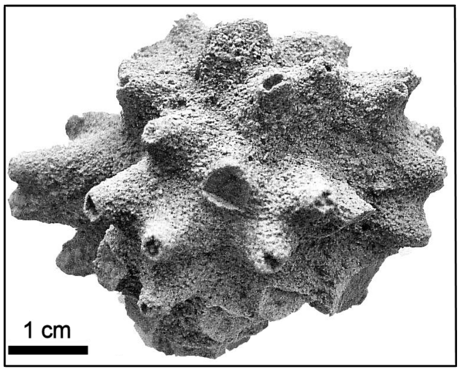

Fig. 13. *Carpospongia pogrebowi* Asatkin, 1949. Holotype. Museum of VSEGEI, St Petersburg, Russia.

distribution of taxa within the astylospongiids revealed close similarities to assemblages of 'blue' sponges in the Miocene and Pliocene fluvial deposits. Thus, they seem to be coeval, which would underscore Krueger's (1990) assignment of the age of some of the 'blue' astylospongiids from the Lausitz area and Sylt as Jõhvi to Keila stages, on the basis of co-occurring fossils. It can tentatively be concluded that the 'blue' astylospongiids originated from identical and probably coeval strata, as those of the Shundorovo Formation. However, a detailed analysis of these assemblages is beyond the scope of the present study.

Biostratigraphical and palaeoecological aspects are useful for explaining the presence or absence of taxa. Below, these are considered briefly, in relation to the sponges discussed here.

Astylospongiids developed in the early Late Ordovician. The oldest spheroclones (the characteristic spicule in astylospongiids) are from erratic sponges from Sylt (Mehl-Janussen 1999, p. 44, pl. 6. fig. 1). Generally, they preferentially inhabited epicontinental seas, including shallower areas (Van Kempen 1978). Probably, they migrated from Baltica to Laurentia (Rhebergen 2007b), where they spread up to Northwest and Arctic Canada during the Silurian (Rigby & Chatterton 1989).

Anthaspidellids developed during the Early Ordovician (Carrera & Rigby 2004), expanded in the Middle Ordovician, and radiated during the Late Ordovician worldwide (Rigby & Webby 1988). Initially, they preferred the outer margins of continental shelves and upper slopes, and were important reef-builders (Carrera & Rigby 2004). However, during the Late Ordovician, they tended to inhabit shallower settings and were distributed worldwide in tropical seas. Carrera & Rigby (1999) made the first attempts to reconstruct patterns of anthaspidellid distribution, and took also the sponge assemblages from Baltica into account, which were not really considered in the literature, probably because they were 'just erratics'.

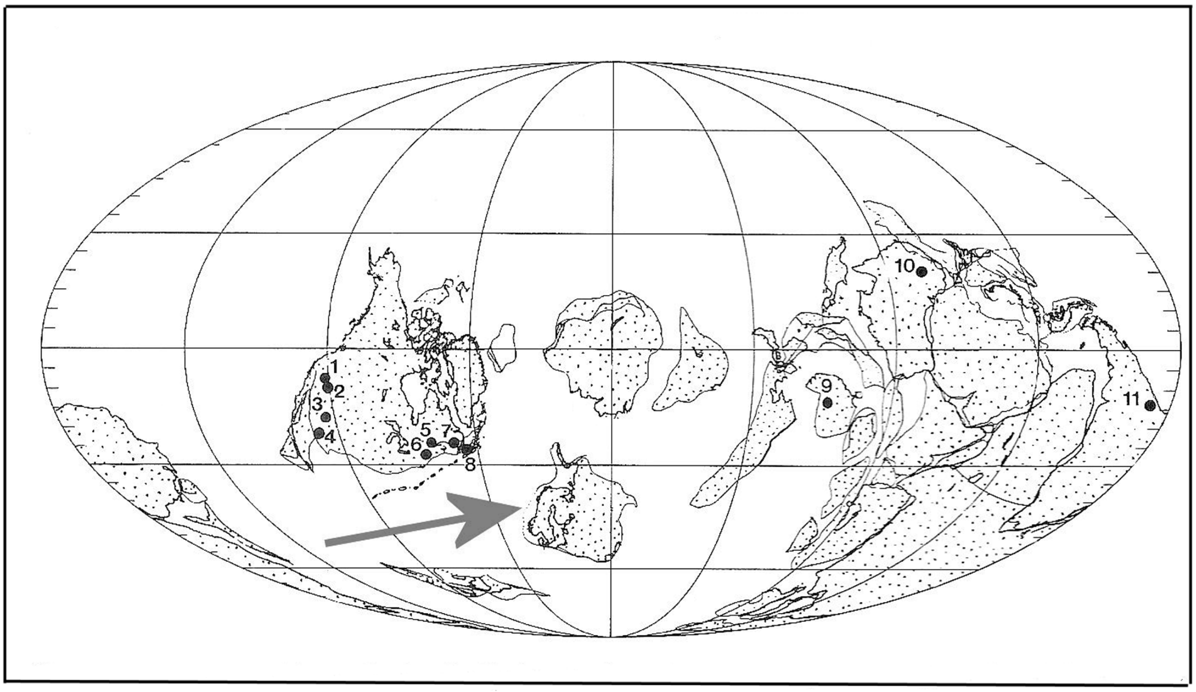

Fig. 14. Palaeogeographic map showing the distribution of major Ordovician sponge faunas throughout the world. Modified after fig. 7 in Beresi & Rigby (1993). 1–8, Laurentia; 9, eastern China; 10, New South Wales, Australia; 11, Argentina. All areas are situated in tropical to subtropical zones. Note that sponges from Baltica (see the arrow) are not recorded. Considering the position of Baltica, its northern margin is a probable habitat for especially anthaspidellid sponges.

The near-absence of anthaspidellids in Upper Ordovician strata of the Shundorovo Formation (C_{IV}) is in accordance with their preferred habitat in deeper, less turbulent waters of the outer shelf areas. Considering the palaeogeographical position of Baltica in the Ordovician (McKerrow et al. 1991), Von Hacht & Rhebergen (1997) assumed that a suitable environment for anthaspidellids existed along the northern margin of Baltica, in the tropical zone (Fig. 14). That would be in accordance with the present position of areas further to the northeast, in the upper reaches of the Pra Neva, or the White Sea area. Probably, the ‘blue’ anthaspidellid sponges, as well as the associated, usually ‘blue’ stromatoporoids, originate from those areas, where Ordovician strata were eroded completely by the Pra Neva (Suuroja 2007).

CONCLUSIONS AND RECOMMENDATIONS

Ordovician clastics from Baltica in the Eridanos River Delta in Germany and the Netherlands form distinct associations, originated from different areas, and were deposited during different stages. The relationship between associations and the age of deposition could be established on the basis of diagenetic phenomena, as well as on fossil assemblages.

There are strong indications that the ‘lavender-blue’ silicifications, the ‘blue’ sponges, as well as associated ‘blue’ stromatoporoids and tabulates, originate from eroded strata in the drainage basin of the Pra Neva. Future studies may reveal the provenance of anthaspidellid sponges, possibly in the White Sea areas, being the upper reaches of the Pra Neva, from where Ordovician strata have disappeared through erosion (Suuroja 2007). Be it as it may, the present study underlines the importance of the Pra Neva as a tributary of the Eridanos River System for Ordovician fluvial clastics in Germany and the Netherlands.

The importance of erratics discussed herein is demonstrated by two examples. Firstly, diagenetically determined preservation of fossils in ‘yellowish-grey’ silicified limestones provides additional data and complements information from those collected in situ. Secondly, further detailed comparison of in situ fossil assemblages with those from fluvial deposits may contribute to the stratigraphy of Baltica, as well as to a better understanding of the Eridanos River System.

The anthaspidellid sponges in Estonian collections noted above are dominated by *Aulocopium discus*, which to date is unknown from fluvial deposits. The specimens need to be re-examined and re-described.

The predominance of astylospongiids in the St Petersburg area is in accordance with their preferred environment, as well as with preliminary lithostratigraphical results (Iskyul & Fedkovets 2008). Similarities to the 'blue' erratic astylospongiids in fluvial deposits suggest that the age of the latter should be reconsidered.

Acknowledgements. I am grateful to Andrey Dronov, Geological Institute of the Russian Academy of Sciences, Moscow, for encouragement and valuable information; to Tatiana Tolmacheva, VSEGEI, St Petersburg, for appreciated support and access to collections; to Georgy Iskyul, VSEGEI, and Anastasija Fedkovets, St Petersburg State University, for fruitful discussions; to Mare Isakar, Museum of Geology of the University of Tartu, and Ursula Toom, Geological Institute of Tallinn University of Technology, for hospitality, access to collections and discussions; to Ulrike Mattern, who let me the specimen in Fig. 12; to Adrian Popp, who photographed the specimen in Fig. 11; and to John W. M. Jagt, Natuurhistorisch Museum Maastricht, the Netherlands, for linguistic corrections. I am indebted to Bert Boekschoten, Vrije Universiteit, Amsterdam, and Roger Schallreuter, Ernst Moritz Arndt-Universität, Greifswald (Germany), for their reviews of the paper and useful suggestions.

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Ordoviitsiumi käsnad (Porifera) ja teised ränistunud fossiilid Põhja-Saksamaa ning Hollandi Neogeeni ja Pleistotseeni fluviaalsetes setetes

Freek Rhebergen

Saksamaa ja Hollandi Miotseeni ning Vara-Pleistotseeni fluviaalsed setted kuhjusid Eridanose deltaaladel, kuid settematerjali täpne päritolumaa on siiani diskuteeritav. Käesoleva töö eesmärgiks oli võrrelda nimetatud setetes leiduvaid Ordoviitsiumi käsnasid Põhja-Eesti ja Sankt-Peterburgi piirkonna Ordoviitsiumi avamuse käsnafaunaga. Selgus, et uuritud rändkivid pärinevad Eridanose lisajõe Pra-Neva valglalt. Lisaks on artiklis esile tõstetud ränistunud rändkivides peituvate fossiilide unikaalset säilimisviisi ja esitatud soovitusi edasisteks uuringuteks.