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Cambrian–Silurian stratigraphy of Børglum Elv, Peary Land, eastern North Greenland

by

Robert L. Christie and John S. Peel

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Cambrian–Silurian stratigraphy of Børglum Elv, Peary Land, eastern North Greenland

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Robert L. Christie and John S. Peel

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Abstract

A sequence of Lower Palaeozoic carbonate and clastic rocks is described from Børglum Elv, Peary Land, eastern North Greenland, and briefly compared to Lower Palaeozoic sections elsewhere in Greenland and in Spitsbergen. Lower Cambrian clastic rocks of the Buen Formation are followed by dolomite of the Lower Cambrian Brønlund Fjord Formation (125 m). Succeeding dolomite and dolomitic limestone of the Wandel Valley Formation (320 m) of Early to Middle Ordovician age are overlain by limestone of the Børglum River Formation (430 m) of Middle to Late Ordovician age. Un-named Early Silurian dolomite and limestone formations (150 m and 320 m respectively) are followed by an un-named Middle Silurian black shale formation (*c.* 100 m) and at least 800 m of a late Middle Silurian and younger un-named flysch formation. Carbonate mounds, originating in the highest beds of the un-named Silurian limestone formation, occupy stratigraphic levels through the overlying black shale formation and into the flysch formation.

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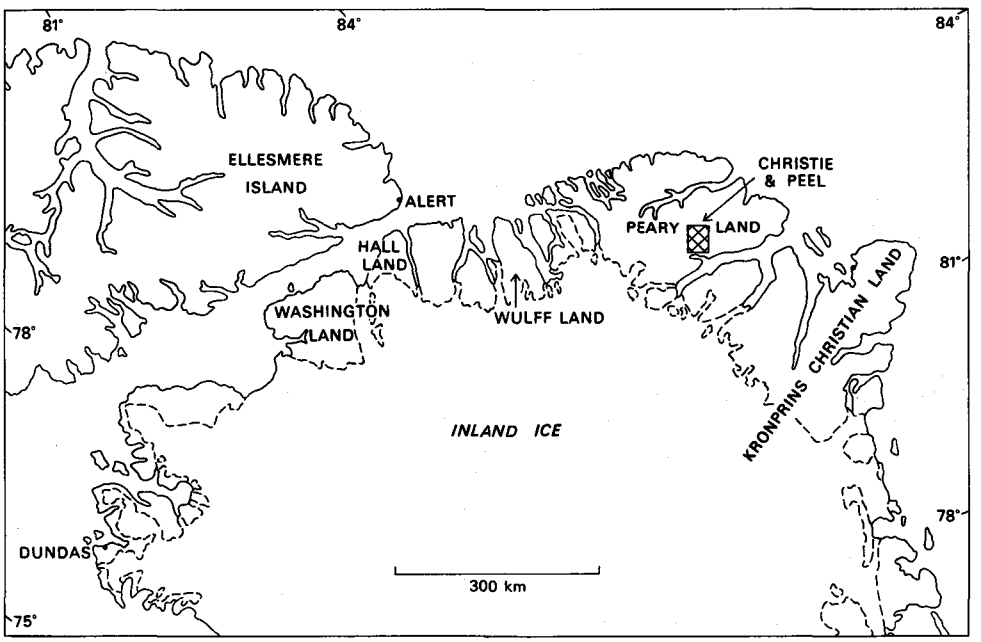

Fig. 1. Northern Greenland and adjacent arctic Canada showing location of the Børglum Elv report area.

INTRODUCTION

The Lower Palaeozoic sequence of the Børglum Elv region of Peary Land (figs 1–3) consists of some 3000 m of early Cambrian to late Silurian carbonate and clastic sediments. The deposits form part of an extensive shelf zone stretching east–west across North Greenland which occupies an intermediate position between the stable craton to the south, and the North Greenland Geosyncline to the north (Dawes, 1971, 1976a; Dawes & Peel, in press).

Southern Peary Land is one of North Greenland's more accessible, and consequently geologically better known, areas. The Lower Palaeozoic is known from early work by Koch (1923) and Troelsen (1949a, 1956). More recently Jepsen (1971) has proposed formal stratigraphy for late Proterozoic to earliest Cambrian beds.

The aim of the fieldwork during the summer of 1974 was to compile a geological reference section through the Lower Palaeozoic sequence of southern Peary Land, as exposed in the valley of Børglum Elv, in preparation for a future regional mapping programme.The project was designed to complement the work of Jepsen (1971) by continuing section description from the early Cambrian, through Ordovician formations previously described by Troelsen (1949a) and into overlying, undescribed Silurian carbonates and clastics (subsequently partly described by Mayr, 1976).

A preliminary description of the section was given by Peel & Christie (1975), while Christie (1975) also discussed aspects of the glacial history.

The Børglum Elv region of southern Peary Land consists of several plateaus rising step-wise towards the north. The prominent cliffs of Buen and Pyramideplateau (fig. 2), immediately north of Jørgen Brønlund Fjord, rise to some 700 m and much of the carbonate terrain in the southern part of the study area, with its deeply incised drainage system, has a similar altitude. The clastic sediments exposed in the northern part of the region form rounded, distinctively terraced hills which rise to several hundred metres above the more southerly carbonate areas.

Map coverage of the entire area is provided by the U.S. Army Map Service 1:250 000 map series. However, errors in topographic representation and altitude in these maps may be considerable. The area immediately around Jørgen Brønlund Fjord is covered by an excellent Geodetic Institute (Copenhagen) 1:50 000 map while the same institute has also prepared 1:100 000 uncontoured photomosaics covering much of Peary Land. A series of four Army Map Service 1:20 000 maps of the Jørgen Brønlund Fjord area is also available.

The topographic base for figs 3 and 4 is taken from the 1:100 000 photomosaics, although contour lines in fig. 3 are sketched after the AMS map series. It should be stressed that these contour lines are little more than form lines drawn to give some representation of relief. Corrected heights on Buen and Pyramideplateau are drawn from the 1:50 000 Jørgen Brønlund Fjord sheet.

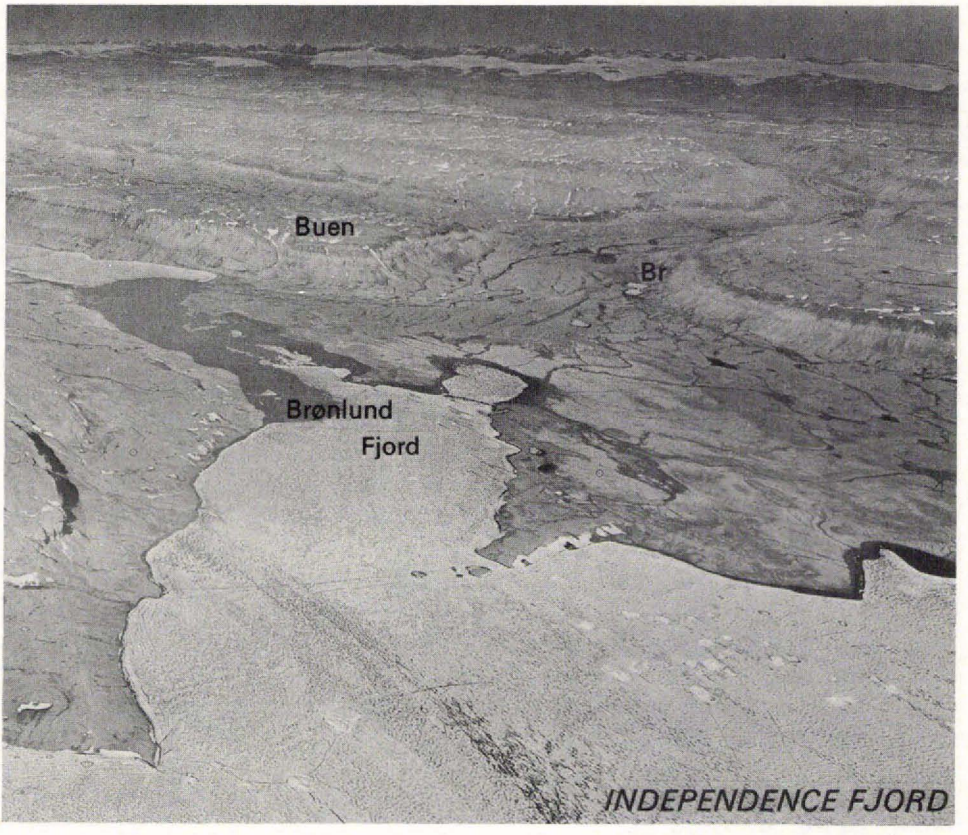

Fig. 2. The Børglum Elv region of southern Peary Land, oblique aerial photograph looking north-west. Børglum Elv flows from Heinrich Wild Iskappe in the middle distance in an increasingly deepened valley cut into the plateau surface before discharging into Jørgen Brøndlund Fjord. Mountains of northern Peary Land form the horizon. The conspicuous white and dark stripe of the lower and middle members of the Wandel Valley Formation (see also fig. 10) is particularly evident on the southern edge of the plateau north of Buen, and east of Brillesø (Br). (Copyright Geodætisk Institut, Danmark).

Previous work

A full discussion of previous geological work in Peary Land and North Greenland in general has been given by Dawes (1971), Jepsen (1971) and Troelsen (1949a).

Koch (1923) briefly described the sequence in southern Peary Land, in the vicinity of Jørgen Brønlund Fjord, referring 1000 m of limestones (the Brønlund Fjord Formation, Wandel Valley Formation and Børglum River Formation of current usage) to the Ordovician (fig. 5). Blocks of sandy shale with monograptids, probably equivalent to the here un-named Silurian flysch formation, were located in river gravels to the east.

The most detailed previous studies of the Lower Palaeozoic of southern Peary Land were made by J. C. Troelsen who visited the area briefly during the summer of 1947, and

over-wintered from 1948 to 1949 as a member of the Danish Peary Land Expedition 1947–1950. His principal account of the geology (Troelsen, 1949a) was based only on the two week visit of 1947 during which he was unable to travel far from the base camp on the south side of Jørgen Brønlund Fjord. Additional comments were given later by Troelsen (1949b, 1950, 1951, 1956) and by Fränkl (1956). Troelsen's field note books (kindly presented to GGU in 1974) and collections contain a significant amount of unpublished, additional material. Remarks on some of this were published by Peel *et al.* (1974) while Poulsen (1974) and Yochelson & Peel (1975) have described some of the fossils collected by Troelsen in Peary Land.

Troelsen (1949a) divided Koch's (1923) Ordovician limestone into three formations, the Brønlund Fjord Dolomite, Wandel Valley Limestone and Børglum River Limestone. He suggested a Cambrian age for the Brønlund Fjord Dolomite, an Early Ordovician age for the Wandel Valley Limestone, and a Middle to Late Ordovician age for the Børglum River Limestone.

Late Proterozoic to early Cambrian clastic and carbonate rocks below the Brønlund Fjord Formation, referred to the Thule group by Troelsen (1949a) and reinterpreted by Cowie (1971), were described more fully by Jepsen (1971), who also established formal stratigraphic nomenclature.

Geologists of Greenarctic Consortium carried out geological work in northern Greenland between 1969 and 1973 in the course of commercial petroleum and mineral exploration, although little of this work has been published. Dawes (1976a) included information from company reports while trilobites from the Lower Cambrian Buen Formation kindly presented to GGU by Greenarctic Consortium were described by Poulsen (1974). Mayr (1976) made brief reference to some aspects of regional stratigraphy in describing the structure of Middle Silurian carbonate mounds from Peary Land.

STRATIGRAPHY

General accounts of the regional geological structure and stratigraphy of North Greenland, including Peary Land, are given by Dawes (1976a) and Dawes & Peel (in press).

About 2500 m of early Cambrian – late Silurian strata were studied in 1974 in the course of measuring nine sections (fig. 5). Earlier Cambrian deposits of the lower Buen Formation and Portfjeld Formation described by Jepsen (1971) were briefly examined. A limited amount of geological mapping to either side of Børglum Elv was undertaken using air photographs as field base maps (fig. 4).

Cambrian and Ordovician units described in previous publications (Troelsen, 1949a; Jepsen, 1971) account for about 1000 m of the section (figs 4–6). Overlying Silurian (?) dolomites (150 m), Silurian limestones (*c.* 320 m), Silurian black shales (*c.* 100 m) and a Silurian flysch sequence (at least 800 m) are described here but not named.

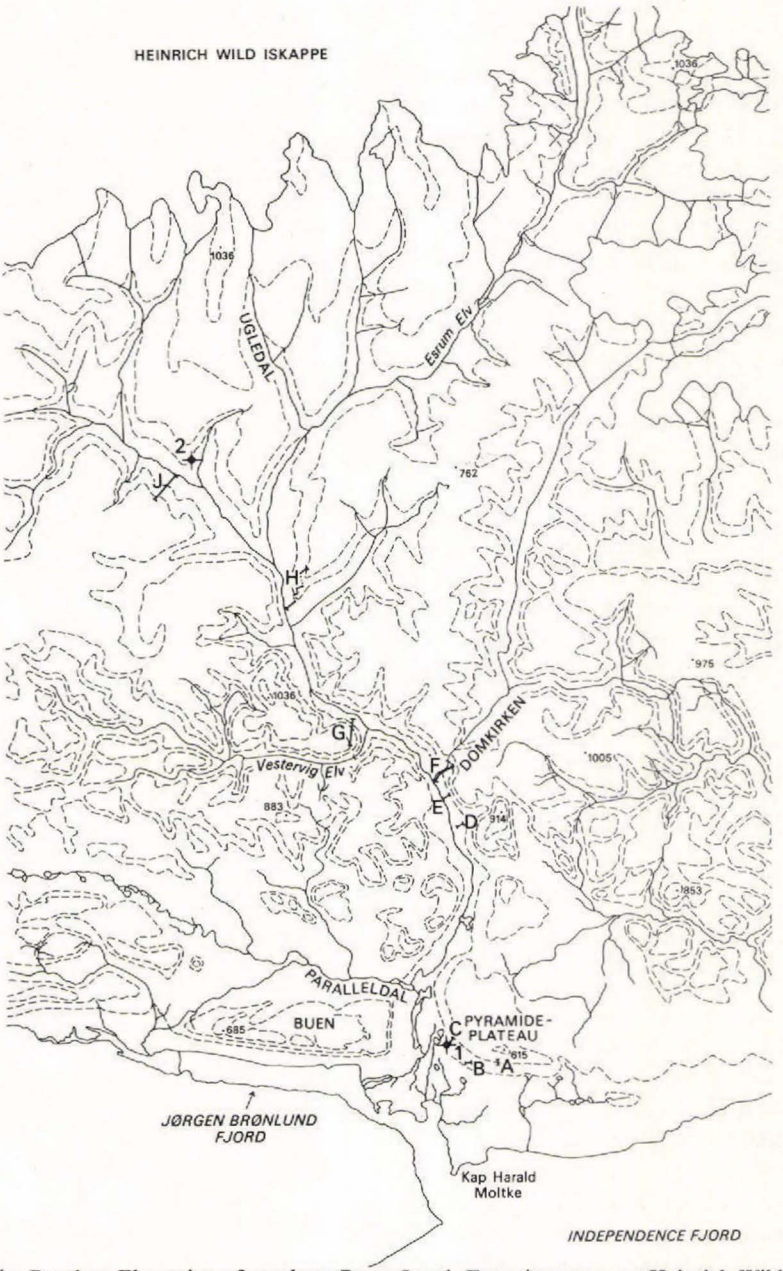

Fig. 3. The Børglum Elv region of southern Peary Land. From its source at Heinrich Wild Iskappe, Børglum Elv flows southward through Ugledal to be joined by Esrum Elv and a large un-named tributary from the north-west (containing section J and locality 2). Additional large tributaries, Vestervig Elv and at Domkirken and Paralleldal, combine prior to discharge into Jørgen Brønlund Fjord. 1: locality in Buen Formation at Brillesø. 2: graptolite locality, un-named Silurian black shale formation. A–H, J: principal stratigraphic sections, see appendix. Scale 1:500 000. Contour lines *sketched* from U. S. Army Map Service 1:250 000. Other topographic features from Geodetic Institute (Copenhagen) 1:100 000 photomosaics.

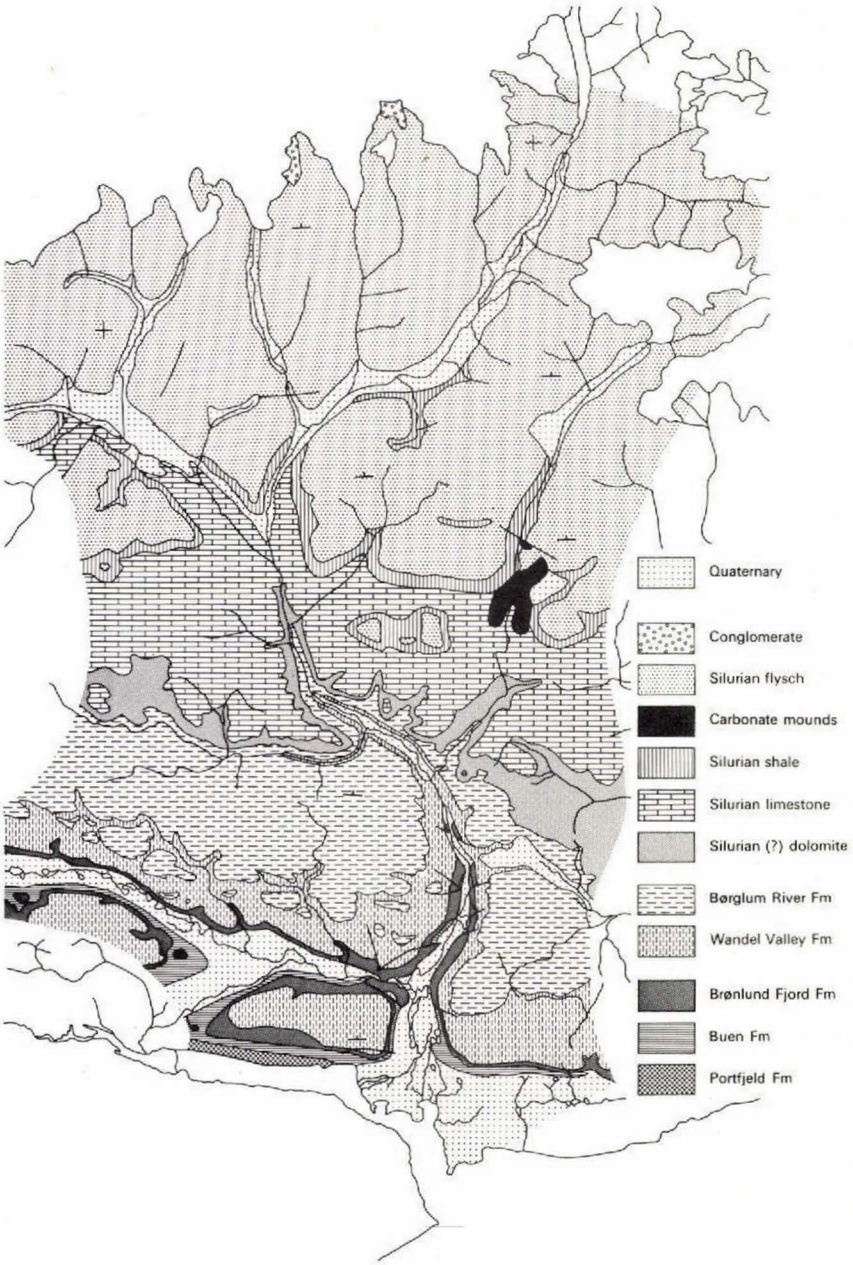

Fig. 4. Geological map of the Børglum Elv region, based on measured sections and photointerpretation. Structural dips indicated conventionally; faults by solid lines. 1:500 000.

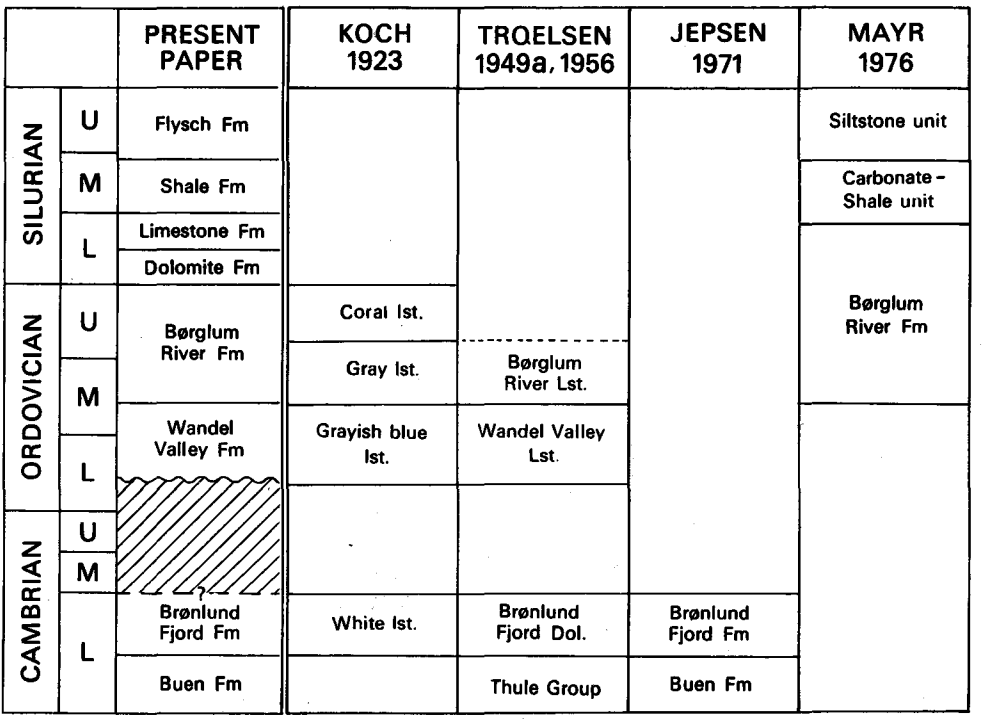

Fig. 5. Stratigraphic nomenclature in the Børglum Elv region. Lower units recognised by Jepsen (1971) but not examined during 1974 are excluded.

Buen Formation

Definition

The name Buen Formation was proposed by Jepsen (1971) for a shale and sandstone sequence earlier included in the 'Eocambrian' Thule Group of Troelsen (1949a). The formation overlies dolomites of the Portfjeld Formation which contain *Cryptozoon* of possible Early Cambrian age and is itself overlain by prominent cliff-forming dolomites of the Brønlund Fjord Formation (figs 6,7).

The Buen Formation comprises two sedimentary cycles of sandstone overlain by shale, the shale interbedded with greywacke. The lower boundary of the formation has not been observed; the base of the overlying Brønlund Fjord Formation was described as a "simple erosional disconformity" by Troelsen (1949a). The Buen Formation is 425 m thick at its type section on the north side of Jørgen Brønlund Fjord, some 15 km from the head of the fjord (fig. 7), although at most the upper 160 m were examined during 1974.

Lithology

About 35 m of fissile shale with abundant olenellid trilobites, exposed to the south-west of Brillesø (locality 1 in fig. 3), appear to occupy a section interval of 125–160 m

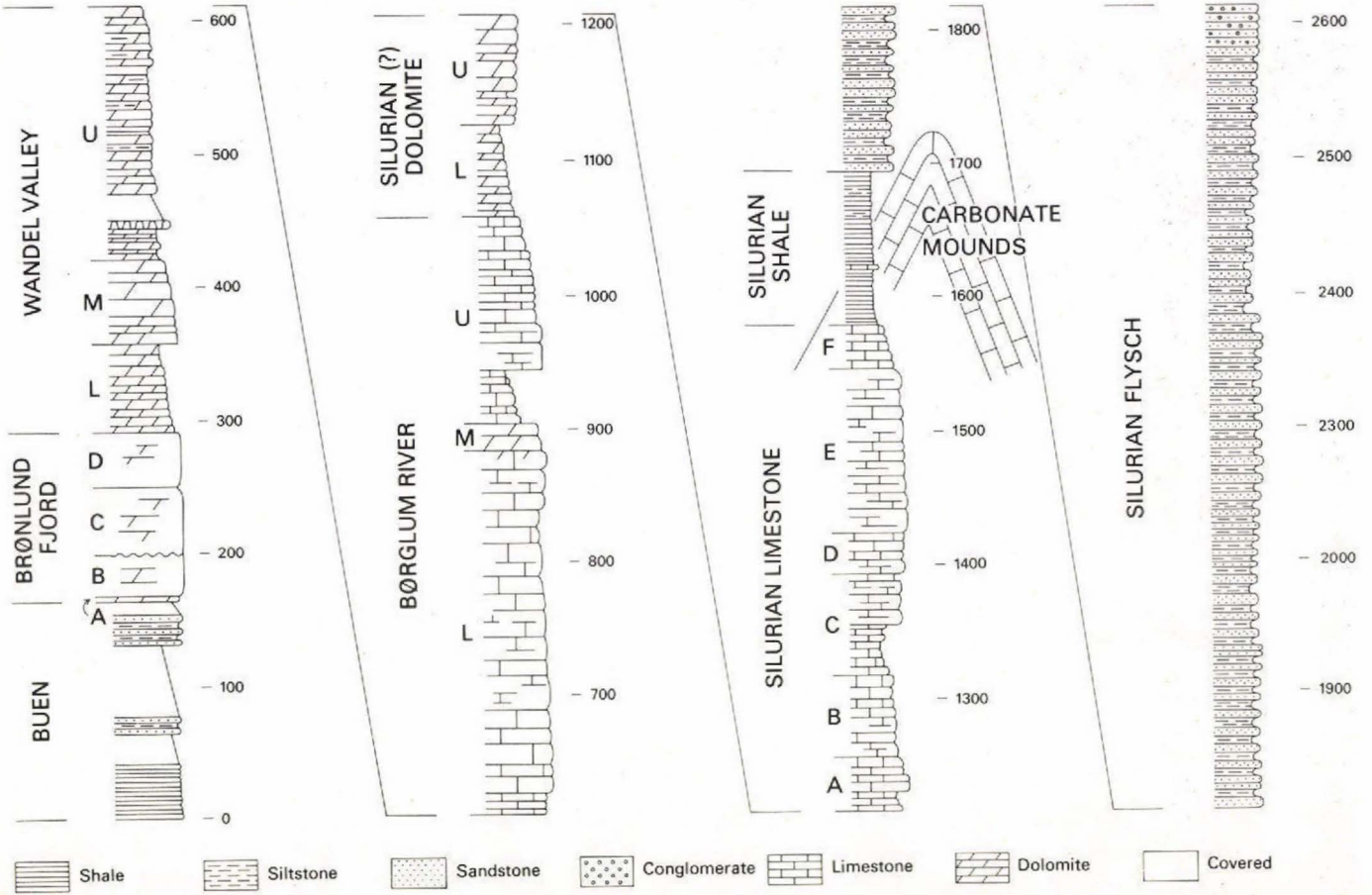

Fig. 6. Cambrium–Silurian sequence exposed in the valley of Børglum Elv. Datum for the section is the lowest black shale bed of the Buen Formation examined at the fossil locality south-east of Brillesø (no. 1 in fig. 3). The undulating erosion surface between members B and C of the Brønlund Fjord Formation (section height *c.* 200 m) and the prominent slump horizon in the Wandel Valley Formation (section height *c.* 450 m) are represented schematically.

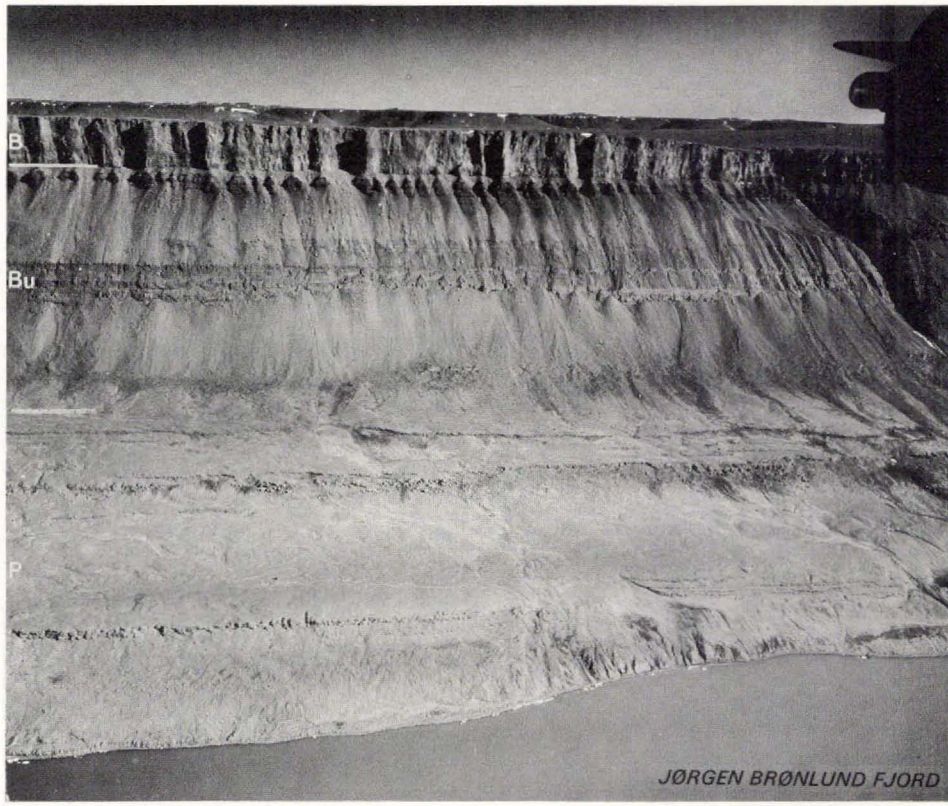

Fig. 7. Type locality of the Buen Formation on the northern side of Jørgen Brønlund Fjord, west of the mouth of Børglum Elv. The cliff is almost 700 m high. B: Brønlund Fjord Formation. Bu: Buen Formation. P: Portfjeld Formation. (Copyright Geodætisk Institut, Danmark).

below the top of the Buen Formation and represent the oldest beds of the formation examined in 1974. The shale is dark grey on the fresh surface and weathers to a dark greenish-grey. A bluish sheen probably represents an oxide stain. Fine flakes of mica may be apparent under the hand lens while tiny nodules and rare burrow infillings of pyrite are also present.

Beds overlying the fossiliferous shales are not well exposed at Brillesø. It appears that about 130 m of thin bedded, alternating, impure sandstone, quartzitic sandstone and silty shale are present, with the shale and sandstone about equally represented. Ripple marks and a variety of sole marks and trace fossils characterise some of the clastic beds. Cross-bedding with widely varying directions of transport was observed in clean, quartzitic, medium to fine grained sandstone high in section B (fig. 3) associated with interbedded, greenish-grey, glauconitic siltstone.

The uppermost beds and the contact of the Buen Formation with the overlying Brønlund Fjord Formation were talus covered in the studied sections but the two units appear to be conformable.

Fauna and age

Olenellid trilobites were discovered in the dark fissile shale at Brillesø by geologists of Greenarctic Consortium in 1969, while Jepsen (1971) also recorded fragments from north of Jørgen Brønlund Fjord. The Greenarctic material, kindly donated to GGU, was described by Poulsen (1974) who referred the few available specimens to *Holmia hyperborea* n. sp., indicating a general Early Cambrian age. Collecting at the type locality in 1974 demonstrated the abundance of well preserved specimens of *H. hyperborea* throughout the shale sequence, associated with conchs, opercula and appendages (= *Helenia*) of hyolithids, large archaeocopid ostracodes (new genus), *Hyolithellus* and a pelagiellid gastropod. Occasional specimens of a probable *Callavia* sp. occur in the lowest exposed beds.

Holmia hyperborea and hyolithids were also collected about 2 km to the north of the Brillesø locality, while higher, more silty beds of the Buen Formation exposed to the north of Brillesø yielded poor hyolithids.

Brønlund Fjord Formation

Definition

The name Brønlund Fjord Dolomite was given by Troelsen (1949a) to the "white limestone 100 m thick, devoid of fossils" of Lauge Koch's earlier (1923) description.The formation overlies the sandstone and shale of the Buen Formation and is succeeded by carbonate beds of the Wandel Valley Formation of Early-Middle Ordovician age. Troelsen later assigned an Early Cambrian age to the Brønlund Fjord Formation on the basis of fossils found at the base of the unit, near Midsommersøerne, to the west of the present area (Troelsen, 1956, p. 87). The type locality lies on the north coast of Jørgen Brønlund Fjord, just west of the mouth of Børglum Elv. Troelsen (1949a, 1956) suggested a thickness of 156 m for the Brønlund Fjord Formation, rather more than the *c.* 125 m measured in 1974.

The Brønlund Fjord Formation forms conspicuous cliffs along the northern side of Jørgen Brønlund Fjord, eastward along Independence Fjord (figs 2,7) and westward throughout Peary Land. The unit descends northward due to the gentle regional dip and disappears beneath younger beds about 20 km from the coast in the valley of Børglum Elv.

Lithology

The Brønlund Fjord Formation comprises four members, here designated A to D: a basal thin, fossiliferous dolomite member and three overlying, much thicker dolomite and dolomite breccia members The basal member appears to be a normal, undisturbed sedimentary unit, but overlying members are variable, complicated by brecciation and slumping, and perhaps by the effects of dolomitisation. The three upper members make up the greatest part of the formation and are distinguished in cliff sections in the vicinity of Børglum Elv by contrasting weathering colours. The top of member B is a distinctive broadly undulating, apparent erosion surface.

Member A: fossiliferous dolomite (*c.* 3 m)

The basal member of grey weathering, medium grained, uniform dolomite, is rarely exposed; it is usually covered by coarse talus from the overlying cliff-forming members. The basal unit was examined at an exposure on the south-western corner of Pyramide-plateau (fig. 3, section B). Bedding planes are somewhat irregular, and stylolitic. Fossils occur in dark brown, phosphatic (?) layers. The contact with the overlying breccia (member B) is very sharp, but amoeboid loading structures of breccia were observed.

Member B: laminated dolomite and dolomite breccia (*c.* 35 m)

Member B includes well bedded dolomite, massive dolomite, and dolomite breccia (fig. 8). The unit is most competent and forms the base of the widespread cliffs near the junction of the valley of Børglum Elv with Jørgen Brønlund Fjord. The breccias of member B occur at varying horizons and on a variety of scales. Breccia formation is almost certainly associated with the large scale slumping of alternating competent and incompetent, often mottled, thin dolomite beds.

The normal undisturbed rock of member B appears to be mainly finely laminated to rhythmically banded, light grey, yellowish-grey weathering dolomite. The laminae are

Fig. 8. Breccia with clasts of laminated and massive pale dolomite in a dark dolomite matrix. Brønlund Fjord Formation, member B. Børglum Elv.

Fig. 9. Alternation of laminated and bioturbated ('mottled') dolomite. Brønlund Fjord Formation, member B. Western edge of Pyramideplateau.

from 0.5 to 2 cm thick in the lower part of the member. Upward, rhythmic bedding is developed, with cycles from 12 to 15 cm apart, in which laminated or sometimes nodular beds alternate with thicker mottled beds. Sometimes the mottling can be clearly ascribed to bioturbation (fig. 9).

The breccias of member B generally consist of variously sized clasts and pseudoclasts of lighter weathering dolomite in a darker dolomite matrix.The pseudoclasts are generally small and rounded, with massive texture, and were probably formed by mottling. The clasts are often larger, and may be tabular and banded; the centres of some of the larger clasts are sometimes coarsely crystalline (fig. 8).

The breccias in places appear to overlie bedded rocks with a normal, planar contact. In other places laminar beds become progressively boudinaged with passage laterally into disoriented breccia, while elsewhere the breccia is clearly transgressive. Bedding in associated laminated dolomite is generally gently distorted, with dips up to ten degrees common, but some beds are tilted to the vertical.

Massive, yellow weathering, medium grained dolomite appears to be gradational from both laminated and brecciated dolomite. This rock occurs most commonly in the upper part of member B.

The upper surface of member B is broadly undulating, with a relief of up to about 2 m. In places the breccias appear to grade upward into nodular dolomite without breccia. In other places, laminar bedded dolomites and breccia of the lower unit, sometimes with locally steepened dips, are overlain by member C with angular discordance. The contact is clearly disconformable, although the stratigraphic importance of the event represented by the erosion surface is still unclear.

Member C: banded, mottled, and nodular dolomite (*c.* 45 m)

Member C characteristically consists of thin to medium bedded (2 to 15 cm), dark grey dolomite that weathers dark grey to purplish-grey. The contrast in weathering colour with the underlying upper part of member B is marked, but the transition to light weathering dolomite of member D is gradational in most sections. The bedded to laminated dolomites are exactly like the laminated rocks of member B. Lamination is not discernible in some sections, especially toward the top of the unit; the rock instead is massive, medium grained, very light grey, and yellow-grey weathering. An irregular network of silica is generally evident on weathered surfaces.

Member D: orange weathering laminated and massive dolomite (*c.* 35 m)

The uppermost unit of the Brønlund Fjord Formation is a variously laminated to massive dolomite which weathers light yellow-grey to light orange. The base of the unit is usually marked by a gradational colour change from the underlying member C, but the contact with the overlying, grey dolomites of the Wandel Valley Formation is most distinct. Brecciation of the laminated rock, with blocks varying greatly in size, has been observed but it is unclear how widespread this structure is. The uppermost beds are invariably yellowish white to light orange-grey weathering, but in some places are massive, in others, finely laminated. The massive rocks are medium to coarsely grained, vuggy, and may contain abundant silica in the form of veinlets and crystals in vugs.

Fauna and age

In the neighbourhood of Børglum Elv, fossils have only been found in member A. The fauna, generally associated with the discontinuous phosphatic laminae or nodules, is closely comparable to one collected by J. C. Troelsen above Midsommersøerne some 100 km to the west, apparently also from the lowest beds of the formation. Troelsen (1956) noted fragments of Olenellidae and *Salterella* but his collection also contains abundant hyolithids and their opercula, the trilobites *Bonnia* and *Calodiscus* (?), pelagiellid gastropods, *Fordilla troyensis, Chancelloria, Hyolithellus* (?), *Linnarssonia* and other inarticulate brachiopods. A general late Early Cambrian age is indicated by the fauna of member A, although the age of the remaining members is uncertain. Dawes (1976b) collected *Linnarssonia* and *Hyolithellus* (?) from somewhat higher in the Brønlund Fjord Formation in western Peary Land, but a precise correlation between the section in this area and that at Jørgen Brønlund Fjord is not established. The billowing surface above member B, noted above, may have more than local significance, although its presence is not out of accord with the strongly slumped horizons below.

In western Peary Land, Dawes (1976b) collected Middle Cambrian fossils (*Peronopsis, Helcionella*) from limestones above the Brønlund Fjord Formation. However, overlying strata of the Wandel Valley Formation in the Børglum Elv section contain *Ceratopea ankylosa* and *C. unguis* of late Early Ordovician (Late Canadian) age (Troelsen, 1949a; Yochelson & Peel, 1975).

Wandel Valley Formation

Definition

Carbonate beds overlying the Brønlund Fjord Formation were named the Wandel Valley Limestone by Troelsen (1949a). The formation, apparently equivalent to the "400–500 m of grayish blue limestones with badly preserved fossils" of Koch (1923), was described by Troelsen as being made up of thin bedded, grey dolomitic limestone in the lower part (the present lower member), passing upwards into dark, greyish brown dolomitic limestone of the currently recognised middle member. The upper dolomitic part of the unit was not exposed at Troelsen's localities, which lay on both the west and the east sides of the mouth of Børglum Elv.

The Wandel Valley Formation caps the plateaus along the north side of Jørgen Brønlund Fjord and adjacent areas of Independence Fjord (Troelsen, 1949a, fig. 7), and forms much of the valley walls before disappearing in the floor of Børglum Elv north of Domkirken (fig. 2).

The Wandel Valley Formation (320 m) appears to conformably overlie the Brønlund Fjord Formation with a distinct contact and abrupt change in lithology, although faunal evidence suggests an unconformity of considerable magnitude. The overlying limestone of the Børglum River Formation is also conformable, but the contact is indistinct. The overlying unit is taken to begin at the first appearance, upward, of limestone.

Lithology

The Wandel Valley Formation comprises three dolomite members. The strong colour contrast between the pale weathering lower member and the dark middle member forms a conspicuous mappable horizon on the valley walls of the lower Børglum Elv (figs 2,10). Thin dark bands in the lowest member, particularly in its upper part, are also distinctive, but appear to vary somewhat in abundance locally.

Lower member: light weathering silty dolomite (45 m)

This member consists of medium grained, light grey dolomite in medium to thin beds. Weathered surfaces are lighter grey. Planar to wavy silty laminae are evident on etched, weathered surfaces. The laminae are truncated in places by small channels, while thin layers of intraformational breccia are also present in some beds. Nodules and lenses of chert occur, together with sheets of silica that may be algal in origin. Silicified fossils are evident on weathered bedding surfaces, where they appear to occur in patchy concentrations. A pair of dark grey dolomite beds, 80 and 60 cm thick, occur about one quarter of the way up from the base of the member. A prominent dark bed about 3 m thick lies near the top.

The basal 0.5 m of the lower member was not examined, but from 'float' it is evident that the change from the light buff-yellow weathering, sugary dolomite breccia of the Brønlund Fjord Formation is abrupt. The upper boundary of the lower member of the Wandel Valley Formation is somewhat indefinite because of interlayering of light grey and silty dolomite characteristic of the lower member, with the dark grey-brown, sugary dolomite typical of the overlying middle member.

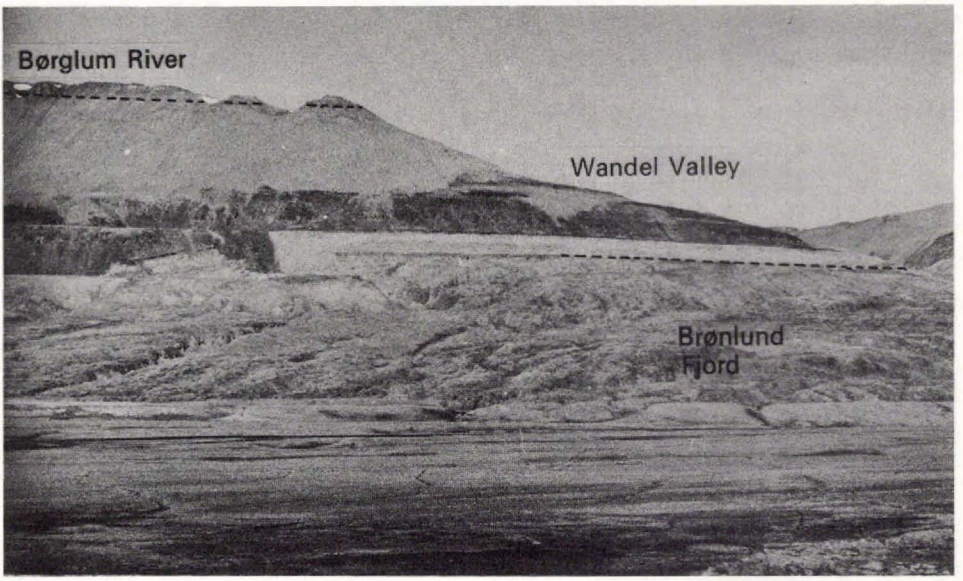

Fig. 10. Valley side north of junction between Paralleldal and Børglum Elv. Dolomite of the Brønlund Fjord Formation (Lower Cambrian) overlain by the Ordovician Wandel Valley Formation and Børglum River Formation. Dark dolomite of the middle member of the Wandel Valley Formation contrasts strongly with the pale dolomite of the lower member, forming a mapping horizon of regional extent (see fig. 2). The upper member of the formation forms the talus covered slopes with more resistant limestone of the Børglum River Formation capping the hill tops. The sequence is cut obliquely by a single normal fault. Quaternary deposits in the foreground lie within the valley of Børglum Elv.

Middle member: dark weathering mottled dolomite (*c.* 75 m)

The middle member is mainly dark grey-brown, mottled, crystalline dolomite. Silty laminae are evident on some weathered surfaces, and numerous beds of intraformational breccia are present. Much of the member is medium bedded, but upward the beds become thicker and more competent; the upper third is uniform and thick bedded. Many beds contain distinctive patches, up to 1 cm diameter, of pink weathering dolomite crystals. Vugs lined with pink carbonate and quartz crystals have formed in places. Nodules of black chert are abundant.

Near the base of the middle member are two or more beds, about 40 cm thick, of pale, pinkish-grey, silty dolomite similar to that of the lower member. Bedding contacts between the light and the dark varieties are abrupt, but a transitional boundary between the members is created by the interlayering of the two varieties. A light weathering bed about the middle of the dark dolomite unit is a most distinctive feature.

Upper member: light weathering dolomite (*c.* 200 m)

The upper member makes up almost two thirds of the thickness of the formation. As in the lower member, the upper beds are light grey weathering and thin to medium bedded

dolomite, and contrast markedly with the dark weathering middle member. Typical beds are uniform, medium bedded, fine grained grey dolomite, often with wavy or irregular bedding planes. A few darker beds, especially in the upper part of the member, give a banded appearance to steep slopes and cliff faces.

Thin beds of intraformational breccia with clasts up to 5 cm occur at many levels, and chert nodules and lenses are abundant in some beds. Silty laminae and partings are apparent on weathered surfaces.The laminae are usually uniform and planar, but not uncommonly may be contorted or truncated. A distinctive slump horizon about 1.5 m thick and 30 m above the base of the member displays contorted dolomite silty laminae, chert nodules and brecciation on a large scale.

Fauna and age

Troelsen (1949a) recorded a rich silicified fauna from the lower and middle members of the Wandel Valley Formation, including the gastropods *Maclurites, Trochonema, Pagodispira,* and *Ceratopea* (= *Raphistomina*) and the cephalopod *Protocycloceras*. He suggested a Late Canadian or possibly Middle Canadian age (Early Ordovician) on the basis of the occurrence of *Ceratopea*.

Yochelson & Peel (1975) re-examined Troelsen's collections and recognised *Ceratopea ankylosa* Cullison, 1944 from the lower and middle members and *C. unguis* Yochelson & Bridge, 1958 from the middle member. The presence of *C. ankylosa* suggests a correlation with the Cotter Formation of the Ozark area of Late Canadian (late Early Ordovician) age, while *C. unguis* possibly indicates a correlation of part of the middle member with the Smithville Formation of Arkansas and other Late Canadian strata of slightly younger age than the Cotter Formation. Unfortunately, from the rather restricted locality information available, Yochelson & Peel (1975) were unable to ascertain the relative stratigraphic position of the two species of *Ceratopea* within the middle member of the Wandel Valley Formation.

Collections obtained in 1974 have yielded *C. ankylosa* from near the base of the middle member and *C. unguis* from the top of the middle member, in good agreement with the correlation proposed by Yochelson & Peel (1975). Silicification in samples from the lower member was poor and no specimens of *Ceratopea* were recovered from residues after digestion in hydrochloric acid. However, specimens of *C. ankylosa* were collected on outcrop on the south side of Pyramideplateau (section A) and the derivation of Troelsen's collections from the lower member is not disputed.

In addition to gastropods and cephalopods the silicified residues from the lower and middle members contain rare brachiopods (*Diparelasma;* J. M. Hurst, personal communication, 1976), chiton plates, abundant disarticulated echinoderm plates and ossicles, (Paul, 1976) and poorly preserved rostroconchs (*Euchasma*?).

Poorly preserved gastropods were observed at several horizons in the upper member but not determined. On the basis of its stratigraphic position between the underlying Late Canadian middle member of the Wandel Valley Formation and the overlying probably Black River strata of the basal Børglum River Formation, a Middle Ordovician, Whiterock – Chazy, age is tentatively assumed. No evidence to suggest a major cessation in sedimentation was recorded.

Børglum River Formation

Definition

The name Børglum River Limestone was assigned by Troelsen (1949a) to the "gray limestone in which *Maclurea* is common" of Koch (1923) that rests on the Wandel Valley Formation. Troelsen described the unit as "black, strongly silicified limestone with stringers of brown dolomite" and mentioned a fauna consisting of *Maclurites,* bryozoans, and cephalopods. Troelsen (1949a) only examined the lower part of the formation near Jørgen Brønlund Fjord and could not take into account overall character and thickness.

Mayr (1976) extended the Børglum River Formation to include essentially Silurian strata here assigned to an un-named dolomite formation, and an overlying un-named Silurian limestone formation (see discussion of carbonate mounds, below).

The Børglum River Formation is a thick, competent unit that underlies a broad belt of the uplands north of Jørgen Brønlund Fjord, at about the latitude of Paralleldal, and probably much of southern Peary Land. With other Lower Palaeozoic units, it descends northward due to the gentle regional dip. The northernmost exposure in the floor of the valley of Børglum Elv is a few kilometres south of the junction of the large un-named north-western tributary with Børglum Elv itself, about 30 km upstream from Jørgen Brønlund Fjord. A thickness of about 430 m was measured.

The Børglum River Formation contrasts markedly with the underlying and overlying, mainly dolomitic units: it is yellowish-grey weathering, conspicuously mottled, and dominantly limestone. The lower and larger part of the formation is thick bedded; upper beds tend to be less competent.

The change from the dolomite of the upper member of the Wandel Valley Formation to limestone of the overlying Børglum River Formation (fig. 11) is abrupt but inconspicuous, due to a general similarity of the grey, weathered surfaces. Silty laminae are present above and below the boundary, but are discontinuous and irregular in the limestone.

Lithology

The Børglum River Formation consists mainly of medium to thick bedded limestone. A dark, somewhat dolomitic member, about 40 m thick, occurs at about two thirds of the way up from the base. Lower beds are thick bedded, competent, coarsely mottled limestone (260 m), upper beds are medium bedded, less competent limestone (130 m). The limestone beds, but not the dolomite, are conspicuously and uniformly fossiliferous with imperfectly silicified gastropods, corals and cephalopods, characteristically weathering out on bedding surfaces (fig. 12).

Lower limestone member (260 m)

The lower limestone member appears uniformly thick bedded with prominent mottling. The main, bedding joints are usually spaced about 1 to 2 m apart to produce the effect of thick bedding, although much more closely spaced, irregular, parallel partings and distinct beds e.g. fossil-rich or cherty layers, are evident. About 15 m of 'transitional' limestone beds at the base of the member, although mottled and with irregular bedding planes, are medium bedded and grey weathering, and thus resemble the underlying dolomite unit.

The mottled effect in the thick bedded limestone is due to an irregular, dark grey network in a light yellow weathering matrix. The dark component stands out on deeply

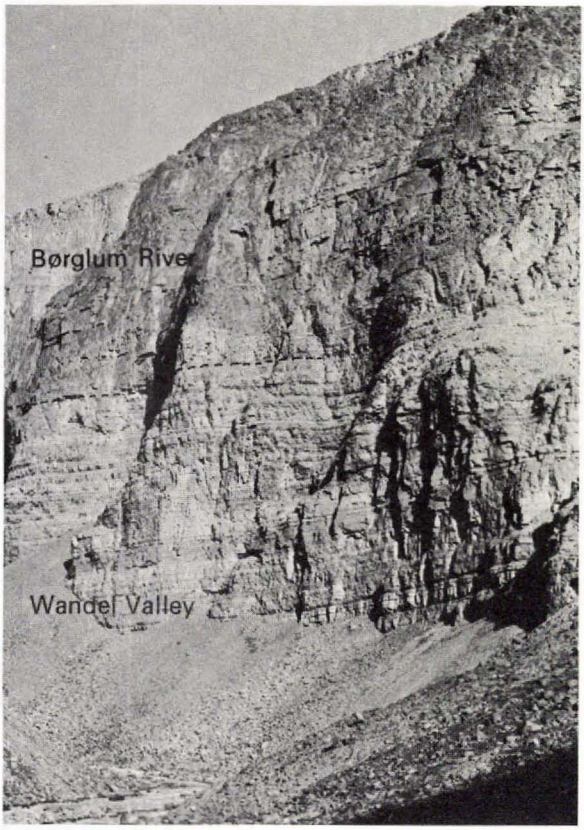

Fig. 11. Thinly bedded dolomite of the upper member of the Wandel Valley Formation overlain by more massively bedded limestone of the Børglum River Formation. The abrupt change from dolomite to limestone is obscured by the gradational change in bedding. South-eastern wall of Domkirken.

etched, weathered surfaces in a very rough, scoriaceous manner. Part of the mottling is clearly related to burrows and bioturbation.

Numerous large, more or less silicified fossils stand out on weathered surfaces to form a distinctive feature of the lower limestone member. Corals and gastropods are most conspicuous; of the latter, *Maclurites* is abundant but relatively poorly silicified (fig. 12). Chert nodules are common throughout, but especially abundant in the lower 60 or 70 m of the unit. In places, chert formation has followed the dark mottling component, burrows and other linear sediment features.

Middle limestone and dolomite member (*c.* 40 m)

The thick bedded, mottled limestone of the lower limestone member passes gradationally but rapidly into darker, mottled limy dolomite and overlying, alternating limy dolomite and limestone. The dolomite beds are dark grey, the limestone grey. Together, these rocks form a darker weathering, non-fossiliferous member about 40 m thick. The weathered surfaces of both rock types are mottled, the limestone more evidently so than the dolomite.

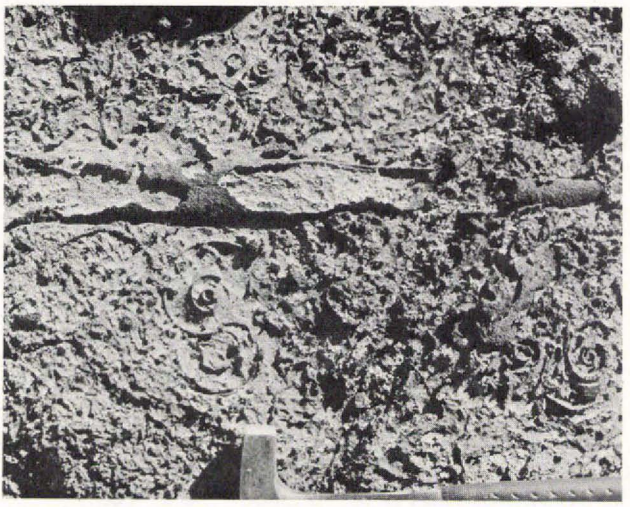

Fig. 12. Poorly silicified gastropods (*Maclurites*) and orthocone nautiloid. Børglum River Formation, lower member. Hillside north of junction between Vestervig Elv and Børglum Elv.

Upper limestone member (130 m)

Light grey to yellowish weathering, fossiliferous limestone abruptly overlies the dark dolomitic beds. The limestone is medium to thick bedded, and mottled on the weathered surface; it is thus similar to the limestone of the lower member. The limestone beds are marked by closely spaced, irregular, silty partings and because of these form rubbly, less competent outcrops. A cliff forming part of the unit about 40 m thick lies a little below the middle of the member.

The member is richly fossiliferous near its base, where a wide range of fossils is present. In the upper part, only the larger fossils, particularly *Maclurites*, are evident on the weathered outcrop. Imperfect silicification of the fossils has taken place at several horizons.

The top of the upper limestone member, recessive and talus covered, was not observed.

Fauna and age

The basal beds of the Børglum River Formation yielded the trilobites *Bathyurus* and *Ceraurus* (?) associated with brachiopods, poorly preserved gastropods and smooth ostracodes. Whittington (1953) recorded *Bathyurus* characteristically from Black River and Trenton strata (middle to late Middle Ordovician age) but Ross (1970) and Ludvigsen (1975) have subsequently identified the genus from somewhat older Middle Ordovician rocks in Nevada and the District of Mackenzie.

Massive beds about 50 m above the base of the lower member contain a partly silicified fauna rich in *Tetradium* cf. *T. tubifer* Troedsson, 1928, originally described from the Gonioceras Bay Formation of Washington Land, western North Greenland. The associated fauna includes *Catenipora, Calapoecia, Labyrinthites* (?), rugose corals, receptaculitids, poorly preserved bryozoans, *Maclurites* and a number of lophospirid gastropods. *Catenipora, Calapoecia, Labyrinthites* and the ubiquitous *Maclurites* occur throughout the remaining part of the lower member.

The middle member has not produced fossils. Immediately overlying beds of the upper member are richly fossiliferous, yielding a typical Arctic Ordovician fauna. *Kochoceras* and large actinoceroids are associated with abundant *Paleofavosites, Catenipora, Calapoecia* and *Lobocorallium*, and lesser numbers of *Saffordophyllum(?), Beatricea, Remipyga, Trochonema, Liospira, Lophospira, Phragmolites, Maclurites, Lepidocyclas* and other brachiopods and trilobites.

The general aspect of the fauna of the Børglum River Formation suggests a range in age from middle Middle Ordovician (Black River) to early Late Ordovician (Eden-Maysville, 'Red River'). Higher beds may be of late Late Ordovician age (Richmond). This part of the sequence proved to be poorly exposed in the sections examined, yielding only poor tabulate corals and *Maclurites*.

Un-named Silurian(?) dolomite formation

Definition

About 150 m of medium bedded dolomite with contrasting light and dark grey weathering colours conformably overlies the Børglum River Formation. The formation is conveniently divided into two members and is conformably overlain by un-named, light and dark weathering fossiliferous Silurian limestones. Mayr (1976) included the unit in an enlarged Børglum River Formation.

The formation is well exposed in the walls of the upper valley of the Børglum Elv (fig. 3, G,H). The upper, dark, member is more competent and so tends to form a dark band on valley wall exposures with talus obscuring the light band below.

Lithology

The formation is dolomite throughout, in contrast with limestone units above and below, although the uppermost beds contain a lime component sufficient to produce a moderate reaction with acid.

Lower member: light weathering dolomite (*c.* 70 m)

These beds were examined principally above the mouth of Vestervig Elv, where they are largely rubble covered. Two types of dolomite were noted: (1) a variety weathering light grey with a brownish cast, and medium grained; and (2) a slightly darker, medium grey dolomite with a few fossils but otherwise similar to (1).

Upper member: dark weathering dolomite (*c.* 80 m)

The upper member consists of medium to thick bedded, dark grey weathering dolomite and limy dolomite. The dark sequence is broken by a few light weathering beds. The dolomite is fine to medium grained, occasionally with calcite patches up to about 1 cm in diameter. Fluorite was also observed in such patches.

The rock appears uniform but regular and distorted laminae, pelletoidal structure, and some intraformational breccia have been observed on weathered surfaces.Thin shelled brachiopods occur in widely separated beds.

Fauna and age

Poorly preserved pentamerid brachiopods from the upper member possibly suggest an Early to Middle Llandovery age rather than Late Ordovician (A. J. Boucot, written communication, 1975). With the exception of the scattered brachiopods, the formation has only yielded occasional poorly preserved tabulate corals.

Un-named Silurian limestone formation

Definition

A variable sequence of limestones (320 m) conformably overlies the un-named dolomite formation described above. The limestones are variously light grey, dark grey, and yellow-grey weathering, and may be richly fossiliferous. A prominent member of thick bedded limestone in the upper part of the formation outcrops over large areas of the uplands, in part because of its competence and in part because a younger, markedly less competent, black shale unit has been stripped away by erosion (fig. 13). Mayr (1976) included strata referred to this formation (with the possible exception of member F, see below) in an extended Børglum River Formation.

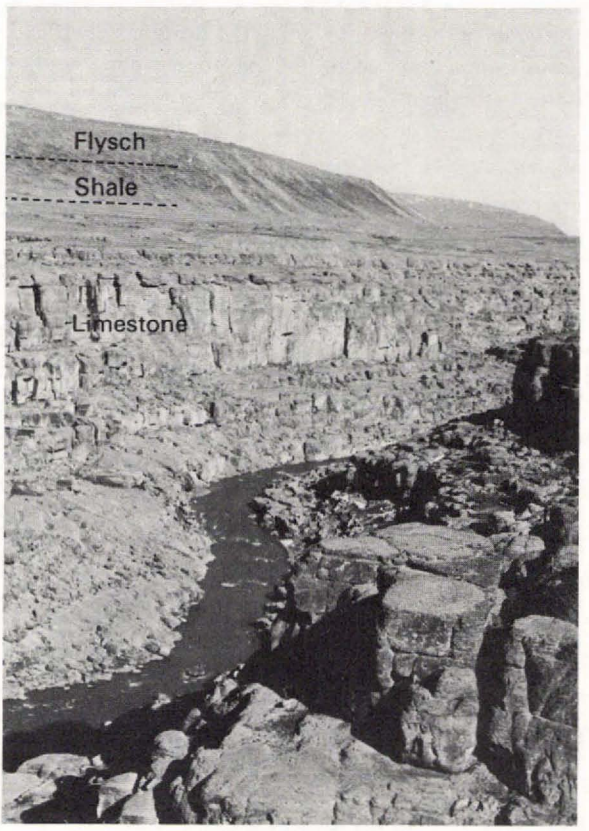

Fig. 13. Gorge of the large un-named north-western tributary of the Børglum Elv looking downstream (to the south-east). Thick bedded limestone of the un-named Silurian limestone formation forming the sides of the gorge and valley floor are overlain by the un-named black shale formation outcropping in the valley sides. Sandstones of the un-named Silurian flysch formation cap the hill tops.

A section of the limestone beds was measured on the east wall of the valley of Børglum Elv just below the junction with the main north-western un-named tributary of Børglum Elv, and about 35 km north from Jørgen Brønlund Fjord (fig. 3, section H).

Lithology

The formation can be divided into six members of more or less distinctive lithological character. The lower four units form two 'cycles' of light grey limestone overlain by dark grey, mottled limestone; a fifth unit is thick bedded, stromatoporoid-rich limestone; and the uppermost unit is silty limestone that breaks easily into rubble.

Member A: light weathering limestone (35 m)

The lowest member consists of medium bedded, light grey to yellow-grey weathering limestone with ostracodes. The lower beds are thinly laminated, with some stromatolite domes. Upper beds are well bedded, fine grained limestone with ostracodes and brachiopods. A distinctive bed, 2.5 m thick, of dark blue-grey, dark grey weathering limestone contains large, thick shelled pentamerid brachiopods.

Member B: dark mottled limestone with silicified fossils (50 m)

Member B is composed of thick bedded, dark grey weathering limestone. This unit is distinctive in being conspicuously mottled and richly fossiliferous.

The basal 2 m is a bed rich in thick shelled pentamerid brachiopods, similar to the brachiopod bed noted in member A (fig. 14 A). *Favosites,* cephalopods, and stromatoporoids are also present. Mottling in the basal beds has figures of coarser grained and lighter weathering dolomite (?) or dolomitic limestone set in a limestone matrix. About one half of the bulk of the rock in the rest of the member is composed of limestone of similar lithology to the matrix component of the mottled bed.

Upper beds of member B contain chert nodules, and many fossils on weathered surfaces are silicified.

Member C: light weathering limestone (*c.* 60 m)

This unit of medium to thick bedded, light grey limestone contains abundant ostracodes and small brachiopods. The limestone is generally grey to dark grey on the fresh surface but weathers light grey to yellow-grey. Mottling is weak or absent. The lower half of the unit is medium bedded, the upper half, thick bedded. About 4 m of thin bedded limestone with ostracodes forms the uppermost part of the unit in the measured section.

Member D: dark mottled limestone with silicified fossils (*c.* 30 m)

A thick bedded, yellowish-grey weathering, fossiliferous, limestone unit overlies the grey beds. The limestone is dark, dusty blue-grey or black on the fresh surface; weathered surfaces are conspicuously mottled. The weathered rock breaks into fine debris due to distinct, wavy or irregular partings.

Member D is rich in fossils and fossil debris. Brachiopods, solitary and colonial corals,

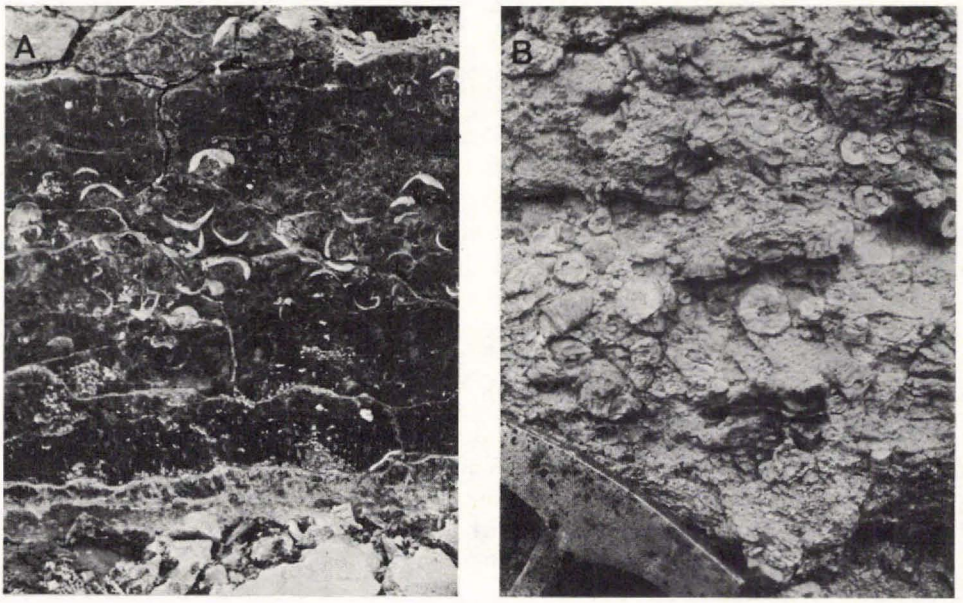

Fig. 14. A: coquina with pentamerid brachiopods. Un-named Silurian limestone formation, member B. Eastern side of Børglum Elv just downstream of the junction with the un-named north-western tributary. Height of exposure *c.* 45 cm. B: echinoderm-rich bioclastic limestone. Larger Silurian carbonate mound, upstream of Domkirken.

and large numbers of subhemispherical stromatoporoids are present. Corals and stromatoporoids on weathered surfaces are often imperfectly silicified.

Member E: thick bedded stromatoporoidal limestone (100 m)

Member E, the most prominent member of the fossiliferous limestone series, is distinctive in its thickness and uniformity, and in the high proportion of stromatoporoid colonies. However, as is the case with other limestones, the calcareous weathering crust developed over most outcrops obscures details of fine structure and many smaller fossils. The unit resembles member D in most respects, but is lighter weathering, mainly less silicified, and is somewhat less resistant to weathering. The base of member E in the measured section (fig. 3, H) is taken to be at the base of about 2 m of light weathering, slabby limestone that overlies the darker grey, silicified and fossiliferous member D.

The thick bedded limestone of member E is dark blue-grey on the fresh surface, and yellowish grey, mainly mottled, on the weathered surface. Irregular lamination results in rapid disintegration into fine rubble. The entire member is rather fossiliferous; large tabulate corals and stromatoporoid domes are widespread, except in minor interbeds of dark grey limestone. Black chert nodules are abundant a few tens of metres below the top of the unit.

Member F: rubbly limestone (*c.* 35 m)

The limestone of member E passes gradationally into medium bedded limestone of member F, which is itself abruptly overlain by black shale.

Member F consists of uniform dark grey, lighter grey weathering, nodular limestones in units of about 1 m thickness. Individual nodular beds are a few centimetres thick and laterally discontinuous. Silty laminae and partings become more common in higher beds and, when combined with the nodular texture of the limestone, cause the exposed limestone to rapidly break down into rubble. Large flat colonies of *Favosites* are scattered throughout the member while other fossils, although probably quite common, are difficult to extract. Rich faunas were, however, collected near the middle and at the top of the member.

Fauna and age

Large smooth pentamerids from members A and B appear to be smooth virgianids of the *Borealis* type, suggestive of an Early to Middle Llandovery age (A. J. Boucot, written communication, 1975). Higher beds are frequently rich in tabulate corals (*Favosites, Halysites, Heliolites*), stromatoporoids, large leperditiid ostracodes and brachiopods. Member F has yielded conodonts of the *Llandoverygnathus celloni* zone, of Late Llandovery age (R. J. Aldridge, written communication, 1976) in association with a rich fauna of scutelluid and encrinurid trilobites, *Strophonella, Liospira, Loxonema* and corals.

The formation is thus presumed to be entirely of Early Silurian (Early or Middle Llandovery – Late Llandovery) age.

Un-named Silurian black shale formation

Definition

A distinctive shale formation about 100 m thick conformably overlies the Silurian limestones and is in turn followed by a thick flysch formation.The shale is recessive; it is usually talus covered and good exposures are rare. Erosion has evidently stripped the soft shale from the underlying competent Silurian limestones so that the shale unit outcrops only along a narrow, sinuous strip at the foot of valley walls or of hills composed of the overlying, relatively competent flysch sandstone formation (fig. 13).

The shale was examined on the south-west side of the valley of the main north-western, un-named, tributary of Børglum Elv where several good exposures occur on the north-facing valley wall (fig. 3, J). Graptolites were collected from an equivalent exposure on the north-east side of the valley (locality 2 in fig. 3).

The shale overlies the uppermost beds of the underlying Silurian limestone formation with an abrupt contact. The upper contact, with the Silurian flysch unit, is to some extent gradational since the uppermost beds of the shale unit are green-grey weathering, very fine grained limy siltstone with thin, black shale beds. However, this rock is abruptly overlain by buff weathering, limy greywacke with characteristic turbidite features, typical of the overlying formation.

Lithology

The shale formation consists mainly of soft black shale and silty grey-green shale, with a few thin beds of black, fine grained limestone.The soft black shale weathers to black flakes or a sooty sludge, the silty shale to a platy or papery debris. A lime carbonate component is present in the silty rocks which appears to increase in proportion upwards. Calcareous nodules may be scattered through the upper beds.

Fauna and age

A collection of graptolites from the upper part of the formation contains *Monograptus flexilis flexilis, Monograptus* aff. *M. riccartonensis, Cyrtograptus* sp. and *Monograptus* sp. considered to indicate the zone of *Cyrtograptus linnarssoni* of late Wenlock age (M. Bjerreskov, written communication, 1975).

Silurian carbonate mounds

Carbonate mounds are characteristic of the Silurian of North Greenland and form a prominent roughly east–west belt from Washington Land in the west, to Victoria Fjord in central North Greenland (Dawes, 1971, 1976a). In Peary Land, to the east of the Victoria Fjord area, exposed carbonate mounds are less conspicuous and more widely spaced while they are as yet, unknown in Kronprins Christian Land. Mayr (1976) has described two of the Peary Land mounds, his work resulting from earlier reconnaissance field work by Greenarctic Consortium. By chance, these same mounds were visited briefly during 1974. Our observations were more restricted due to the shortness of the visit, but are essentially in agreement with the description of Mayr (1976), although some differences in strati graphic nomenclature are evident.

Definition

Mayr (1976) extended the Børglum River Formation stratigraphically to include almost the entire carbonate sequence here included in the Børglum River Formation, the un-named Silurian (?) dolomite formation and the un-named Silurian limestone formation. The highest unit of Mayr's Børglum River Formation, the 'stromatoporoidal floatstone', is clearly the same as our Member E: thick bedded stromatoporoidal limestone, of the un-named Silurian limestone formation; the distinctive lithology is readily recognisable from his description. The overlying rubbly weathering limestone assigned by us to member F appears to have been included by Mayr in his shale-limestone unit in which the carbonate mounds occur. We were unable to examine the bases of the carbonate mounds east of Børglum Elv in 1974 although it appeared that development of the largest mound began contemporaneously with carbonates ascribed to our member F. The two mounds thus apparently occupy stratigraphic levels from the highest beds of the un-named Silurian limestone formation, through the Silurian black shale formation and into the flysch formation. These beds have been assigned ages from Late Llandovery to Wenlock, possibly Ludlow and the mounds would appear to have existed as positive features on the sea floor during this time interval.

Lithology

Mayr (1976) presented a map and sections indicating the structure of the two carbonate mounds and described the constituent lithologies.

The larger mound (figs 4,15) forms a crescentic hill nearly 2 km long, although pale weathering hills to the south appear to form a continuation (as indeed described by Mayr, 1976). The crescent shaped hill thus represents the northernmost extremity of an inverted Y-shaped mound. A smaller carbonate hill about 1 km to the north was reasonably interpreted by Mayr (1976, fig. 2) as the exposed tip of a second mound.

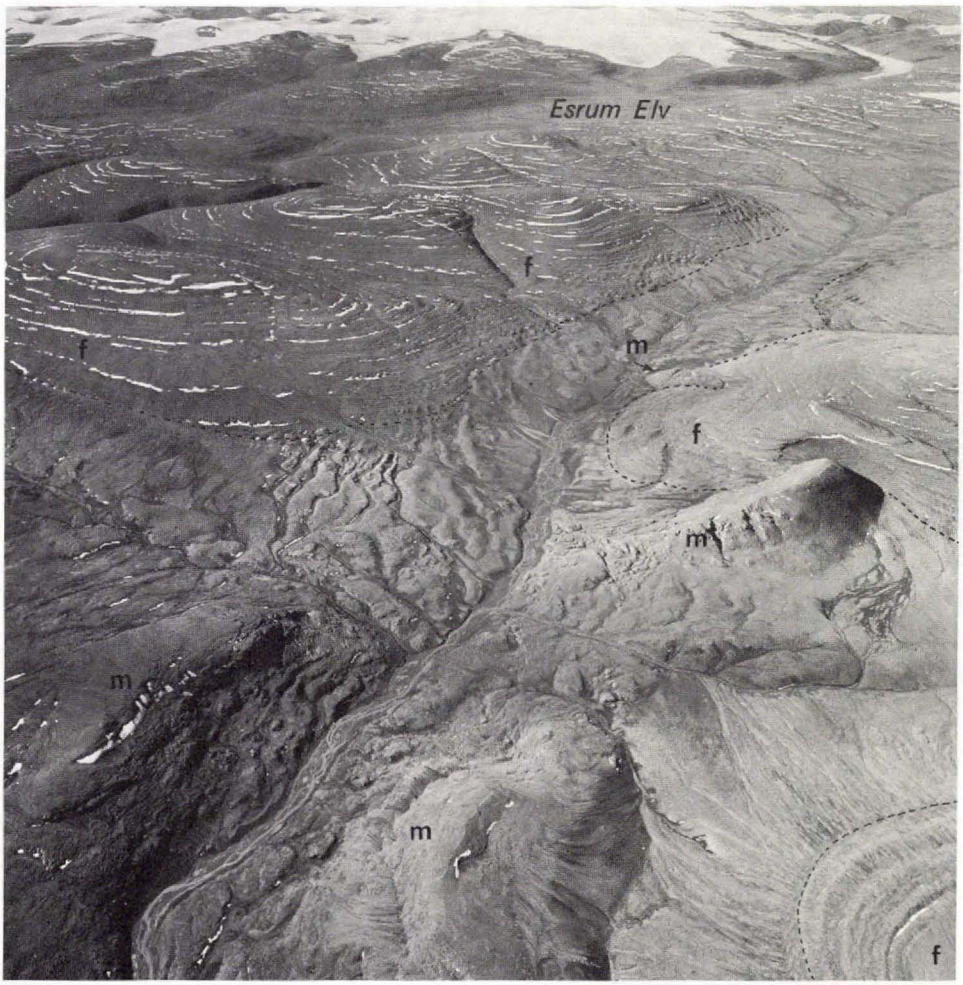

Fig. 15. Silurian sequence north of Domkirken. looking northward beyond Heinrich Wild Iskappe to the mountains of northern Peary Land. Silurian carbonate mounds (m) occupy stratigraphic levels through the un-named black shale formation forming the dark, wet outcrop areas in valleys into the overlying un-named flysch formation (f). Resistant sandstones in the flysch formation produce distinctive terraced hillsides. (Copyright Geodætisk Institut, Danmark).

The constituent rocks of both mounds are grey to light grey, mainly bioclastic limestones which generally weather light yellow-grey. The mounds appear to be largely organic with coral and stromatoporoid growths and infilling bioclastic debris (fig. 14 B), often with pockets of fossils. White or yellowish white carbonate fills the spaces between clasts, but considerable porosity remains. Black bitumen (?) occupies original cavities in some corals and stromatoporoids.

Rude bedding in the sides of the mounds dips up to 40° away from the centre, but is flat lying at the top and in the exposed core.The stromatoporoid rich core rock is relatively compact and only weakly bedded. Overlying sloping units are almost entirely clastic material in which algal fragments appear to be a major component. Near horizontal bedding is often evident in the sloping units.

Fauna and age

Fossils are common throughout the mounds. Mayr (1976) listed a fauna of mainly corals and brachiopods considered to indicate a Wenlock to early Ludlow age. R. J. Aldridge (written communication, 1976) has referred limestones of member F of the underlying formation to the Late Llandovery on the basis of the conodont fauna. These limestones are probably laterally equivalent to the lower levels of the mounds suggesting a slightly older initiation of mound formation than evisaged by Mayr. A. J. Boucot (written communication, 1975) considers large pentamerids from the southernmost mound to indicate a late Llandovery–Wenlock age. This is supported by the occurrence of the gastropod *Megalomphala robusta* (Whiteaves) originally described from the Ekwan River Limestones in Canada. P. D. Lane (written communication, 1977) has identified the trilobites *Meroperix ataphrus* and *Chiozoon cowiei* originally described from Kronprins Christian Land in limestone of Wenlock age (Lane, 1972). Associated specimens include *Calymene, ? Dicranopeltis, Lacunoporaspis* and fragments of cheirurine, bumastine, goldillaenid and odontopleurid trilobites.

M. Bjerreskov (written communication, 1975) has identified late Wenlock graptolites from the laterally equivalent un-named black shale formation (see above).

Un-named Silurian flysch formation

Definition

The Lower Palaeozoic carbonates of North Greenland pass northwards into a zone of clastic deposits characteristic of the North Greenland geosyncline (Dawes, 1971, 1976a; Dawes & Peel, in press). A lateral facies change is not seen in the Børglum Elv region where the carbonate platform sequence was inundated by flysch during the middle or late Silurian. The thick, uniform series of interbedded impure sandstone and siltstone, with some shale, conformably overlies the un-named Silurian black shale formation. The flysch formation, generally flat lying or with a shallow northerly dip, underlies large areas of rolling topography in southern Peary Land, where the alternation of resistant and less resistant beds forms distinctive terraced hillsides (Dawes, 1976a, fig. 249; see also fig. 15).

A section about 800 m or more in thickness was briefly examined in Ugledal, and younger deposits are probably exposed to the north. The junction with the underlying black

shales was examined on the south-western side of the large, un-named north-western tributary of Børglum Elv (fig. 3, H). The upper part of the shale formation consists of fine siltstones and shales which are abruptly overlain by calcareous turbidite sandstones, without apparent stratigraphic break.

The name Kjoveslette Sandstones has been used in connection with samples of Silurian grey micaceous sandstone with *Monograptus* collected from the marine post-glacial deposits exposed in eastern Peary Land, near Kjovesletten (Fränkl, 1956; Peel *et al.*, 1974) but is not employed here.

Lithology

The flysch series is well bedded, with beds varying from about 1 cm to 1–2 m thick. Most of the formation is fine to medium grained, blue-grey calcareous sandstone, weathering grey to buff-brown. Mica flakes are evident in coarser, or medium grained varieties. The fine to medium grained sandstone often grades upward into very fine grained sandstone or siltstone. Thin shale and silty shale interbeds tend to be darker green-grey to black in colour. Intraformational conglomerate beds occur throughout the section examined, but are most common in the middle of the section. Clasts of dark silt or shale in the pale sandstone are frequent.

The sandstone–siltstone sequence exhibits typical features characteristic of flysch deposition. Massive, graded sandstones with channelled and loaded bases fine upwards into thinly bedded sandstones and siltstones, with occasional shale partings. Micro-cross-lamination and ripple marks are abundant in these upper beds. The under surfaces of loose blocks in the solifluxion deposits are replete with flute, groove and prod casts, and other sedimentary structures (fig. 16 A,C,D,). Channels may be present on all scales from a few centimetres to tens of metres in width. Slumping and convoluted bedding are widespread (fig. 16 B).

The highest beds of the flysch sequence examined comprise a few tens of metres of conglomerate with rounded chert pebbles exposed near the ice cap at the head of Ugledal.

Fauna and age

Graptolites, associated with eurypterid fragments, from the calcareous sandstones in the lower part of the flysch formation in Ugledal were referred to *Monograptus* aff. *M. riccartonensis* by M. Bjerreskov (written communication, 1975). The same form has also been recorded from the underlying black shale formation in association with graptolites referred by Bjerreskov to the *Cyrtograptus linnarssoni* zone of late Wenlock age. *M. riccartonensis* is itself associated with the slightly older Wenlock zone bearing its name. A general late Middle Silurian and younger age is indicated. In Hall Land, western North Greenland (fig. 1), the flysch sequence has yielded early Devonian graptolites (Berry *et al.*, 1974) and vertebrates (Bendix-Almgreen & Peel, 1974), and a similar stratigraphic range may reasonably be expected in Peary Land.

Monograptids were noted by Koch (1923) and Peel *et al.*, (1974) in similar grey micaceous sandstone from eastern Peary Land.

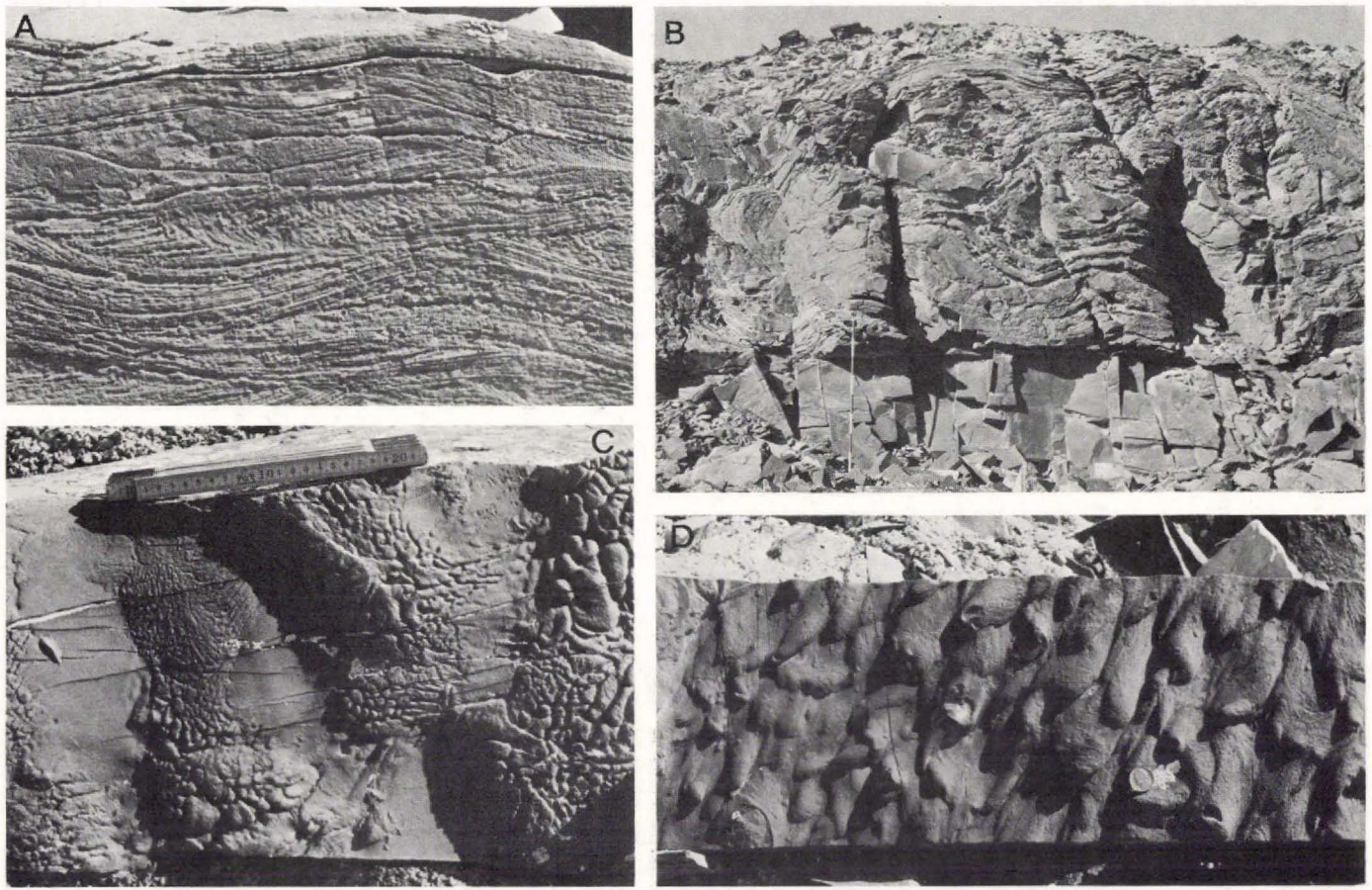

Fig. 16. Sedimentary features of the un-named Silurian flysch formation. A: truncated ripples, height of exposure *c.* 15 cm. B: slumped sandstone and siltstone overlying massive sandstone, height of rod 160 cm. C: undersurface with load casts, scale in cm. D: undersurface with flute casts.

COMPARISON WITH OTHER GREENLAND LOWER PALAEOZOIC SEQUENCES

North Greenland

Modern summaries of the Lower Palaeozoic throughout North Greenland are given by Dawes (1976a) and Dawes & Peel (in press). In addition to the areas discussed in the following two sections, relatively complete Cambrian to Silurian sequences occur in Wulff Land, central North Greenland, and in the clastic facies belt of the North Greenland Geosyncline, bordering the northern coast (fig. 1). Unfortunately, stratigraphic details in both these latter mentioned areas are as yet too sparse to merit detailed comparison with southern Peary Land.

Dawes (1976b) has recently described a section in extreme western Peary Land which differs significantly from the Børglum Elv sequence in the presence of some 500 m of carbonate rocks between strata assigned to the Lower Cambrian Brønlund Fjord Formation and the late Lower Ordovician Wandel Valley Formation. At least part of this intervening sequence is of Middle Cambrian age (Peel *in* Dawes, 1976b).

Washington Land

Cambrian strata in Washington Land (fig. 1) were mapped by Koch (1929; see also Cowie, 1971) on the basis of crude lithological comparison with the section from Inglefield Land, to the south-west. However, confirmatory fossil evidence was lacking and strata considered to be both Precambrian and Ordovician by Koch (1929) are now assigned to the Cambrian. Poulsen (1927) described early Ordovician faunas and stratigraphy while Troedsson (1926, 1928) and Teichert (1937) discussed the middle and late Ordovician. Troelsen (1950) revised earlier stratigraphic schemes, interpolating extra formations into the Ordovician sequence. Silurian strata and fossils have been described by Poulsen (1934, 1941, 1943) and Norford (1972).

Recent work by GGU, during the seasons 1975–1977, has been partly summarised by Henriksen & Peel (1976) and Peel (1977), but is yet largely unpublished. Information given below is mainly taken from this work in progress.

Early, Middle and Late Cambrian are represented in Washington Land whereas only the Early Cambrian has been demonstrated in the Børglum Elv sequence. An un-named formation of sandstone with *Skolithos* and interbedded glauconitic sandstone and siltstone with *Cruziana,* exposed in south-eastern Washington Land, forms the basal unit. The glauconitic sandstone–siltstone alternation is reminiscent of the higher beds of the Buen Formation, as exposed on the western slopes of Pyramideplateau, which may be of approximately equivalent age – Early Cambrian. In both areas deposition of thick dolomite units follows.

The dominantly dolomite Kastrup Elv Formation (*c.* 145 m) of Washington Land has only yielded fossils in the uppermost few metres where Middle Cambrian trilobites were first discovered by Greenarctic Consortium geologists (Dawes, 1976a). Succeeding limestone of the Telt Bugt Formation (*c.* 40 m) also contains rich faunas of Middle Cambrian trilo-

bites, as does the lower part of the overlying Cass Fjord Formation (*c.* 470 m). This latter formation, previously referred entirely to the Early Ordovician, has also yielded diverse Late Cambrian faunas throughout much of its thickness (Dawes, 1976a; Henriksen & Peel, 1976). Early Ordovician faunas are known only from the highest beds.The Cape Clay, Christian Elv, Poulsen Cliff and Nygaard Bay Formations (*c.* 300 m) of Early Ordovician (early Canadian) age seemingly follow conformably and are in turn overlain by the later Canadian Cape Weber and Nunatami Formations, all yielding good faunas.

Middle and Upper Cambrian rocks are seemingly absent from the Børglum Elv section, although it is not inconceivable that the upper part of the Brønlund Fjord Formation is partly of this age. Lower Canadian deposits are also missing with the Ordovician first represented by the late Canadian (late Early Ordovician), and younger, Wandel Valley Formation. The latter contains *Ceratopea* (Yochelson & Peel, 1975), now also recorded from the Nunatami Formation.

The Cape Webster Formation of southern Washington Land (early Middle Ordovician?) contains thin bedded, alternating dilomite and siltstone possibly equivalent to the upper member of the Wandel Valley Formation. Both units lack diagnostic fossils but occupy similar stratigraphic positions.

Of particular note is the transgression resulting in the change from pale dolomite to dark limestone marked by the Børglum River Formation in the Børglum Elv region and the Gonioceras Bay Formation in Washington Land. Early beds of both these units, which appear to be of Black River age (Middle Ordovician), gradually succeed the underlying dolomite units. Generally similar limestone deposition with the characteristic Arctic Ordovician fauna continued in both regions during the Late Ordovician.

The Silurian of Washington Land, as currently known, comprises a thick facies complex of carbonate mounds and laterally equivalent dark shale and limestone conglomerate facies (Norford, 1972; J. M. Hurst, personal communication, 1976).The sequence differs greatly from the flat-bedded sequence of Børglum Elv where carbonate mounds are considerably more restricted both in size and distribution. The Silurian of Børglum Elv extends from the Early or Middle Llandovery through to the Ludlow. A comparable age range has not yet been demonstrated in Washington Land, although the sequence possibly occupies a greater time range than the approximately Late Llandovery age suggested by the as yet rather restricted studies.

Kronprins Christian Land

Descriptions of Cambrian – Silurian strata and faunas in Kronprins Christian Land are given by Adams & Cowie (1953), Cowie (1961, 1971), Lane (1972), Scrutton (1975) and Dawes (1976a).

The Danmarks Fjord Formation (10 m of dolomite) appears to correlate with the much thicker Brønlund Fjord Formation of Early Cambrian age. Underlying clastics and carbonates of the Campanuladal, Fyns Sø and Kap Holbaek Formations (in all 710 m), the latter with *Skolithos,* similarly seem to compare with the Early Cambrian Buen and Portfjeld Formations in southern Peary Land, although diagnostic Cambrian faunas are not recorded.

The succeeding Amdrup Formation in Kronprins Christian Land has yielded an Early Ordovician (late Canadian) fauna, demonstrating an apparent stratigraphic break between

the Early Cambrian and the late Canadian comparable to that found in southern Peary Land. The overlying Centrum Formation (2050 m) is approximately equivalent to the Børglum River Formation of Middle to Late Ordovician age.

The presence of Lower and Middle Llandovery strata, apparently present in southern Peary Land, was not demonstrated by Adams & Cowie (1953) and subsequent workers on their material. Scrutton (1975) suspected that some of the earlier Llandovery had been cut out. However, geologists of Greenarctic Consortium (personal communication *in* Dawes, 1976a) recorded *Virgiana* from the area, seemingly indicating that at least the Middle Llandovery is represented, possibly as the highest levels of the Centrum Formation.

As in Peary Land, clastic sediments replace carbonate rocks in the Middle Silurian in Kronprins Christian Land, where shales of the Profilfjeldet Formation overlying limestone of the Drømmebjerg Formation have yielded late Wenlock graptolites (Strachan *in* Lane, 1972).

East Greenland

The statigraphy of the Cambro-Ordovician sequence of East Greenland between 72° and 74° N has been described by Cowie & Adams (1957). A recent summary is given by Henriksen & Higgins (1976).

Lower Cambrian clastic sediments with trace fossils are followed by carbonates with rich Early Cambrian faunas (Poulsen, 1932; Cowie & Adams, 1957). Overlying dolomite and calcareous dolomite of the Dolomite Point Formation (*c.* 400 m) have not yielded fossils so that direct evidence for the presence of Middle and Upper Cambrian rocks is not available, as is also the case at Børglum Elv.

Muddy limestone of the overlying, so-called Cass Fjord Formation (270 m) is mainly of Early Canadian (early Early Ordovician) age and, together with much of the overlying Cape Weber Formation (*c.* 1100 m), forms a time interval apparently without representative deposits in the Børglum Elv section in southern Peary Land. Upper beds of the Cape Weber Formation and lower, *Ceratopea*-bearing beds of the overlying Narhval Sund Formation (Yochelson, 1964) are of Late Canadian (late Early Ordovician) age, equivalent to the lower and middle members of the Wandel Valley Formation. The presence of *Ceratopea,* a characteristic Late Canadian gastropod, in the lower Narhval Sund Formation would seem to refute the suggestion made by Fortey & Bruton (1973) that the higher beds of the Cape Weber Formation may be of Whiterock (early Middle Ordovician) age.

The succeeding Heim Bjerge Formation (320 m) possibly ranges from the Middle Ordovician into the Late Ordovician, and can probably be loosely correlated with the lower part of the Børglum River Formation.

Southern West Greenland

Blocks of Palaeozoic limestone and dolomite occur as a fissure filling unofficially known as 'Fossilik' in the Precambrian gneissic basement near Sukkertoppen at about 65°40'N (Poulsen, 1966). A range in lithologies is present, including pale fine grained dolomite resembling parts of the lower member of the Wandel Valley Formation and brownish grey limestone comparable to the Gonioceras Bay Formation of Washington Land. Fossiliferous material is scarce but Poulsen (1966) reported poorly preserved trilobites, brachiopods

and graptolites probably of Middle Ordovician age, to which may be added similar aged conodonts and scolecodonts (Stouge & Peel, in press). There is currently too little material available to deduce the relationship to either North or East Greenland, or the Canadian Arctic, but the occurrence is of considerable interest in demonstrating the former wide distribution of at least Middle Ordovician rocks over the Precambrian Shield areas of Greenland.

LOWER PALAEOZOIC OF NY FRIESLAND, SPITSBERGEN

The group of islands comprising Svalbard preserves a number of Lower Palaeozoic sections in close geographical proximity to North Greenland. A recent comparative summary of the sequences in the two areas has been presented by Fortey & Bruton (1973) while describing the Cambrian – Middle Ordovician section from northern Ny Friesland, Spitsbergen. Only the early subdivision of the Cambrian is present in Ny Friesland, as in the Børglum Elv region, with basal clastics of the Tokammane Formation succeeded by dolomite units of variable lithology, including intraformational conglomerates.

The succeeding Kirtonryggen Formation begins with richly fossiliferous Lower Canadian limestone (20 m), followed by Middle Canadian alternating dolomite and limestone (250 m). Deposits of this age are not recognised in the Børglum Elv section. The uppermost 220 m of the Kirtonryggen Formation consists of limestone of Late Canadian age, with a rich fauna of trilobites quite unlike the *Ceratopea* fauna from the dolomite of the apparently equivalent lower parts of the Wandel Valley Formation.

The Valhallfona Formation (*c.* 225 m) of Late Canadian – Whiterock age represents a dramatic change in lithology with dark limestone overlying the white limestone of the Kirtonryggen Formation. The change can perhaps be correlated with the similar prominent colour change occurring between the light coloured lower member, and dark coloured middle member of the Wandel Valley Formation (figs 2,10). The lithologies are somewhat different in the two areas but in each case can be interpreted in terms of increasing water depth.

The *Ceratopea* assemblages of the dolomite and dolomitic limestone of the Wandel Valley Formation probably represent a more nearshore assemblage than the trilobite assemblages recognised by Fortey (1976) in the various limestones of the Valhallfonna Formation. A sequence from a nearshore *Ceratopea* assemblage, through illaenid-cheirurid and nileid assemblage types to an offshore olenid assemblage can possibly be postulated, perhaps with increasing distance from the stable Greenland craton. The situation parallels Early Ordovician palaeoenvironments described by Ross (1976) in the western United States where a nearshore *Ceratopea* assemblage in dolomite, developed under high salinity conditions, passes offshore into limestone with bathyurids and hystricurids deposited in more normal marine environments.

The highest beds of the Valhallfonna Formation contain rich faunas of early Middle Ordovician (Whiterock) age. This time interval is probably represented in the Børglum Elv region by the lower part of the upper member of the Wandel Valley Formation, although

age confirmation from fossils is lacking. Younger Ordovician strata are not represented in the sequences described by Fortey & Bruton (1973) from northern Ny Friesland.

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APPENDIX

Measured sections, Børglum Elv region

The location of the principal stratigraphic sections measured during 1974 is indicated in fig. 3, A–H, J.

A *Brønlund Fjord and Wandel Valley Formations, southern side of Pyramideplateau*

Unit no.	Lithology	Thickness (metres)
	Top of section: erosion surface	
	Wandel Valley Formation	
	Upper member	
9	Dolomite; medium bedded, light grey weathering. Thickness not measured.	
	Middle member	
8	Dolomite; competent, very dark grey, mottled dark grey weathering; beds 5 to 20 cm thick, with nodular surfaces. Chert lenses and beds very abundant, especially in lower part. Vugs (up to 9 × 5 cm, some lined by pink dolomite crystals) occur in some beds. Bioclastic textures are more apparent in the upper part of the unit, with fragments of gastropods and brachiopods. Basal contact with underlying light weathering beds is sharp and conformable.	60
	Lower member	
7	Dolomite; thin to medium bedded, fine grained, light grey weathering, with thin silty laminae. Fragmental textures are evident. Some beds are coarser grained, sugary in texture. Pale brown weathering colours and light yellow weathering chert lenses occur in the upper part. Two distinctive beds of dark grey weathering dolomite, one over 2 m and the other about 1 m thick, occur in the upper part of the unit.	28
6	Dolomite breccia; fossiliferous, dark grey, banded. Bands consist of black weathering, massive dolomite and cyclic beds of graded, clastic dolomite weathering dark grey. Tabular fragments up to 2 cm, and entire gastropods observed in the clastic beds. The fossils (GGU 184043, including *Ceratopea*) are silicified, and stringers and formless masses of silica are also present. Vugs, up to 4 cm and partially filled by pink carbonate crystals, are present particularly in the upper part.	2
5	Dolomite; thin bedded, very fine grained, light grey, weathering very light grey. Silty laminae are evident on some weathered surfaces. Pyrite nodules up to 1 mm. Clastic textures are more apparent higher in the unit; graded beds and flake-like fragments observed.	20
4	Dolomite; medium bedded (10 to 50 cm), fine grained, light grey. Interbeds are fragmental, with flakes (up to 3 cm) of dark dolomite in a light grey dolomite matrix. Basal contact not exposed.	20
	Brønlund Fjord Formation	
	Member D	
3	Dolomite; very thick bedded, light yellow to orange weathering; thinly laminated at the base, becoming coarsely crystalline and vuggy without laminae toward the top.	30
	Member C	
2	Dolomite; dark grey, laminated (2 cm) beds may be irregular, nodular, and show 'boudinage' structure. Basal beds appear to be conformable to unit 1.	40

Member B

Unit no.	Lithology	Thickness (metres)
1	Dolomite; light yellow weathering, thinly laminated (1 cm). Base of unit not exposed.	5

Underlying beds not exposed.

B *Buen and Brønlund Fjord Formations, south-west side of Pyramideplateau*

Unit no.	Lithology	Thickness (metres)

Overlying beds of the Brønlund Fjord Formation not examined.

Brønlund Fjord Formation

Member C

8	Dolomite; dark grey, thin to medium bedded (up to 10 cm thick); weathering dark purplish-grey. Irregular patches and cross-cutting veins of light mineral, presumably dolomite, are abundant. Upper contact not examined, thickness is not a measure of the unit. Basal contact appears to be sharp and conformable.	25 +

Member B

7	Dolomite; dark grey, purple-grey, and light grey, well bedded or banded, weathering light yellow upwards. The banding results from alternating layers of light and dark weathering rock; separating surfaces are variously nodular to very irregular. Mottling, bioturbation and 'pseudo-brecciation' apparent. Dips vary in direction, and range in magnitude up to 10°. The basal contact is sharp and apparently conformable with the underlying breccia, although some variation in the section height of the lithological change is evident.	20–29
6	Dolomite breccia; a spectacular breccia in which small to large clasts of lighter weathering dolomite lie in a darker dolomite matrix. Most of the smaller fragments are rounded and of uniform texture, but some have coarsely crystalline centres. Some of the small fragments and most of the larger ones, especially when of tabular shape, are banded or bedded. Clasts up to 20 cm in diameter and 2 cm thick were observed. Complete disorder occurs in many places, but the breccia apparently passes upward into a nearly normally bedded rock in which large (up to 40 cm) clasts are only slightly displaced.	1–10

Member A

5	Dolomite; fossiliferous, grey, medium grained with irregular, nodular and stylolitic bedding planes 2 to 10 cm apart. Dark brown (phosphatic?), fossil-rich material occurs discontinuously along bedding planes; a particularly fossiliferous bed lies 30 to 40 cm below the upper contact (GGU 184022). The upper contact of the unit is very sharp, with small amoeboid fingers of matrix of the overlying breccia intruding the uppermost bed.	3

Buen Formation

4	Covered interval.	10
3	Sandstone, shale; interbedded; beds up to 12 cm thick. The sandstone is light grey, medium to fine grained, well-sorted, glauconitic(?). Cross-bedding and slumps are common, with very variable directions of transport indicated. Shale interbeds are green-grey, and silty; bedding surfaces are characteristically burrowed. The unit becomes slightly thicker bedded upward, where the sandstone is finer grained and cross-bedding less apparent. The top of the unit weathers to a conspicuous bright yellow-green sludge.	20
2	Covered interval.	55
1	Shale, sandstone; green-grey, flaky shale with minor quartzitic sandstone beds up to 2 cm thick; bedding planes wavy.	15

Underlying beds of Buen Formation not exposed.

C *Buen and Brønlund Fjord Formations at Brillesø*

Unit no.	Lithology	Thickness (metres)
	Overlying beds of the Brønlund Fjord Formation: not examined.	
	Brønlund Fjord Formation	
	Member C	
6	Dolomite; dark grey weathering, well bedded (2–15 cm). Continuous beds about 2 cm thick alternate with less regular or discontinuous units with lighter grey, irregular patches in a dark grey weathering matrix. There appears to be a gradation from beds with irregular or wavy bedding, through discontinous beds with boudinage structure to a breccia in which bed fragments are displaced and contorted. Upper contact not examined, thickness is not a measure of the unit. Basal contact is sharp and undulating with a distinct contrast in lithology and colour. Beds of unit 6 appear to fill depressions in the underlying surface in places.	20
	Member B	
5	Dolomite; mainly grey, thinly laminated (0.5–2 cm) with widely spaced bedding joints. Other lithologies, mainly in the upper part, are: massive grey dolomite; vuggy and variegated light grey bedded dolomite; and light grey to light yellow dolomite breccia. The brecciated rock is discontinuous, and may be equivalent to one or more of the other types; relationships are not clear. Bedded dolomite appears in places to pass upward into vuggy, more thickly banded dolomite and into cavernous breccia. The rock becomes more coarsely crystalline upward and weathers light yellow. Some breccias are reddish weathering. The uppermost surface of the unit is a prominent undulating surface, with waves tens of metres across with a relief of up to 2 m, which appears to truncate gently dipping bedding in places.	25
4	Covered interval.	95
	Buen Formation	
3	Not exposed, but abundant float of sandstone; dark green-grey, fine grained, impure, tightly cemented. Thin bedded, with wavy bedding planes. Abundant biogenic and mechanical bottom structures. Sand pipes (vertical water transport) may be present.	30
2	Covered interval.	8
1	Shale; dark blue-grey, weathering dark green-grey, often with a bluish surface stain. Under a hand lens the fissile shale appears slightly micaceous. Trilobite and other fossils scattered throughout (GGU 184002-8).	35
	Underlying beds of Buen Formation not exposed.	

D *Wandel Valley Formation, south of Domkirken*

Unit no.	Lithology	Thickness (metres)
	Overlying beds of upper member, Wandel Valley Formation not examined.	
	Wandel Valley Formation	
	Upper member	
13	Dolomite; light and dark grey; prominent slump horizon (see also section E, F, unit 5) silty banding warped and broken to form breccia with clasts up to 8 cm long.	3
12	Dolomite; dark and light grey, thin bedded; both massive, sugary textured and fine grained, laminated dolomite are present. Pink weathering dolomite forms veins and linings of vugs up to 10 cm long. The form of the larger vugs suggests replacement of algal domes. Gastropods scattered over weathered surfaces (GGU 184195).	7
11	Dolomite; light grey forming a distinctive competent bed ('Marker Ledge', see also section E, F, unit 3).	4

10 Dolomite; thin bedded becoming medium bedded upwards; weathering pale purplish-grey; dark violet-grey on fresh surface. Weathered surfaces appear silty, with fine laminae. Pale yellow weathering chert is present as nearly continuous, lensoid beds up to 5 cm thick. 18

Middle member

9 Dolomite; competent, medium to thick bedded; very dark grey weathering. Breccia beds and mottled beds interlayered, with abundant lenses of black chert. Light pink weathering dolomite occurring as patches and linings of vugs up to 1 cm in diameter is abundant and conspicuous. Silicified cephalopods and gastropods occur in several beds, especially in breccia (GGU 184192). 34

8 Dolomite; very dark grey to black; weathers dark grey. Mainly medium bedded; minor thin beds. Silty laminated beds, mottled beds, and breccia beds alternate. Mottling consists of light brown, amoeboid patches in a dark brown to dark grey weathering matrix in which, on a weathered surface, faint silty? laminae are evident. Breccias with dark grey clasts (up to 2 cm) in a matrix of lighter grey weathering rock. Some brown weathering, but mainly black chert nodules and beds are common. Certain horizons rich in poorly silicified gastropods (GGU 184190). Pale grey weathering beds in the upper part of the unit form a distinctive marker horizon. 39

7 Dolomite; mixed dark and light grey beds; medium bedded. The dark dolomite is strongly silicified, and mottled on weathered surfaces. About 1.5 m from the base of the unit fine breccia in the dark beds gives way to silty laminae. The light dolomite weathers with a pinkish, silty, laminated surface. Silicified gastropods on weathered surfaces (GGU 184189). 34

Lower member

6 Dolomite; very light grey weathering, silty, with three thin (10 to 40 cm) dark weathering interbeds. Medium bedded. One massive bed weathers to a light pinkish buff colour. 7

5 Dolomite; distinctive, very dark grey bed. Medium grained, with mottling due to irregular, contrasting patches of very dark grey and dark grey weathering dolomite. The unit is strongly marked by black chert lenses and by veins and patches (up to 4 cm) of pink dolomite crystals. Silicified gastropods or bedding surfaces (GGU 184185). Pockets of breccia occur above about 30 cm from the base of the unit, with clasts varying from angular and flat, to small and well-rounded. 3

4 Dolomite; grey to light grey, weathering very light grey; medium to thin bedded. The beds are alternately medium grained, massive or nearly massive, and fine grained with conspicuous thin, silty laminae. The laminae are variously uniform and distorted, or may appear brecciated. Poorly silicified gastropods and cephalopods may be locally abundant. A thin, very dark grey dolomite bed lies near the base of the unit. 23

3 Dolomite, dolomite breccia; distinctive, dark grey weathering bed. The bed comprises three quite differing layers. A thick basal layer consists of interlaminated medium and fine grained silty dolomite; laminae in the upper part are truncated by the overlying breccia layer, consisting of angular fragments (up to 3 cm) of light weathering, silty dolomite in a dark grey dolomite matrix. The upper layer, very dark grey, medium grained dolomite with patches and veins of white dolomite, overlies the breccia with an undulating to irregular surface, and is rich in silicified gastropods (GGU 184179, 184180). 0.8

2 Dolomite; thin to medium bedded (10–70 cm), fine to medium grained, grey, light grey weathering. Most beds display wavy silty laminae on the weathered surface. Chert nodules and thin layers become abundant upward, where thin beds of fine breccia also occur. 10

Brønlund Fjord Formation

1 Dolomite breccia; medium grained, sugary texture; weathering light yellow-grey. Fragments, weathering to a lighter colour than the matrix, are often thin flakes up to 50 cm long, perhaps algal slabs. Small silicified algal domes are present.

Underlying beds of the Brønlund Fjord Formation not examined.

E, F *Wandel Valley and Børglum River Formations, near Domkirken*

Unit no.	Lithology	Thickness (metres)
	Overlying beds of Børglum River Formation, not examined	
	Børglum River Formation	
	Lower member	
13	Limestone (dolomitic); mottled, dark grey, grey to brownish grey weathering, thick bedded, with abundant fossils, including *Maclurites* and tabulate corals (GGU 184174). Black chert lenses occur throughout, and are very abundant above about 30 m. Distinctive mottling, with grey-brown, medium crystalline dolomite in a matrix of fine grained, dark grey limestone tends to parallel the bedding. Total thickness of unit not measured.	85
12	Limestone; dark grey, medium bedded. A basal, breccia bed, with abrupt change from underlying dolomite, contains angular fragments up to 10 mm; immediately overlying beds or laminae are distorted as though by slumping of soft sediment. Scattered gastropods.	10
	Wandel Valley Formation	
	Upper member	
11	Dolomite; thin and medium bedded at base of unit, becoming medium bedded upward; grey weathering, with a few dark grey bands. The rock is mainly fine grained, with silty laminae and some microbreccia and slumps.	50
10	Dolomite, dolomitic shale; medium to thick bedded, uniformly laminated, fine grained, grey; bedding surfaces somewhat irregular. Dolomitic shale forms a minor component; associated with disturbed laminae and possible soft-sediment deformation at bedding contacts.	23
9	Dolomite, shale; medium and thin bedded, yellow-grey weathering. Silty laminae, evident, often warped. Fine intraformational breccias, graded beds, and vertical water-transport pipes evident. A bed of shale 1.5 m thick lies near the top of the unit. Above this, a rude cyclicity is developed in which laminated beds pass into beds with disturbed laminae, which in turn pass gradually upward into fine grained, massive grey dolomite.	27
8	Covered interval.	18
7	Dolomite, shale; thin to medium bedded, dark to light grey, uniform to wavy bedding. Fissile interbeds give a shaly appearance, although only a few thin beds are shale. Vertical pipes and microbreccias due to vertical transport of water.	27
6	Covered interval.	23
5	Dolomite, dolomite breccia; (prominent slumped horizon of section D, unit 13), fine grained, brown weathering, with silty laminae. The laminae are wavy to slumped and broken to form autobreccia. Chert is abundant as large, irregular knots and as bands perhaps replacing dolomite fragments.	5
4	Dolomite; thin bedded, fine grained, light grey, weathering very light grey; some interbeds slightly limy. Intraformational breccia at the base of the unit. Numerous white dolomite patches and veins.	7
3	Dolomite; competent, ledge forming unit ('Marker Ledge' unit 11 of section D); light grey to light buff brown weathering, but dark grey on fresh surface. Bedding planes and silty laminae are wavy; upper beds are mottled and marked by a siliceous network.	6
2	Dolomite; thin to medium bedded, light mauve-grey weathering. Fresh surfaces are grey to dark grey; a silty texture is apparent on weathered surfaces.	9
1	Dolomite; medium bedded, very dark grey to black, weathering dark grey; weathered surfaces mottled, with buff-weathering network in a dark grey matrix or dark grey network in a lighter grey matrix. White dolomite crystals present as patches up to 10 mm. Chert present throughout, but more abundant in upper part. Scattered gastropods.	49
	Underlying beds of Wandel Valley Formation not examined.	

G *Wandel Valley and Børglum River Formations, and un-named Silurian dolomite formation, near Vestervig Elv*

Unit no.	Lithology	Thickness (metres)
	Top of section: erosion surface	
	Un-named Silurian dolomite formation	
	Upper member	
18	Dolomite; medium to thick bedded, competent, very dark grey. Pentamerid brachiopods occur near the top of the section (GGU 184163).	55
17	Dolomite; alternating light grey and dark grey weathering beds, with light beds dominating.	19
16	Dolomite; medium bedded, dark grey, weathering dark grey with light coloured patches of calcite. Pentamerid brachiopods occur at the top of the unit (GGU 184162).	19
	Lower member	
15	Dolomite; medium bedded, uniform light grey, recessive.	58
	Børglum River Formation	
	Upper member	
14	Limestone; recessive, medium bedded, dark grey to grey, mottled, yellow-grey weathering; similar to unit 13 but less competent. *Maclurites*, tabulate corals and other fossils occur throughout (GGU 184161).	57
13	Limestone; competent, thick bedded, mottled grey-brown, very fossiliferous (GGU 184158). Closely spaced silty or argillaceous partings result in fine, rubbly debris. Recessive, brown weathering mottling component is evidently less calcitic than positive, grey weathering material (unlike unit 9, where the dark grey, positive network is dolomitic).	42
12	Limestone; medium bedded, recessive, very fine grained, grey, weathering grey to yellowish-grey. Bedding is irregular, and the presence of numerous silty partings results in rubbly debris. Richly fossiliferous; brachiopods, gastropods, trilobites, cephalopods, corals (GGU 184155). Basal contact with the underlying, competent dolomitic limestones abrupt and very fossiliferous.	30
	Middle member	
11	Dolomite, dolomitic limestone; interbedded, dark grey dolomite and grey dolomitic limestone. Both rock types are mottled, the dolomitic limestone more heavily so than the dolomite.	30
10	Limy dolomite; thick bedded, dark grey, weathering dark grey, slightly mottled. The rock appears similar to unit 9, but with the dark component more abundant; the contact is abrupt.	10
	Lower member	
9	Limestone; thick bedded to very thick bedded, strongly mottled, as unit 8. Abundant poorly silicified fossils, especially *Maclurites*. Horizontal burrowing pronounced.	140
8	Limestone; thick bedded to very thick bedded; dark grey, strongly mottled. Mottling results from a dark grey (dolomitic?) network in a light yellow-grey, recessive matrix; the mottling appears connected with horizontal burrows. Black chert forms nearly 10 % of the rock near the base of the unit; silica also replaces parts of the mottling. Fossils, including corals, cephalopods, trilobites, and gastropods and stromatoporoid domes are abundant and often silicified. *Maclurites* is characteristic.	55
7	Limestone; thick bedded, medium grained, dark grey. Weathered surfaces are dark grey and brownish-grey, strongly mottled. The mottling is due to a network of more coarsely crystalline, lighter brown-grey rock in a fine grained, dark grey matrix, and is in part bioturbation with large horizontal burrows. The mottling network is mainly parallel to bedding but amoeboid and sub-columnar structures also are apparent perpendicular to bedding. Chert nodules and poorly silicified fossils are present.	52
6	Limestone; medium bedded, grey to dark grey, weathering dark grey. Little change in general character from unit 5, but the transition to limestone is abrupt. Richly fossiliferous (GGU 184149). Bedding planes are irregular, and a weak mottled effect is apparent on weathered surfaces. Slight silicification of bedding planes and some fossils is apparent.	15

Wandel Valley Formation

Upper member

Unit no.	Lithology	Thickness (metres)
5	Dolomite; medium bedded, grey, weathering various shades of light grey and grey. Fractures in one bed filled by black, powdery bitumen (?) and a petroliferous odour is produced on breaking the rock. Laminated and breccia beds are present. Carbonate (some calcite) patches, lenses, and veins present in upper beds.	23
4	Dolomite; medium bedded, fine to medium grained, similar to units 1 and 3 but without shale fraction. Weathering colours are various shades of grey, brownish-grey, and mauve-grey. Silty laminae and microbreccia evident. Dome-shaped and linear, laminated 'rolls' associated with breccia layers appear to be due to slumping of soft sediment. The linear features trend northerly.	32
3	Dolomite, shaly dolomite; medium bedded, fine grained grey, weathering light grey. Silty laminae conspicuous; chert nodules and lenses abundant in some beds. Intraformational breccia beds and local breccia zones numerous. Disrupted laminae probably due to vertical water transport. Shale beds form about 10 % of the unit, which becomes thicker bedded near the top where the dolomite weathers to a distinctive pinkish to pale brown-grey colour.	12
2	Covered interval.	10
1	Dolomite; shaly dolomite; medium bedded, fine grained, grey, weathering light grey. Bedding planes flat to slightly wavy. Silty laminae visible on weathered surfaces are variously distorted and brecciated. Some black chert lenses and shaly dolomite interbeds.	26

Underlying beds of the Wandel Valley Formation not exposed.

H *Un-named Silurian dolomite and limestone formations, downstream of junction between Børglum Elv and principal un-named north-western tributary*

Unit no.	Lithology	Thickness (metres)
16	Shale in black weathering knolls on upland; not examined.	

Un-named Silurian limestone formation

Member F

15	Limestone; medium to thin bedded, recessive, with wavy or irregular bedding surfaces and silty partings in the upper part of the unit. The beds become thicker and less silty downward and pass gradationally into the biogenic beds of unit 14. A rich fossil horizon about the middle of the unit contains gastropods, brachiopods, trilobites, cephalopods, and corals (GGU 184125). Upper contact of unit 15 not examined.	35

Member E

14	Limestone; thick bedded, biostromal dark grey, weathering yellow-grey. Large hemispherical stromatoporoids and tabulate corals often comprise 50 % of the volume. Many colonies are in growth position, and others are 'tumbled'. Minor interbeds of massive fine grained limestone observed. Black chert nodules abundant above about 65 m above base of the unit. Irregular parting in the rock results in rubbly debris upon weathering (GGU 184122, 184123).	100
13	Limestone; medium bedded, mainly dark grey, mottled as in unit 12, but in the upper part light grey weathering.	10

Member D

12	Limestone; thick bedded, competent, very dark grey, weathering grey to yellow-grey, is conspicuously mottled. Richly fossiliferous with silicified corals and stromatoporoids in growth position and tumbled, non-silicified brachiopods. Chert nodules, weathering light grey occur in the upper part (GGU 184118, 184120).	30

Member C

11	Limestone; thin bedded to fissile, fine to medium grained, black, weathering dark yellow-grey. Ostracodes (GGU 184117).	4

10	Limestone; thick bedded, fine grained, alternating light grey and grey weathering. Darker beds are more or less mottled with silicified stromatoporoids and colonial corals.	25
9	Limestone; medium and thin bedded, fine grained, dark grey, weathering light grey to yellow-grey. Bedding surfaces slightly wavy. Stylolites marked by a black powder (bitumen?); some mottling. Brachiopods and large ostracodes (GGU 184114, 184115).	33
	Member B	
8	Limestone, dolomitic; thick bedded, medium grained, dark blue-grey, weathering to a distinctly mottled dark and light grey in which a coarser grained, dolomitic? network (dark weathering) lies in a fine grained (light weathering) matrix. Basal contact is abrupt, characterised by numerous fossils, mainly banks of thick-shelled pentamerid brachiopods. Corals, cephalopods, and stromatoporoids are also present, the tabulate corals generally in 'growth' position. Fossils become more abundant and more silicified in the upper third of the unit (GGU 184102, 184105, 184106, 184108).	47
	Member A	
7	Limestone: medium bedded, fine grained, grey, weathering yellow-grey. Rich in ostracodes and brachiopods (GGU 184100, 184101). A bed 2.5 m thick about the middle of the unit is rich in thick-shelled pentamerid brachiopods (GGU 184113).	35
6	Limestone; thin bedded, laminated, weathering light grey. Petroliferous odour on breaking. Calcite crystals in patches in some cases disturbung algal laminae. Ostracodes conspicuous (GGU 184098).	10
	Un-named Silurian dolomite formation	
	Upper member	
5	Dolomite; thick bedded, dark grey, medium to coarse grained. Marked by conspicuous calcite patches and by numerous branching and ? non-branching burrows 2 mm diameter.	13
4	Dolomite or limy dolomite; thin bedded, light grey weathering. Closely spaced laminae and thin, longate lenses of microbreccia evident on the weathered surface.	1.5
3	Limy dolomite: thick bedded, dark grey, weathering dark grey to nearly black. Irregular laminae and bioclastic texture evident on the weathered surface. Bedding planes are irregular with black gummy residue (bitumen?). Brachiopods occur about 10 m above the base of the unit (GGU 184094).	40
2	Dolomite; medium bedded, dark grey, weathering light grey, with laminae evident on the weathered surface. Brachiopods abundant 80 cm above base (GGU 184093).	4.5
1	Dolomite; medium to thick bedded, fine grained, dark grey, weathering dark grey. Numerous patches of calcite crystals up to 2 cm with occasional fluorite. Clasts up to 5 mm observed. Scattered fossils (GGU 184089).	20
	Underlying beds not examined.	

J *Un-named Silurian shale and flysch formations, un-named north-western tributary of Børglum Elv*

Unit no.	Lithology	Thickness (metres)
	Top of section: erosion surface	
	Un-named Silurian flysch formation	
7	Limy greywacke, shaly greywacke, greywacke sandstone, siltstone; interbedded, often cyclic; mainly thin and medium bedded, fine grained. Abundant bottom structures; some channels and cross-bedding. Minor intraformational conglomerate at the upper contact of thick beds; shale flakes up to 4 cm long lie in sandstone. Upper contact not examined; thickness is not a measure of the unit.	130
6	Limy silty shale, limy greywacke; transitional unit. Black shale grades into green-grey weathering, very fine grained limy greywacke. A layer of black carbonaceous material 1 cm thick forms an interbed.	5

Un-named Silurian shale formation

5	Shale, silty shale, limestone; shale black, soft; silty shale interbeds are slightly limy, weathering yellow-grey or green-grey; minor thin interbeds of black limestone similar to unit 3.	40
4	Shale; recessive, black. Silty, more competent beds near the top of the unit, with rare, poorly preserved graptolites.	18
3	Limestone; fine grained, black; partly fragmental. Fossils occur at the base of the unit (GGU 184064).	2
2	Shale, limestone; shale fissile; thin interbeds of black, fine grained limestone.	40

Un-named Silurian limestone formation

Member F

1	Limestone; medium bedded, becoming silty, thinner bedded, and rubbly toward the top of the unit, where fossiliferous beds also occur (GGU 184062).	30

Underlying beds of the un-named Silurian limestone formation not described.

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