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LATE ORDOVICIAN BRACHIOPODS FROM EASTERN NORTH GREENLAND: EQUATORIAL OFFSHORE MIGRATION OF THE RED RIVER FAUNA

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Abstract: Late Ordovician rhynchonelliformean brachiopods, typical of the North American Red River fauna, are found sporadically in the Børglum River Formation of the Centrum Sø area, Kronprins Christian Land, eastern North Greenland. The geographical distribution of this characteristic brachiopod fauna is thus extended to the easternmost extremity of the Laurentian craton. The assemblage compares specifically with the *Hiscobeccus* brachiopod fauna, based on key taxa such as notably *Hiscobeccus gigas* (Wang, 1949), and indicates a late Katian age for this part of the succession. For the first time, this typically inland, shallow-water fauna is found associated with genera like *Bimuria*, suggesting a transitional marginal facies with outer shelf benthos. The current study describes a *Hiscobeccus* fauna that lived at the seaward edge of its preferred habitat. Furthermore, an unpublished *Hiscobeccus* fauna, from the Børglum River Formation of Peary Land, central North Greenland, as well as several occurrences from the Kap Jackson and Cape Calhoun formations in various parts of Washington Land, western North Greenland, are described here. These show a distinct shift from older strata containing *H. capax* (Conrad, 1842) to younger strata exclusively yielding specimens of *H. gigas*. As *H. gigas* occurs in the upper part of the Cape Calhoun Formation in Washington Land, it indicates that the upper boundary of the Cape Calhoun Formation is considerably younger than previous estimates, reaching into the uppermost Katian (middle Cautleyan–Rawtheyan). The Cape Calhoun Formation correlates with the upper member of the Børglum River Formation and further demonstrates that the *Hiscobeccus* fauna was widespread in Laurentian marginal settings of North Greenland. Even though the *Hiscobeccus* fauna was pan-continental during the late Katian (Richmondian), it possesses a strong provincial signal during the later Ordovician. The new occurrences indicate that this fauna extended to the north-eastern margin of the Laurentian Craton. It lived in close association with cosmopolitan faunal elements that may have been the earliest sign of the succeeding invasion of migrants from Baltica that arrived later during the Hirnantian. The offshore migration of this atypical *Hiscobeccus* fauna likely demonstrates the path of warm-water currents as the Centrum Sø locality was located at the equator during the Late Ordovician.

Key words: Kronprins Christian Land, Washington Land, Katian, *Hiscobeccus* fauna, Børglum River Formation, Cape Calhoun Formation.

THE shores of Kronprins Christian Land, in the eastern part of North Greenland, have only been explored during the last Century. As a consequence, limited palaeontological material has only been collected from this vast region in the high Arctic. This is especially the case in the region southwest of Centrum Sø (Fig. 1). Situated far from the coastline and only some 25 km from the Inland Ice, detailed geological information from this region has just been published within the past 15 years. Prior to the major geological mapping project in 1993–1995 (Henriksen 1996; Jepsen 2000), undertaken by the Geological Survey of Greenland (GGU, now GEUS), this region was uncharted (Peel *et al.* 1981; Higgins *et al.* 1991).

Before the mapping project, the geology of Kronprins Christian Land was primarily known from dog sledge parties travelling along the outer coast. The interior of this region was first described in crude terms by geologist Lauge Koch, who, during the summer of 1933, made two long reconnaissance flights from Svalbard using a seaplane (Koch 1935*a*, *b*, 1936). Although he only drew very basic sketches that mainly concerned the topography, he did note some of the major geological features. In 1938–1939 Koch's map of the region was significantly improved as sledge teams from the Danish Northeast Greenland Expedition travelled the outer coast and penetrated, for the first time, deep into the regions large fjords and even into

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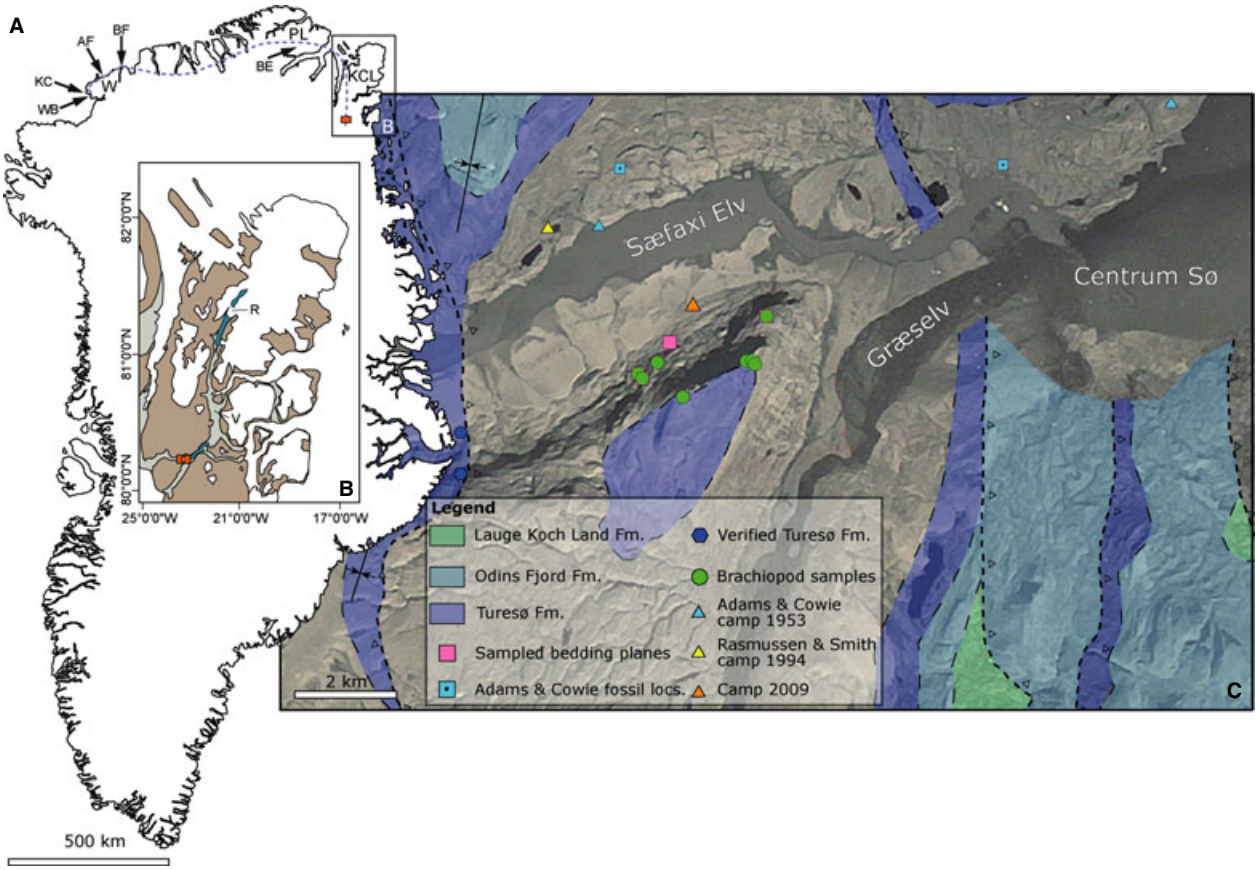


FIG. 1. Locality maps indicating localities discussed in the text. A, outline of Greenland showing Kronprins Christian Land, Peary Land and Washington Land. Dashed line illustrates the approximate position of the transect shown in Figure 3. B, enlarged view of Kronprins Christian Land. Study area indicated by small rectangle. C, ortho photograph showing general geology and sampling sites. Unshaded areas represent outcrops of the Børglum River Formation. Abbreviations: AF, Alegatsiaq Fjord; BE, Børglum Elv; BF, Bessels Fjord; KC, Kap Calhoun; KCL, Kronprins Christian Land; PL, Peary Land; R, Romer Sø; V, Vandredalen; W, Washington Land; WB, Wright Bugt. See legend for further explanation of colours and symbols used in the ortho photograph.

Vandredalen and Romer Sø (Nielsen 1941; Fig. 1). Nielsen (1941) made several notes on the general geology and stratigraphy and also concluded that both Upper Ordovician and Lower Silurian strata occurred. Furthermore, he argued that some of the lithological units, such as his definition of the Offley Island Formation, were identical to those established by Koch in northwest Greenland (Koch 1920). Although this observation was not entirely correct, it still demonstrates the great resemblance between many of the lithological units in east and west North Greenland.

The first proper reconnaissance in central Kronprins Christian Land was carried out by Lauge Koch's Danish Expedition to East Greenland (1947–1952). Two geological teams were deployed by seaplane in the field season of 1952. One team concentrated on the heavily folded zone east of Centrum Sø (Fränkl 1954, 1955), while another team focused on the region from the southernmost parts of Danmark Fjord eastwards to Centrum Sø (Adams and Cowie 1953). One of their localities was situated on the northern shore of the large braided river of Sæfaxi Elv, just opposite the present study locality (Fig. 1). They defined the Centrum Limestone, a stratigraphic unit about 2500 m thick, which they inferred, based on fossil evidence, spanned the Ordovician–Silurian boundary.

Since then, a number of papers have dealt with the general geology of the region, mostly with respect to the Caledonian fold belt, the main geological feature in this region (Haller 1970, 1971; Peel 1980; Hurst and McKerrow 1981*a*, *b*; Peel *et al.* 1981; Rasmussen and Smith 1996, 2001; Smith and Rasmussen 2008). With a few exceptions (Lane 1972; Scrutton 1975), the study of macrofossils was limited to preliminary faunal lists.

Therefore, the present study on the Late Ordovician brachiopod fauna from the Centrum Sø region is the first taxonomic treatment of the fossil macrofauna from this area that is closely tied to stratigraphy and further corre-

lated with coeval occurrences in central and western North Greenland. It also constitutes the second part of an on-going systematic study of the brachiopod faunas of North Greenland (Jin *et al.* 2009).

GEOLOGICAL SETTING

During the Late Ordovician, North Greenland was positioned on the palaeoequator at the north-eastern margin of Laurentia (Fortey and Cocks 2003, p. 254; Cocks and Torsvik 2011; Jin *et al.* in press). Warm-water carbonates were extensively deposited on the shelf, whereas fine-grained siliciclastic sediments were deposited in trough and slope environments (Higgins *et al.* 1991; Surlyk 1991; Surlyk and Hurst 1984).

Sediments on the north coast of Greenland can almost exclusively be associated with to the evolution of the Franklinian Basin. A shallow-water carbonate facies in the southern part of North Greenland is sharply separated from turbiditic siliciclastics in the north by the Navarana Fjord Fault (Hurst and Surlyk 1982; Surlyk and Ineson 1987). The carbonates are mostly horizontally stratified. The northernmost outcrops in west and central North Greenland and almost the entire sequence in Kronprins Christian Land are exceptions. This is due to the influence of two separate orogenies that greatly affected the region during the Palaeozoic (Surlyk 1991). The extreme north coast is heavily deformed by the Devonian Ellesmerian folding, whereas the entire Greenlandic east coast from Scoresby Sund to the northernmost extremity of Kronprins Christian Land is characterized by the Caledonian tectonism (Henriksen and Higgins 1976; Higgins *et al.* 1991; Smith *et al.* 2004). It is within this eastern foldbelt that the Centrum Sø locality is situated. This area is characterized by para-autochthonous Upper Ordovician – Lower Silurian carbonate rocks that become increasingly folded and deformed towards the east.

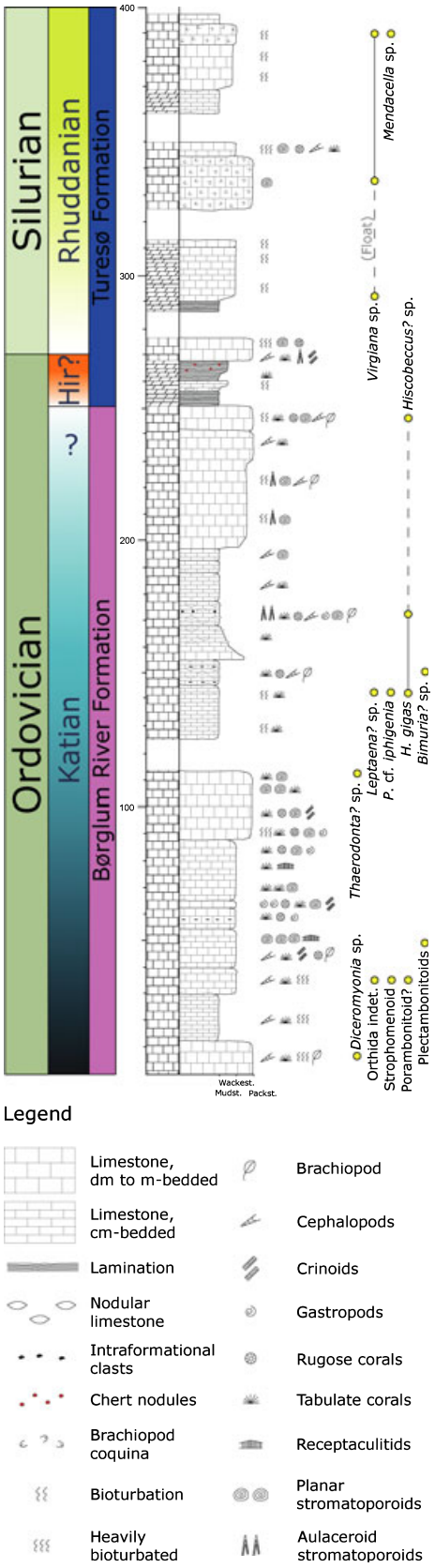
Lithostratigraphical units in eastern North Greenland. The lithostratigraphical units in the area are characterized by the carbonates of the Ryder Gletcher Group (Wandel Valley and Sjælland Fjelde formations), the Børglum River and Turesø formations of the Morris Bugt Group, and the Odins Fjord and Samuelsen Høj formations of the Washington Land Group (Smith *et al.* 2004). Together these constitute the modern lithostratigraphical framework that has replaced the Centrum Limestone of Adams and Cowie (1953). The succession shows a sequence shallowing upward during the Ordovician and then deepening in the Silurian, from the upper part of the Turesø Formation continuing in the overlying Odins Fjord Formation. The Ordovician–Silurian boundary lies within the Turesø Formation (Smith *et al.* 2004).

The brachiopods described in this study are sampled from the upper part of the Børglum River Formation. This formation consists of heavily bioturbated carbonate mudstone to wackestone with bedding thickness ranging from centimetre to metre scale. The dark, almost black, mottling is clearly distinguishable from the light to dark grey matrix. Marly and rubbly intervals occur sporadically throughout the succession. There is an abundant and diverse macrofauna consisting chiefly of tabulate corals like *Catenipora, Palaeofavosites, Palaeophyllum, Syringopora* and *Troedssonites*, with some rugose corals and algal mats. In addition, a very diverse nautiloid fauna, rich in orthoconic cephalopods, and other molluscs, like *Maclurina,* are found throughout the section. Crinoids are very abundant in certain intervals and so is *Receptaculites* to a lesser extent. Planar stromatoporoids are also found throughout the formation and towards the top of the formation, abundant metre-sized aulaceroid stromatoporoids, which occur at the same stratigraphical level in Peary Land, are seen, as are large ostracods. The uppermost beds become dolomitized, and some of them are thin beds of pure dolomite. Therefore, the boundary to the overlying dolomites of the Turesø Formation is gradual. Contrary to the opinions expressed in the literature (Armstrong and Lane 1981; Hurst 1984), the same has been observed in Peary Land by the author.

Figure 2 is a composite lithological log through the studied section at Centrum Sø. The log shows the upper part of the Børglum River Formation and almost the entire Turesø Formation. Chronostratigraphical ages are based on the occurrence of key brachiopod taxa, such as *Hiscobeccus gigas* (Wang), *Diceromyonia* Wang, *Plaesiomys* cf. *iphigenia* (Billings) and *Virgiana* Billings. The Ordovician–Silurian boundary in Figure 2, is based tentatively on regressive – transgressive shifts in lithology that occurs below the first occurrence of *Virgiana.* However, it is not discussed in this study.

Lithostratigraphical units in western North Greenland. As the described Centrum Sø brachiopods will be correlated with the western units in the following sections, a short introduction to the lithological units of the succession in Washington Land in the western part of North Greenland, is presented below.

The Washington Land succession is different from that seen in Kronprins Christian Land and Peary Land. The Lower Cambrian–Middle Ordovician Ryder Gletcher Group is overlain by the Morris Bugt Group, which is composed of the wacke–packstone of the Kap Jackson Formation (lower Upper Ordovician). This formation is further subdivided into the Gonioceras Bay and Troedsson Cliff members (Smith *et al.* 1989). The Kap Jackson Formation is succeeded by the marly limestone facies of the Cape Calhoun Formation. Previous age estimates for



this formation indicated a Sandbian?–middle Katian age. This study shows that its upper boundary must lie within the upper Katian, at least in south-western Washington Land, where the formations most westerly outcrops are found. The Cape Calhoun facies is a fine-grained marly limestone that has been interpreted as deposited in deeper water settings (Higgins *et al.* 1991). Thus, similar to the correlative facies in Kronprins Christian Land, the *Hiscobeccus* fauna is here also found in an unusual setting, compared to the shallower water inland occurrences where they have traditionally been reported from in Laurentia.

Finally, the uppermost formation within the western part of the Morris Bugt Group, the Alegatsiaq Fjord Formation, is characterized by carbonates, and spans the Ordovician–Silurian boundary as it reaches into the upper Rhuddanian. This entire western sequence was deposited in a deeper water environment than the succession in eastern North Greenland (Higgins *et al.* 1991). However, the present study indicates that in Kronprins Christian Land, at least part of the Børglum River Formation was deposited under similarly deeper water conditions, or, at least deeper than what is seen in the Børglum River Formation of Peary Land. A revised correlation of the lithological units within the Morris Bugt Group is shown in Figure 3.

SAMPLING

Brachiopods are rare in the Børglum River Formation. As the succession is several hundred metres thick, bed by bed sampling was not possible. Due to constraints of field work time and air freight in the short high arctic summer, only a limited number of well exposed fossiliferous beds were targeted and studied in detail (Fig. 4). All brachiopods were photographed and catalogued. The best specimens were sampled using a rock saw for further study in the laboratory, where key specimens were prepared mechanically with high-pressure air chisels.

FIG. 2. Composite lithological log through the Centrum Sø section showing the upper part of the Børglum River Formation and the Turesø Formation (measured by J. A. Rasmussen, J. Walløe and the author). Chronostratigraphical ages are solely based on the occurrences of key brachiopod taxa. As the Turesø Formation is by and large devoid of fossils, the Ordovician–Silurian boundary is inferred based on transgressive–regressive pulses deduced from shifts in lithology, prior to the first occurrence of *Virgiana*. See legend for further explanation of symbols used.

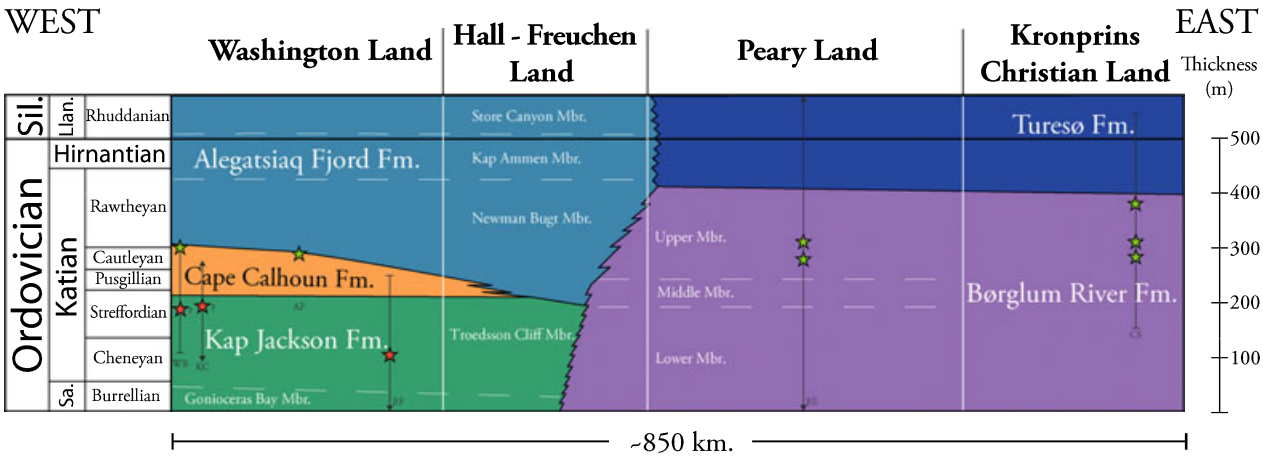


FIG. 3. Correlation of the lithological units within the Upper Ordovician – Lower Silurian Morris Bugt Group across North Greenland. The lithological units are correlated and further tied to chronostratigraphical ages. In addition, their relative thicknesses are roughly indicated. The upper boundary of the Cape Calhoun Formation in Washington Land is revised according to the current study. The stratigraphical range, as well as relative lateral distribution, of *Hiscobeccus gigas* (green star) and *H. capax* (red star) within the Morris Bugt Group, is shown. Specimens that are sampled within a measured section are shown by a grey line depicting the approximate length of the section, whereas specimens collected as a loose block, are indicated by a star indicating the approximate level the sample was collected from. Abbreviations as in Figure 1, except: CS, Centrum Sø; Sa., Sandbian; Sil., Silurian; Llan., Llandovery. Redrawn from Rasmussen (2009) – see Rasmussen (2009) for references used to construct this figure.

THE RED RIVER FAUNA AND ITS AGE

The brachiopods presented in this study are mostly known from the North American Red River fauna. This fauna is also known as the Arctic Ordovician fauna (Nelson 1959; Jin and Zhan 2000). It is recognized as a heavily mottled facies with very characteristic *Thalassinoides*-type burrows (Jin *et al.* 2011) with a typically abundant and diverse fauna dominated by large shelled organisms. More recently, Jin *et al.* (in press) used this very characteristic and easily recognizable facies and fauna, to constrain the Late Ordovician Equator to a narrow belt crossing the Laurentian Craton; the fauna is particularly well known from the Williston Basin in west-central North America, but also from other places in Arctic Canada eastwards extending to Peary Land, central North Greenland (Bolton 1977; Jin and Zhan 2001; Jin *et al.* 2008) and further eastwards to Kronprins Christian Land, some 200 km further east, on the margin of the Laurentian craton (Jin *et al.* 2011).

There has been much debate as to the age of the Red River fauna. Traditionally it is viewed as representing a large interval in the Late Ordovician (Cincinnatian), but Mohawkian or Richmondian has also been suggested (Sweet 1979, 2000). Jin and Zhan (2001) assigned the rhynchonelliform brachiopods of the Red River fauna to the Late Edenian – Early Richmondian.

The upper part of the Børglum River Formation, however, can be better constrained stratigraphically. Several taxa within the upper 100 m of the formation in the sampled section, notably *Hiscobeccus gigas* (Wang 1949), show that these brachiopods can be assigned to the *Hiscobeccus* fauna, a largely late Katian (Maysvillian–Richmondian) brachiopod fauna that was markedly endemic. In the Williston Basin the fauna is best developed in the Selkirk Member of the Red River Formation. This member is interpreted as developed in open marine conditions, at least in southern Manitoba (Jin and Zhan 2001). The Selkirk facies is very similar to the one observed in the Børglum River Formation, and therefore, the latter could be viewed as a more expanded equivalent to the Selkirk Member (Jin *et al.* 2011). The remaining members of the Red River Formation, however, cannot be compared to the Børglum River Formation (J. A. Rasmussen, pers. com. 2010). Despite this, the occurrence of *H. gigas* in the Centrum Sø section, indicates a slightly younger age for the upper part of the section, as this species is only known from the overlying Gunn and Penitentiary members of the Stony Mountain Formation in southern Manitoba, indicating a latest Katian (Rawtheyan) age for the upper part of the section (Jin and Zhan 2001). In the Williston Basin, *H. gigas* occurs within the *Diceromyonia* Community, as it is associated with *Diceromyonia* in the Centrum Sø area. Following Jin and Zhan (2001), this further indicates that the upper part of the Børglum River Formation correlates with the *D. occidentalis* – *H. capax* biozone of the Churchill River Group of the Hudson Bay Basin (Jin *et al.* 1997).

FIG. 4. Photomosaic showing one of the studied bedding planes within the Børglum River Formation at the Centrum Sø locality. The boundary between the limestones of the Børglum River Formation and the more dolomitic limestone of the Turesø Formation is indicated. Middle photographs shows the weathered surface with the brownish, silicified fossils cropping out. These include tabulate corals, cephalopods and *Diceromyonia* sp. Image to far right is a close up on the specimen of *Diceromyonia* sp. (MGUH 30226).

In North Greenland, conodonts of the Red River fauna reach their acme in the Cape Calhoun Formation (Smith *et al.* 1989). The Cape Calhoun Formation is the western correlative of the upper part of the Børglum River Formation. This is in accordance with the current study on macrofossils, which finds brachiopods comparable to this fauna within the upper part of the Kap Jackson Formation, as well as the Cape Calhoun Formation, including *H. capax* (Troedsson 1928; this study). This confirms the correlation of the Centrum Sø succession with the *D. occidentalis* – *H. capax* biozone of Jin *et al.* (1997), although the current study suggests that *H. gigas* occurs stratigraphically above *H. capax* in North Greenland (Fig. 3).

This conclusion is further supported by Bergström (2003), who questioned previous age estimates of the Red River fauna. Based on a re-assessment of the regional biostratigraphic data, Bergström showed the fauna to be constrained entirely within the Richmondian. This is somewhat younger than previous estimates. The present study agrees with Bergström (2003) and others, in that the faunas upper boundary reaches into the Richmondian.

DISTRIBUTION AND IMPORTANCE OF THE LATE ORDOVICIAN *HISCOBECCUS* FAUNA

According to Jin (1996, 2001), the earliest rhynchonellids were distributed on several tropical palaeoplates during mid Darriwilian times. They became increasingly endemic up through the Sandbian. By the early–mid Katian, descendents within this family, notably *Hiscobeccus*, *Lepidocyclus* and *Hypsiptycha* – taxa constituting the typical

Hiscobeccus fauna – became markedly endemic within the Laurentian epicontinental seas and thus contributed greatly to the increased species richness so characteristic of the later parts of the Ordovician Period. However, they became extinct within the first pulse of the succeeding Hirnantian mass extinctions.

To demonstrate this provincialism, the distribution of Katian occurrences of *Hiscobeccus* species and the commonly associated key taxa *Hypsiptycha* and *Lepidocyclus*, is shown with asterisks in Figure 5. Furthermore, the contemporaneous cosmopolitan deep-water genera, here represented by *Bimuria*, *Christiania*, *Rhynchotrema* or *Rostricellulla,* are shown with hexagons, where the distribution of *Thaerodonta* is symbolized by dark circles. According to Jin (2001), this genus, as well as other thin-shelled plectambonitoids, is typically found within deep-water associations of the inland basins. Figure 5 also shows the global distribution of the other taxa found in the Børglum River and Cape Calhoun facies. These include *Diceromyonia* (diamonds), as well as *Hesperorthis* and *Plaesiomys* (light circles and squares).

A few occurrences are questionably noted here and elsewhere in the literature. These are indicated by question marks in Figure 5 and include one occurrence of *Plaesiomys* sp., from the upper Katian Cystoid Limestone of the Iberian Peninsula (Villas 1985) and one occurrence of *Lepidocyclus*? *laddi* from the upper Katian Chokpar Formation of the Chu-ili Terrane (Klenina *et al.* 1984). This latter occurrence was also questioned by Rong and Boucot (1998) and Jin (2001), as the interior structures of this species remains unknown.

The *Hiscobeccus* fauna (green overlay in online version), together with *Diceromyonia* (red overlay in online version) are both endemic to the Laurentian Craton (Fig. 5). Both these occurrences may be regarded as warm-water associations. Therefore, a shaded tropical band shows their latitudinal distribution, which indicates a possible southward shifted warm-water belt during the end of the Ordovician. This result also agrees with Jin (2012), who demonstrated how the predominance of *Diceromyonia,* within Katian occurrences of the Dalmanellidae on Laurentia, correlates with low latitude. This suggests that *Diceromyonia* preferred equatorial settings. Contrary to these lower latitude distributions, the cosmopolitan deep-water genera are distributed from low to high latitude (blue overlay in online version) and the

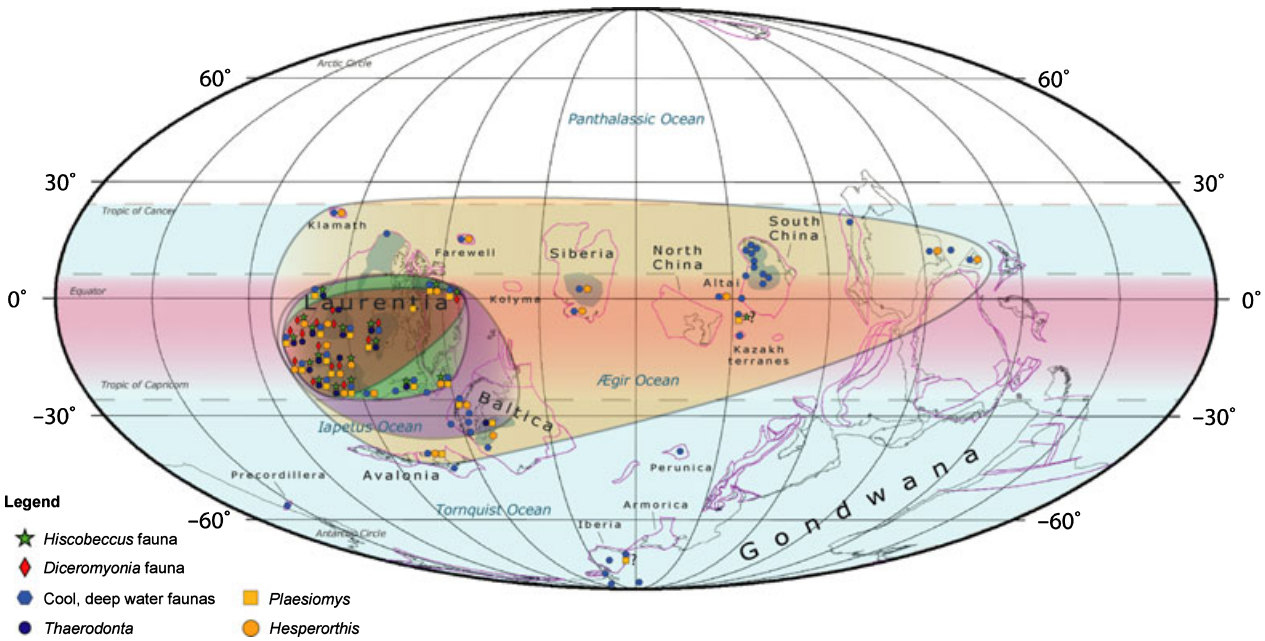


FIG. 5. Global distribution of the Katian brachiopod faunas discussed in the text, showing the general mix of endemic, shallow-water faunas with cosmopolitan, deep-water faunas. The endemic faunas include genera that are typically associated within the *Hiscobeccus* fauna – here represented by *Hiscobeccus, Hypsiptycha* and *Lepidocyclus*. Note the marked provincialism within the Laurentian Craton by the core members of the *Hiscobeccus* fauna and *Diceromyonia*. Their distribution is latitudinally constrained, whereas the deep-water faunas reach high latitudes. The orthids, as well as *Thaerodonta*, are typically regarded as representing deeper water faunas within the epicontinental settings, notably in the Iapetus region and Laurentia. For ease of reading, the total extend of the faunal occurrences are shown by a shaded overlay matching the colour of their symbols. This figure is conducted using GIS-software (Esri, Redlands, CA, USA) to depict the global occurrences precisely. The mollweide palaeoprojection is provided by Trond Torsvik, Norwegian Geological Survey.

Hesperorthis–Plaesiomys associations have a more intermediate distribution.

The Centrum Sø fauna is composed of a mix of components from different fauna associations. On this particular part of the continental margin the otherwise endemic faunal components occurred together with more cosmopolitan taxa. This mix of faunal components is not seen farther south, or north. Southern faunas from the Midland Valley Terrane are rich in the cosmopolitan, deep-water genera, such as *Bimuria* and *Christiania*, but lack the typical *Hiscobeccus* components. The opposite is seen on the Laurentian margin, where for example in the Anticosti Basin, the *Hiscobeccus* fauna is dominant without associated deep-water components. North of the Centrum Sø area, in for example the Klamath and Farewell terranes, both *Bimuria* and *Christiania* are abundant, but the Laurentian rhynchonellid endemics are lacking.

This faunal distributional pattern suggests that the eastward, offshore migration of the *Hiscobeccus* fauna found at Centrum Sø is related to its geographical position on the palaeoequator. Arguably, this warmer water setting permitted more extensive carbonate deposition that possibly favoured key components of the *Hiscobeccus* fauna to spread out into the marginal settings.

THE *HISCOBECCUS* FAUNA IN NORTH GREENLAND

An occurrence of the *Hiscobeccus* fauna was described from Kap (Cape) Calhoun, SW Washington Land, in the most westerly part of North Greenland by Troedsson (1928). Troedsson described several taxa known from the *Hiscobeccus* fauna, such as *H. capax* (Conrad, 1842), *Hesperorthis tricenaria* (Conrad, 1843) and *Dinorthis iphigenia* (Billings, 1865), and other taxa typical of the Red River Fauna. The present study had access to Troedsson's original type material, which is reposited at the Natural History Museum of Denmark. Based on the measured parameters listed in Table 1 and those published by Jin *et al.* (1997) and Jin and Zhan (2001), I am confident that Troedsson's (1928) type material indeed should be identified as *H. capax* (Conrad, 1842). However, in this study, *H. tricenaria* and *D. iphigenia* are reassigned to *Hesperorthis pyramidalis* and *Plaesiomys iphigenia*, respectively. Figures 6–8 show various morphotypes of *H. gigas*, *H. capax*, as well as *P. iphigenia* and *H. pyramidalis* within the studied material – including some of Troedssons original types, which has been refigured for this study.

Troedsson's material was collected in 1921 by Lauge Koch during the Bicentennial Jubilee Expedition (1920–1923), from beds that Troedsson (1928) attributed to the Cape Calhoun Formation. However, he used an expanded version of this formation, compared to present day usage, including a large part of what is now known as the Troedsson Cliff Member of the Kap Jackson Formation (Peel and Hurst 1980). Further, as Troedsson's material was collected as loose blocks from the talus beneath the steep cliffs of Kap Calhoun, the exact stratigraphical position of his figured specimens is not known (Koch 1929; Peel and Hurst 1980).

Fortunately, more material has subsequently been collected from other coeval localities during GGU mapping projects in Washington Land in 1976, 1977 and 1984 (Fig. 1). The GGU material was collected from Wright Bugt, a few kilometres southeast of Kap Calhoun and from Alegatsiaq Fjord, some 70 km north of Kap Calhoun by John Peel, Uppsala, and from the western side of Bessels Fjord in northern Washington Land, by Paul Smith, Oxford. In addition, John Peel and Robert Christie collected specimens of what is here determined as *H. gigas,* at Børglum Elv in central Peary Land, during a GGU expedition in 1974 (Fig. 1). All the GGU sampled occurrences of the *Hiscobeccus* fauna are first published here. Following careful analysis of this material, I find that specimens of both *H. gigas* and *H. capax* occur. *H. pyramidalis* and *P. iphigenia* often co-occur with the *Hiscobeccus* species at the localities discussed in this study, as do other brachiopods first reported by Troedsson (1928), such as large strophomenoids. Therefore, the Kap Calhoun fauna closely matches other occurrences of the *Hiscobeccus* fauna within North Greenland, as it does with the typical *Hiscobeccus* faunas known from elsewhere in Laurentia (Bolton 1977; Jin and Zhan 2001, 2008; Macomber 1970).

Figure 3 show the stratigraphical range, as well as relative lateral distribution, of *H. gigas* and *H. capax* within the Morris Bugt Group. On the figure, the approximate thicknesses of the lithological units has been incorporated, to show more precisely at what stratigraphical level the studied *Hiscobeccus* specimens are collected from. Specimens, which are sampled within a measured section, are shown by a star on a grey line depicting the approximate length of the section. Specimens that are collected as a loose block, are indicated by a star, indicating the approximate level the sample was collected from. Troedsson's specimens are further denoted with a question mark, to indicate their uncertain stratigraphical position.

Within the GGU material, this study has identified *H. gigas* and *P. iphigenia* at a level approximately 115 m below the top of the Børglum River Formation, in a section measured and sampled at 'Vestervig', Børglum Elv, central Peary Land (GGU samples 184158 and 184159). In addition, *H. gigas* is found 145 m below the upper boundary (GGU sample 184155). In Washington Land, the oldest occurrence of *Hiscobeccus*, is that of *H. capax*. This occurrence (GGU sample 318166) is from the West side of Bessels Fjord, in northern Washington Land, in

beds assignable to the middle part of the Troedsson Cliff Member of the Kap Jackson Formation. In the Alegatsiaq Fjord area in west-central Washington Land, *H. gigas* is found in two separate samples, collected a few kilometres apart (J. Peel, pers. com. 2012): GGU 242009 collected from talus immediately below the top of the Cape Calhoun Formation and GGU 242047 collected from the same general level a few kilometres to the North. Further south, and also south of Troedsson's specimens from Kap Calhoun, *H. gigas* is found within GGU sample 206450, from Wright Bugt, in beds referable to the topmost beds of the Cape Calhoun Formation. Fifty metres below this level, in the lower part of the Cape Calhoun Formation, *H. pyramidalis*, *P. iphigenia* and large strophomenoid brachiopods are found in association with *Rostricellula* cf. *transversa* Cooper, 1956. This indicates that the lower part of this formation is no younger than of earliest Katian age. In addition, Troedsson (1928) noted an occurrence of *H. capax* from Wright Bugt, in beds probably assignable to the Troedsson Cliff Member of the Kap Jackson Formation.

In summary and as illustrated in Figure 3, the current study has found that the *Hiscobeccus* fauna occurs in a 200–300 m thick interval across the Franklinian Basin, ranging at least from the middle part of the Kap Jackson Formation and almost to the top of the Børglum River Formation. It is interesting to note that *H. capax* appears to be the older of the two studied *Hiscobeccus* species.

PALAEOECOLOGICAL IMPLICATIONS

The *Hiscobeccus* fauna is dependent on continuous limestone deposition (Jin 2001) and therefore usually associated with relatively shallow-water settings. In Centrum Sø, the *Hiscobeccus* fauna was also collected in carbonate facies. However, it differs from its Laurentian inland counterparts in that it is neither diverse, nor abundant, possibly due to its position on the edge of its preferred habitat. Although not as diverse, the Centrum Sø *Hiscobeccus* fauna resembles most closely to that in other marginal basins, such as the Anticosti Basin (Jin 2001; Jin and Zhan 2008) or Melville Peninsula (Bolton 1977). The sustained limestone deposition of the Franklinian Basin, and in particular the Børglum River facies, provided the needed environment for this fauna. Interfingering beds with local clusters of thin-shelled plectambonitoid brachiopods, such as *Thaerodonta*, indicate a deeper environment than would normally be associated with the *Hiscobeccus* fauna. This is supported by the presence of *Bimuria*? sp. (Fig. 9G).

Bimuria is a Late Ordovician genus found in deep-water environments, particularly in Laurentia and various peri-Laurentian terranes, such as the Midland Valley Terrane, Eastern Klamath Terrane and the Farewell Terrane (Cooper 1956; Mitchell 1977; Harper 1989; Potter 1990; Jin and Norford 1996; Rasmussen *et al.* 2012), although it is also known from Baltica (Jaanusson 1962; Cocks 2005), Kazakhstan (Nikitin and Popov 1984) and South China (Zhan and Cocks 1998).

Both the occurrence of thin-shelled plectambonitoids and *Bimuria*?, together with the unusually rare *Hiscobeccus* fauna, support that at least this part of the Børglum River limestone was deposited in deeper water environments on the Laurentian margin, in a transitional facies on the edge of the range of a typical shallow-water brachiopod fauna. This would indicate deposition within the lower part of the BA4 range of Boucot (1975, p. 49). Other groups typical of the Red River facies are abundant. Corals, for instance, are diverse and very abundant and indicate that despite being deep-water, deposition still took place within the photic zone throughout the succession. Cephalopods also show high diversity and abundance, indicating high levels of food to sustain a large number of highly specialized predators.

The environmental interpretation is also supported by sedimentological data. Often metre-scale beds are observed, densely packed with undisturbed *Thalassinoides* burrows and huge, *in situ*, tabulate coral colonies. This suggests a quiet depositional environment, not affected by storm events.

The brachiopods of the Børglum River Formation contrast markedly with the brachiopod faunas of the overlying, mostly Silurian, succession starting with the Turesø Formation. These are characterized by the dominance of monospecific pentameroid coquinas with great lateral distribution. In most of these coquinas only ventral valves are preserved and they are often fragmented. These coquinas were therefore deposited in shallower, turbulent environments. Pentameroids were also present in North Greenland during the late Katian (Rawtheyan). In the G. B. Schley Fjord region, in north-eastern Peary Land, *Proconchidium* occur in up to 150 m thick coquinas in a facies that is probably deeper than that interpreted for the Turesø Formation (Harper *et al.* 2007). However, this Upper Ordovician pentameroid-bearing facies was not deposited as deep as that found in the Centrum Sø area and these brachiopods reflect a different ecological setting.

LATE ORDOVICIAN BIOGEOGRAPHY AND ITS IMPACT ON GLOBAL DIVERSITY

The Ordovician period was characterized by probably the fastest and most sustained dispersal of continents within

the Phanerozoic Eon. As a result, the large increase in divergence zones caused a crustal upheaval that again resulted in what was likely a Phanerozoic sea level maximum (Hallam 1992; Nielsen 2004). Therefore, as the Ordovician progressed, provinciality became more and more pronounced. Consequently the brachiopod faunas became more endemic as distances between continents became larger and larger. Brachiopods, like many other benthic animal groups, diversified rapidly from the Darriwilian onwards, in what is now known as the Great Ordovician Biodiversification Event (Harper 2006). By the Katian the high sea level was almost mirrored by an equally distinctive peak in diversity. There has been much discussion as to what caused this radiation event, but the dispersal of continents and the high sea level seem to be the controlling agents. Recent studies on the succeeding End Ordovician mass extinctions indicate that γ-diversity largely controlled the global fluctuations in diversity (Rasmussen and Harper 2011*a*). Thus, the continents dispersal likely facilitated this high γ-diversity.

In Laurentia, endemic shallow-water faunas were particularly successful. Jin and Zhan (2001) demonstrated that the brachiopods of the Red River fauna are typical of the marked provincialism seen in Laurentia during the Katian. This was an interval in the Late Ordovician when provincialism became most pronounced (Jin 1996), which is emphasized by the presence of elements of this fauna occurring along the north-eastern margin of Laurentia. It also illustrates that even on the margins, not many of the invading taxa, present in the Hirnantian and Rhuddanian, had yet reached Laurentia (Jin and Copper 2008; Rasmussen and Harper 2011*a*, *b*).

From a biogeographical perspective, it is interesting to note that the Centrum Sø succession consists of massive bedded *Thalassinoides* facies that are associated with the occurrence of *Diceromyonia*. Following Jin *et al.* (in press), this facies and its associated key taxa, indicate that the Centrum Sø region was positioned within 10 degrees of the equator during the latest Katian.

The late Katian interval saw the greatest brachiopod diversity within the Ordovician Period (Harper *et al.* 2004; Rasmussen and Harper 2011*a*). Yet, the succession in the Centrum Sø area does not reflect this global trend. Instead, it is in line with the rest of the Laurentian margins, characterized by low values of α- and β-diversity; the main species ′pumps‘ were situated in the diverse habitats associated with mid-ocean island arc faunas (Rasmussen and Harper 2011*b*). The only exception is the Anticosti Basin, which by the latest Katian, was possibly already introduced to invading taxa from Baltica and the peri-Laurentian terranes and thus experienced increased species richness (Jin and Copper 2008). The Centrum Sø facies was deposited in too deep environments, thus explaining the lower brachiopod diversity. However, the mix of cosmopolitan, deep-water species with endemic, shallow-water species probably did increase the species richness compared with limestones of similar water depth elsewhere. This is arguably explained by the favourable climatic conditions due to the equatorial position of Centrum Sø at this time.

SYSTEMATIC NOTES ON THE CENTRUM SØ FAUNA, WITH COMPARATIVE REMARKS ON THE COEVAL FAUNA IN WASHINGTON LAND

In the following section, the better preserved specimens from the Centrum Sø section are described and, where possible, compared with coeval conspecific, usually better preserved specimens from Washington Land. This includes the original type material of Troedsson (1928), from which relevant specimens have been refigured for this study. In addition, material from previously undescribed localities in Washington Land have been used to compare and update some of the species names used by Troedsson (1928). Further, some taxa not described by Troedsson (1928), are also described here.

Abbreviations. All specimens are reposited at the Natural History Museum of Denmark, in Copenhagen. CS, brachiopod sample collected by the author during the Centrum Sø expedition in 2009; GGU, Field sample (collective lot of specimens) collected by the Geological Survey of Greenland, now GEUS; MGUH, Figured material from the type collection at the Geological Museum, Copenhagen.

Order RHYNCHONELLIDA Kuhn, 1949
Superfamily RHYNCHONELLOIDEA Gray, 1848
Family RHYNCHOTREMATIDAE Schuchert, 1913

Genus HISCOBECCUS Amsden and Sweet, 1983

Hiscobeccus gigas (Wang, 1949)
Figure 6A–T

1949 *Lepidocyclus gigas* Wang, p. 16, pl. 10D.
1957 *Lepidocyclus perlamellosa* (*pars*) Ross (*non* Whitfield, 1878), p. 477, pl. 39, figs 1–5.
1957 *Lepidocyclus capax* Ross (*non* Conrad, 1842), p. 477, pl. 39, figs 21, 24–27.
1970 *Lepidocyclus gigas* Wang; Macomber, p. 447, pl. 80, figs 1–17.
1981 *Lepidocyclus capax*; Bolton (*non* Conrad, 1842), pl. 3, fig. 1.
1989 *Lepidocyclus gigas* Wang; Jin, p. 65, pl. 9, figs 13–22; pl. 10, figs 1–5, pl. 26, figs 4, 5.

1997 *Hiscobeccus gigas* (Wang); Jin, Caldwell and Norford, p. 39, pl. 29, figs 2–14.

Material. One ventral valve (CS0926) and one conjoined specimen (MGUH 30220).

Description. Medium to large, sub-circular shell, with maximum width between mid-valve and anterior third of valve length. Dorsi-biconvex, unisulcate. Ornament of simple, sub-rounded and relatively low costae, numbering to approximately 18. Dorsal fold with four costae and ventral sulcus with three costae. Entire shell lamellose. Ventral valve weakly convex with pronounced sulcus, forming truncated, tongue-like structure. Dorsal valve moderately convex with moderately elevated fold, and seven to eight costae on each side of the fold. Ventral valve possesses a high, curved palintrope which extends posteriorly as an incurved beak. Delthyrium low, wide. Dorsal beak strongly incurved and, thus, hidden in the ventral delthyrium. Seen laterally the commissural plane bends ventrally at a characteristic obtuse angle just anterior to the umbonal zone. Interiors not examined. Dorsal interior possibly with median septum.

Discussion. Although it is not possible to discern whether the Centrum Sø specimens have dental plates, they do seem to lack a deltidial cover. On this basis, the material is referred to *Hiscobeccus*. This generic assignment is also based on the nature of the costae, the incurved beak and the strongly incurved dorsal umbo that buries into the delthyrial cavity. In dorsal view, the ventral palintrope and beak protrude beyond the posterior margin of the dorsal valve in a unique way compared with other genera that might easily be confused with *Hiscobeccus* (e.g. *Gnamptorhynchos*, *Hypsiptycha*, *Lepdidocyclus*, *Rhynchotrema*, *Rostricellula* and *Stegerhynchus*). These, like *Hiscobeccus*, are biconvex and coarsely costate. Jin *et al.* (1989, 1997) and Jin and Zhan (2001) showed that the ventral palintrope in *Hiscobeccus* is much larger and wider, extending almost to the cardinal extremities. This feature is not observed in any of the related genera, which mostly possess a narrow palintrope on an erect beak that is not as strongly incurved as in *Hiscobeccus*.

Some features in the present specimens from Centrum Sø indicate that they may represent an entirely new species. However, the best specimens are strongly deformed; therefore, a new species cannot be erected with confidence. The imbricate shell where coarse growth laminae are distributed along the entire shell is typical of the upper Katian *H. gigas* (Wang, 1949). *Hiscobeccus capax* (Conrad, 1842), which, as already mentioned, is known from elsewhere within the Franklinian Basin, is too globose, possessing a strongly convex dorsal valve as opposed to the Centrum Sø species (compare Figs 6 and 7). Further, as noted by Jin *et al.* (1997), it has a much higher anterior tongue projecting almost perpendicular to the commissural plane. *Hiscobeccus kananaskia* Wilson, 1926 is more similar to *H. capax* in outline and profile, but possesses weaker growth lamellae. *Hiscobeccus mackenziensis* Jin and Norford, 1996 is similar to *H. kananaskia*, but less transverse with nearly isometric shell. Thus, the size of the Centrum Sø specimen is in the absolute maximum range of *H. kananaskia* and *H. mackenziensis*, as it is with *H. capax*. The extremely rare *H. rowleyi* (Foerste, 1920) is also more similar to *H. capax*. One of the largest species, *H. windermeris* (Wilson, 1926), is also more globose than the Centrum Sø specimens (Jin *et al.* 1989). Therefore, the Centrum Sø specimens most resemble *H. gigas*.

The better preserved specimens from Washington Land further support the generic assignment to *Hiscobeccus* as they lack dental plates in a well preserved ventral valve (Fig. 6X), and the deltidial plates in a conjoined specimen (Fig. 6Q). In addition, the thickness/width ratios of the GGU specimens from the Washington Land localities show that at least two different species of *Hiscobeccus* occur in North Greenland; some specimens are notably wider and flatter, whereas others are narrower and more globose. Thus, following Jin *et al.* (1997), the former are assigned to *H. gigas*, whereas the latter are referred to *H. capax*. The globose profile is noticeable in the convexity of the ventral valve. The ventral valve in *H. gigas* is shallower than in *H. capax*, which in some specimens almost appear equi-biconvex. Table 1 lists the measured parameters of the studied *Hiscobeccus* specimens.

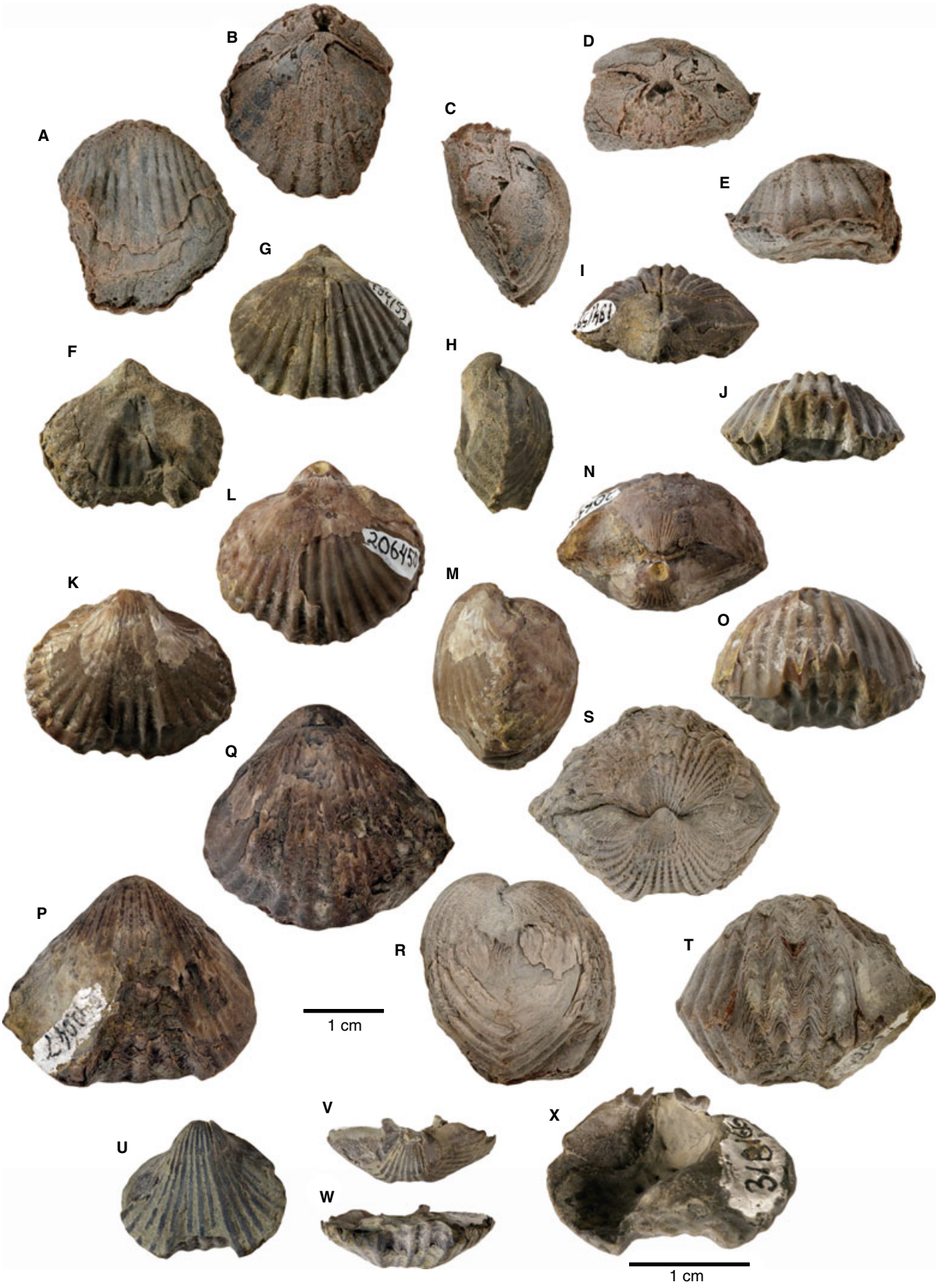
Distribution. Upper Member, Børglum River Formation of Kronprins Christian Land and Peary Land, as well as upper Cape Calhoun Formation, Washington Land, North Greenland (Troedsson 1928; this study); Vaureal Formation, Anticosti Island, eastern Canada (Jin and Zhan 2001); the Caution and Chasm Creek formations of the Hudson Bay Basin (Jin *et al.* 1997); from the Williston Basin the species is known from the Gunn and Penitentiary members of the Stony Mountain Formation in southern Manitoba, Canada and from the Bighorn Formation of Wyoming, USA (Jin and Zhan 2001).

Order ORTHIDA Schuchert and Cooper, 1932
Superfamily ORTHOIDEA Woodward, 1852
Family PLAESIOMYIDAE Schuchert, 1913

Genus PLAESIOMYS Hall and Clarke, 1892

Plaesiomys cf. *iphigenia* (Billings, 1865)
Figure 8C–N

1865 *Orthis iphigenia* Billings, p. 133, text-fig. 110.
1892 *Plaesiomys iphigenia* (Billings); Hall and Clarke, p. 222.
1897 *Dinorthis iphigenia* (Billings); Schuchert, p. 215.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1915 *Dinorthis iphigenia* (Billings); Bassler, p. 443.
1928 *Dinorthis iphigenia* (Billings); Troedsson, p. 86, pl. 21, figs 1–5.

Material. One conjoined specimen (MGUH 30227).

Discussion. Only the posterior part of a single specimen is available for study. It is characterized by a small, to medium-sized shell, plano-convex profile with obtuse cardinal extremities. Ventral interarea low, apsacline and slightly curved; delthyrium open. Dorsal interarea low, anacline to almost orthocline. Ornamention multicostellate, with bifurcation originating in the umbonal zone.

This species is assigned to *Plaesiomys* based solely on the appearance of the ornamentation, which bifurcates and is multicostellate contrary to the costate ornamentation of *Dinorthis*. According to Jin and Zhan (2001), this is one of the main features differentiating in the exterior of these two genera.

Distribution. Whereas the genus is more widely known from Late Ordovician rocks of the USA and Canada, this species has only previously been reported from the Cape Calhoun Formation of Washington Land in North Greenland (Troedsson 1928; this study). The current study also includes a specimen from the Troedsson Cliff Member of the Kap Jackson Formation, and a specimen from the upper member of the Børglum River Formation at Børglum Elv, central Peary Land (GGU 184158). This latter occurrence is associated with an occurrence of *H. gigas*.

Family HESPERORTHIDAE Schuchert and Cooper, 1931

Genus HESPERORTHIS Schuchert and Cooper, 1931

Hesperorthis cf. *pyramidalis* (Twenhofel, 1928)
Figure 8O–V

1928 *Orthis davidsoni* var. *pyramidalis* Twenhofel, p. 174, pl. 15, figs 4–6.
1928 *Orthis tricenaria* Conrad; Troedsson, p. 83, pl. 20, figs 5–8.
1970 *Hesperorthis* cf. *pyramidalis* (Twenhofel); Macomber, p. 427, pl. 75, figs 1–7.
2008 *Hesperorthis pyramidalis* (Twenhofel); Jin and Zhan, pp. 11–12, figs 4–5, pl. 1, figs 1–19.

Material. One conjoined specimen (MGUH 30229, selected within GGU sample 242047)).

Description. Shell medium-sized with strongly ventri-biconvex pyramidal profile, and subcircular to rectangular outline. Maximum width at cardinal extremities, which are at right angles or slightly obtuse. Ventral valve convex posteriorly with a strongly pyramidal profile. Umbo positioned slightly beyond hinge line. Dorsal valve almost flat towards anterior two-thirds of shell, but becoming strongly convex towards the hinge line. Ornament of approximately 30 simple, well defined costae with a few bifurcating costellae. Growth laminae developed towards anterior margin, almost giving the shells a filate appearance. Anterior commissure rectimarginate. Ventral interarea very high, strongly apsacline to nearly catacline. Interarea planar except for slight curvature apically. Delthyrium high, narrow, covered apically by incipient pseudodeltidium. Dorsal interarea low, flat and anacline with wide notothyrium almost entirely covered by chilidium. No interiors collected.

Discussion. The specimen described here is almost certainly conspecific with *H. pyramidalis* (Twenhofel, 1928) from the Prinsta Member of the Ellis Bay Formation of Anticosti Island (Jin and Zhan 2008). Although no interiors are available for study, this identification is based on the very characteristic catacline interarea, which is otherwise unusual for this genus, as well as the size, general outline, profile and high number of ribs (almost 30).

This species is found within the Troedsson Cliff Member of the Kap Jackson Formation, the Cap Calhoun Formation, and possibly the lower part of the Newman Bugt Member of the overlying Alegatsiag Fjord Formation. Troedsson's type material of *H. tricenaria* Conrad, 1843, from Kap Calhoun, is here also referred to *H. pyramidalis*, even though the figured specimen (Fig. 8T) has a

FIG. 6. A–T, *Hiscobeccus gigas* (Wang, 1949). A–E, conjoined specimen (MGUH 30220) in ventral, dorsal, lateral, posterior and anterior views. Note that the ventral valve is notably deformed. Børglum River Formation, upper member, south of head of Sæfaxi Elv and its conjunction to Centrum Sø, Kronprins Christian Land, eastern North Greenland; F–J, conjoined specimen (MGUH 30221, selected within GGU sample 184159) in ventral, dorsal, lateral, posterior and anterior views. Note that the ventral valve is partially compressed in this specimen. Upper member, Børglum River Formation, Vestervig, Børglum Elv, central Peary Land, central North Greenland; K–O, conjoined specimen (MGUH 30222, selected within GGU sample 206450) in ventral, dorsal, lateral, posterior and anterior views. Head of Wright Bugt, southern Washington Land, western North Greenland; P–T, conjoined specimen (MGUH 30223, selected within GGU sample 242047) in ventral, dorsal, lateral, posterior and anterior views. U–X, *Hiscobeccus capax* (Conrad, 1842), disarticulated ventral valve (MGUH 30224, selected within GGU sample 318166) in ventral, posterior, anterior and postero-dorsal (enlarged to show the lack of dental plates) views. Middle part of Troedsson Cliff Member, Kap Jackson Formation, west side of Bessels Fjord, northern Washington Land, western North Greenland.

TABLE 1. Measured parameters on the *Hiscobeccus* material discussed in the text.

Material	Width (mm)	Length (mm)	Thickness (mm)	Thickness/Width
Troedsson's type specimens				
Kap Calhoun, southern Washington Land				
MGUH 2962 (conjoined)	25.11	23.99	21.75	0.87 (= *capax* range*)
MGUH 2963 (conjoined)	22.88	22.29	19.95	0.89 (= *capax* range*)
MGUH 2964 (conjoined)	31.74	32.47	27.09	0.85 (= *capax* range*)
This study				
Centrum Sø, southern Kronprins Christian Land				
CS0909 (conjoined)	23.76	23.89	N/A	N/A
CS0926 (ventral valve)	20.74†	22.16	N/A	N/A
GGU specimens				
Vestervig, Børglum Elv, central Peary Land				
GGU 184155 (conjoined)	9.25	8.72	5.08	0.55 (= *gigas* range*)
GGU 184158 (conjoined)	31.46	24.97†	22.76	0.72 (= *gigas* range*)
GGU 184158 (conjoined)	31.40†	26.67	21.74	0.69 (= *gigas* range*)
GGU 184159 (conjoined)	30.56†	25.89	N/A	N/A
GGU 184159 (conjoined)	22.69	19.58	N/A	N/A
Wright Bugt, southern Washington Land				
GGU 206450 (conjoined)	25.79	23.54	16.92	0.65 (= *gigas* range*)
Alegatsiaq Fjord, central Washington Land				
GGU 242009 (conjoined)	21.26	21.84	18.40	0.87 (= *capax* range*)
GGU 242047 (conjoined)	31.46	28.19	23.87	0.76 (= *gigas* range*)
Bessels Fjord, northern Washington Land				
GGU 318166 (conjoined)	21.65	20.42	16.81	0.78 (= capax range*)
GGU 318166 (conjoined)	18.70	20.26	21.40	1.14 (= *capax* range*)
GGU 318166 (ventral valve)	20.49	17.70	6.58	N/A

*Measured ranges are according to Jin *et al.* (1997). †Estimated.

wider outline and acute cardinal extremities. The assignment to *H. pyramidalis* is based on the much larger size, a curved, strongly apsacline ventral interarea (Fig. 8U–V), and also the fact that all of the other figured specimens within Troedsson's material (pl. 20, figs 5a–8b) possess slightly obtuse cardinal extremities. All specimens show growth lamellae presenting a slightly filate appearance. This is also known from other species in the literature (Macomber 1970; Jin and Zhan 2008).

Distribution. Apart from the middle to upper Katian occurrences in Washington Land described by Troedsson (1928) and here, this species has also been reported from the upper Katian Upper Bighorn Dolomite of Wyoming (Macomber 1970) and from the middle Hirnantian Prinsta Member of the Ellis Bay Formation, Anticosti Island (Jin and Zhan 2008).

Superfamily DALMANELLOIDEA Schuchert, 1913
Family PLATYORTHIDAE Harper, Boucot and Walmsley, 1969

Genus DICEROMYONIA Wang, 1949

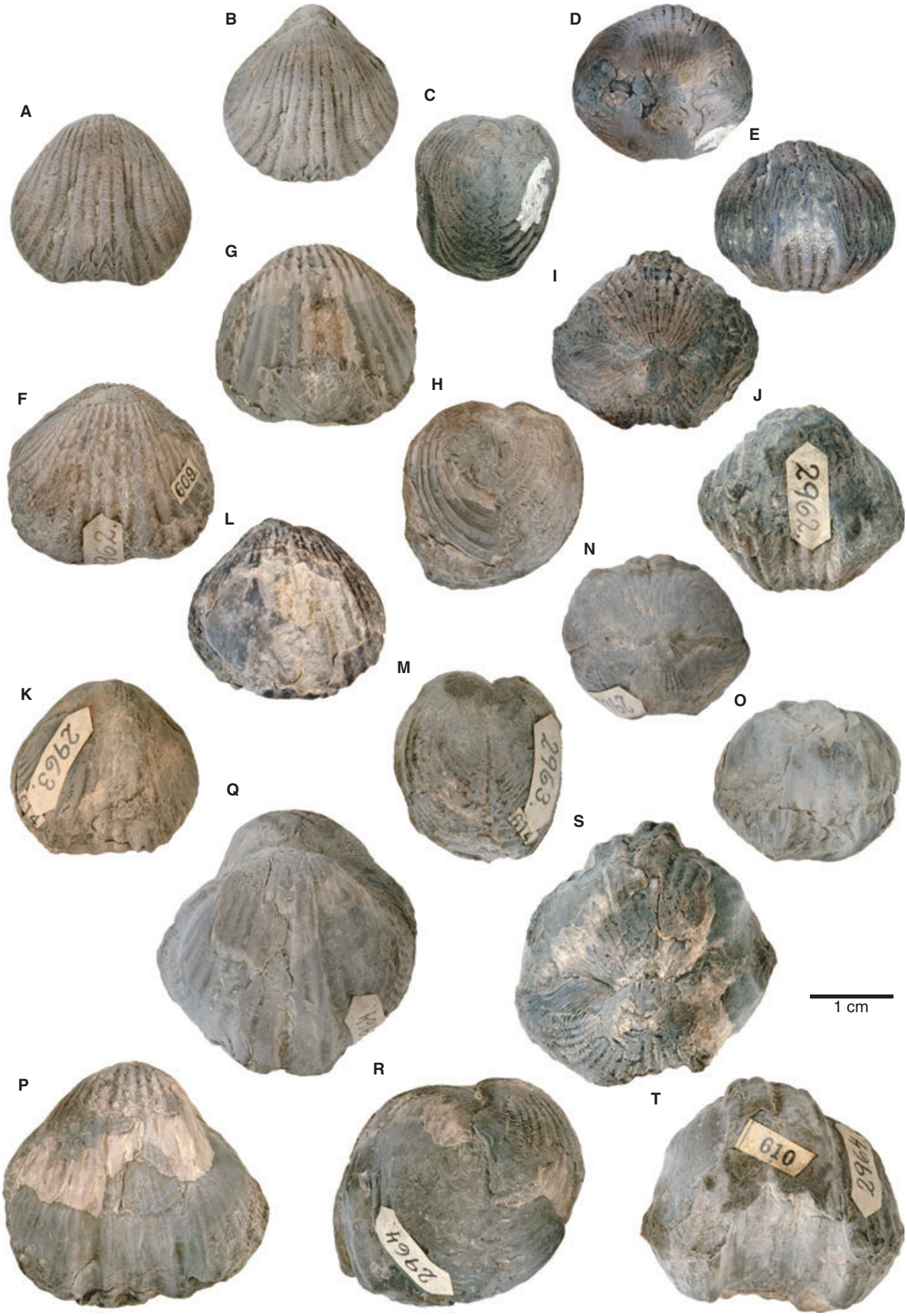
Diceromyonia sp.
Figure 8A–B

Material. Two dorsal valves (CS0914; MGUH 30226).

Description. Valves medium to large, with moderately convex dorsal profile and semi-oval outline. Possibly with weak sulcus. Maximum width at mid-valve. Ornamentation of simple costellae. Interarea minute, possibly missing.

Interiors with elevated notothyrial platform bounded by dominant, widely divergent brachiophores. Cardinal process not pre-

FIG. 7. *Hiscobeccus capax* (Conrad, 1842) from Washington Land, North Greenland. A–E, conjoined specimen (MGUH 30225, selected within GGU sample 242009), Cape Calhoun Formation, Alegatsiaq Fjord, SW Washington Land, North Greenland, in ventral, dorsal, lateral, posterior and anterior views; F–T, Troedsson's (1928) type specimens; F–J, conjoined specimen (MGUH 2962) in ventral, dorsal, lateral, posterior and anterior views; K–O, conjoined specimen (MGUH 2963) in ventral, dorsal, lateral, posterior and anterior views; P–T, conjoined specimen (MGUH 2964) in ventral, dorsal, lateral, posterior and anterior views. All 'Cape Calhoun Formation' *sensu* Troedsson (1928), Kap Calhoun, SW Washington Land, North Greenland. Note that this species is in general less wide and has a more globose profile than *H. gigas* (Fig. 6).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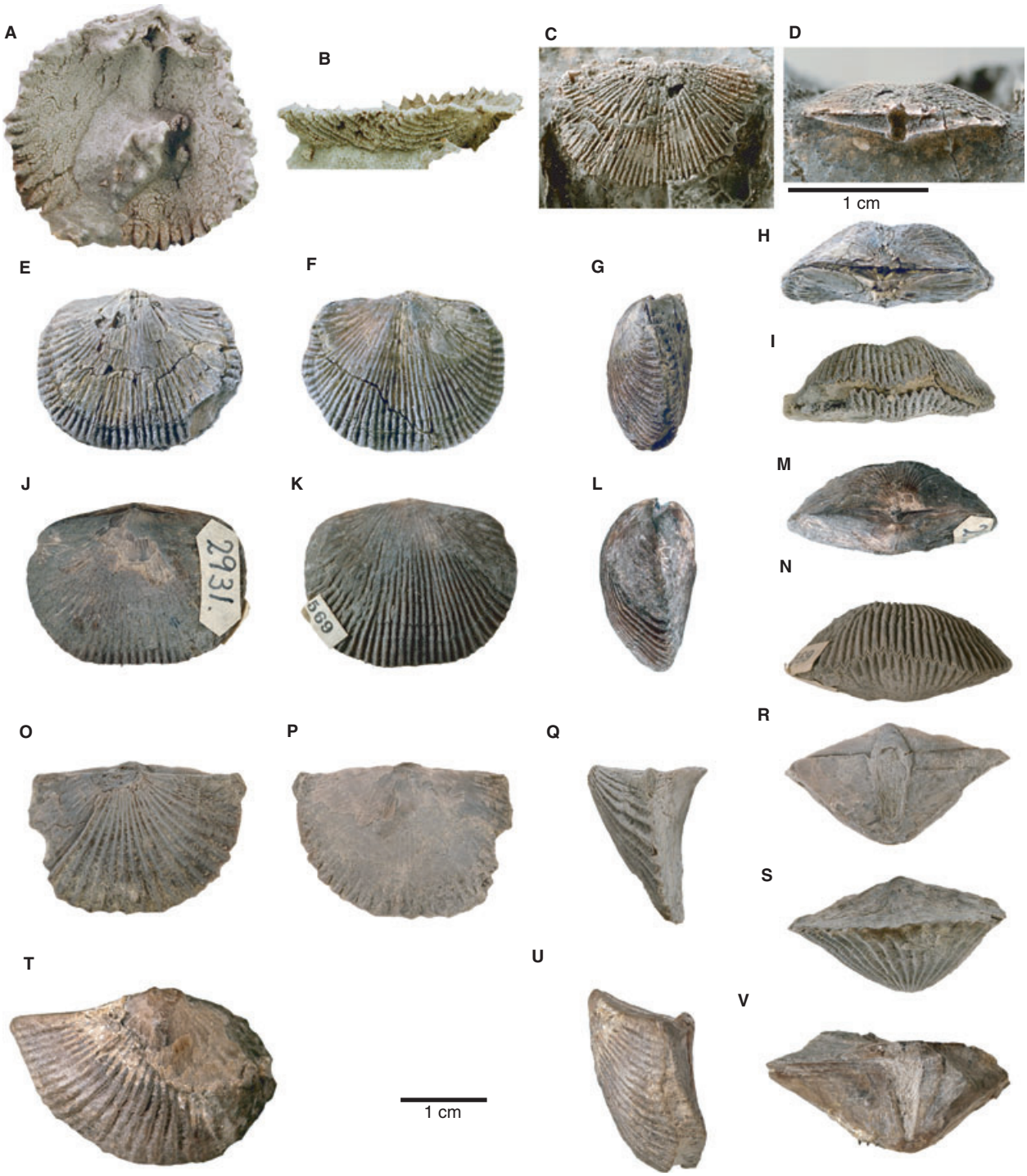
served. Anteriorly, the notothyrial platform forms a wide, low dorsal median septum that extends to mid-valve.

Discussion. The specimens collected are referred to *Diceromyonia* based on the semi-oval outline, obtuse cardinal extremities and a possibly very short dorsal interarea. As the cardinal process is missing, this genus may be difficult to differentiate from other dalmanellids. However, the above-mentioned characteristics in combination with the configuration of the dorsal median septum, separates *Diceromyonia* from, for instance, *Onniella* and *Paucicrura*.

Several species are assigned to *Diceromyonia*. *D. subrotundata* Wang, 1949 and *D. crassa* Howe, 1965 are multicostellate and therefore different from the present



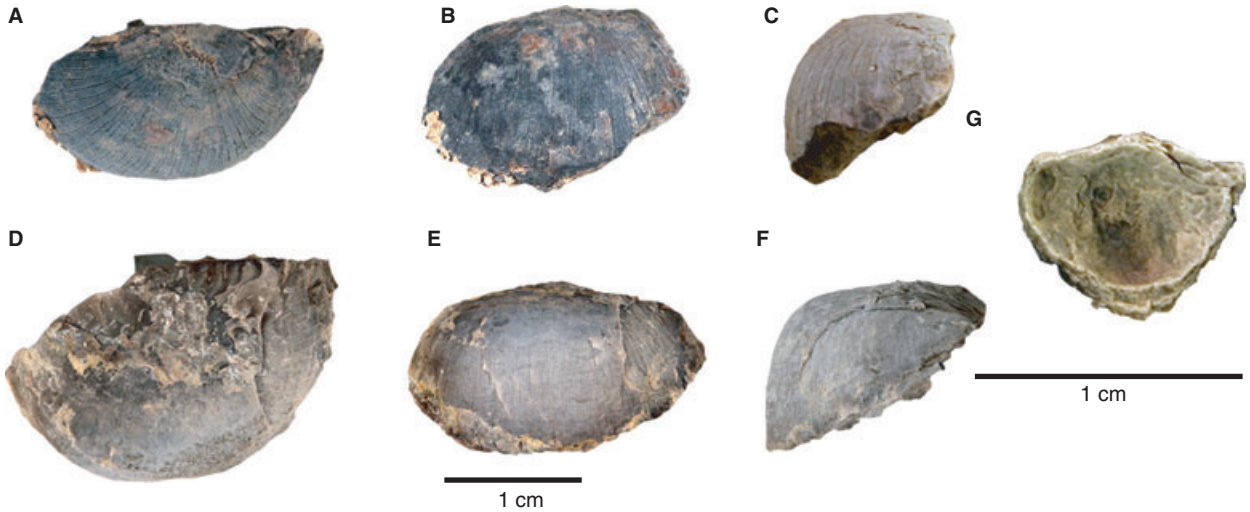


FIG. 9. Selected plectambonitoid species associated with the *Hiscobeccus* faunas of North Greenland. A–C, *Thaerodonta* sp., dorsal valve (MGUH 30230) in external, anterior and lateral views. Børglum River Formation, upper member, Centrum Sø locality, Kronprins Christian Land, eastern North Greenland. D–F, *Thaerodonta* sp., dorsal valve (MGUH 30231, selected within GGU sample 318166) in external, anterior and lateral views. Troedsson Cliff Member, Kap Jackson Formation, Bessels Fjord, northern Washington Land, North Greenland. G, *Bimuria*? sp., interior of ventral valve (MGUH 30232). Børglum River Formation, upper member, Centrum Sø locality, Kronprins Christian Land, eastern North Greenland.

specimens. According to Jin and Zhan (2001), separation between *D. storeya* (Okulitch, 1943), *D. ignota* (Sardeson, 1897) and *D. tersa* (Sardeson, 1892) can only be made by comparing the ventral muscle field. Therefore, with only two dorsal valves collected, further comparisons are impossible this genus is best left under open nomenclature.

Distribution. Besides the occurrence from the Børglum River Formation in eastern North Greenland, the genus is known from the Bad Cache Rapids Group and Churchill River Group of the Hudson Bay Basin (Jin *et al.* 1997), the Red River and Stony Mountain formations of southern Manitoba (Jin and Zhan 2001), upper Maquoketa, Fernvale and Viola formations of Iowa, Illinois, Missouri and Oklahoma (Amsden 1974; Wang 1949; Howe 1988), upper Bighorn Dolomite, Wyoming (Macomber 1970) and Ely Springs Dolomite of Nevada (Howe and Reso 1967).

Order STROPHOMENIDA Öpik, 1934
Superfamily PLECTAMBONITOIDEA Jones, 1928
Family SOWERBYELLIDAE Öpik, 1930

Genus THAERODONTA Wang, 1949

Thaerodonta sp.
Figure 9A–F

Material. One dorsal valve (MGUH 30230).

Description. Shell large, convexo-concave, transverse with a subcircular outline. Maximum width at cardinal extremities. Ornamentation mostly preserved as mould. Some original shell material at the most posterior part of the valve display strong rugation. The rest of the specimen show a distinctive ornament

FIG. 8. Orthid brachiopods associated with the *Hiscobeccus* faunas of North Greenland. A–B, *Diceromyonia* sp., interior and lateral views of a dorsal valve (MGUH 30226). Centrum Sø locality, Kronprins Christian Land, North Greenland. C–D, *Plaesiomys* cf. *iphigenia* (Billings, 1865), conjoined specimen (MGUH 30227), in dorsal and posterior views. Børglum River Formation, upper member, Centrum Sø locality, Kronprins Christian Land, North Greenland. E–I, *P.* cf. *iphigenia* (Billings, 1865), conjoined specimen (MGUH 30228, selected within GGU sample 242009) in ventral, dorsal, lateral, posterior and anterior views. Note the paraplicate anterior commissure in I, compared to the slightly uniplicate in N. This placation is caused by subsequent deformation. Cape Calhoun Formation, Alegatsiaq Fjord, central Washington Land, North Greenland. J–N, *P. iphigenia* (Billings, 1865), conjoined specimen selected among Troedsson's type material (MGUH 2931) in ventral, dorsal, lateral, posterior and anterior views. 'Cape Calhoun Formation' *sensu* Troedsson (1928), Kap Calhoun, SW Washington Land, North Greenland. O–S, *Hesperorthis* cf. *pyramidalis* (Twenhofel, 1928), conjoined specimen (MGUH 30229, selected within GGU sample 242047), in ventral, dorsal, lateral, posterior and anterior views. Note the nearly catacline ventral interarea in Q. Cape Calhoun Formation, Alegatsiaq Fjord, central Washington Land, North Greenland. T–V, *H.* cf. *pyramidalis* (Twenhofel, 1928), conjoined specimen (MGUH 2921), in ventral, lateral and posterior views (refigured specimen from Troedsson 1928, plate 20, Fig. 6). 'Cape Calhoun Formation' *sensu* Troedsson (1928), Kap Calhoun, SW Washington Land, North Greenland.

of deep furrows interspaced by 3–6 more vaguely impressed furrows (counted at the anterior margin). Radial ornamentation interrupted by very faintly impressed, closely spaced, growth lines through entire valve length. No interiors available for study.

Discussion. This specimen is referred to *Thaerodonta* based on the general outline and profile, as well as the ornament. However, the hinge line, is not well preserved. Thus, hinge-line denticles, which are a diagnostic feature of this genus, are not observed. The better preserved Washington Land material from Alegatsiag Fjord further includes several specimens that can be referred to *Thaerodonta*, supporting the occurrence within the Centrum Sø area (Fig. 9D–F).

Distribution. This genus is widespread in Katian rocks of Laurentia, i.e. Howe (1965, 1988), Macomber (1970), Amsden (1974), Jin *et al.* (1997) and Jin and Zhan (2001). The genus has also been reported from the lower Sandbian of the Midland Valley Terrane (Candela 2003), as well as the middle Katian–Hirnantian of Baltica (Cocks 1988, 2005).

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