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Open File Series 92/8

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Ujarassiortut Kalaallit Nunaanni Misissuisoqarfiat
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PREFACE

The main stratigraphical and structural results of the Geological Survey of Greenland expeditions to North Greenland in 1978-80 and 1984-85 have been published in Survey publications (Bulletins, Reports, Map sheets) and as numerous articles in international journals. This report provides supplementary data on aspects of early Cambrian to early Silurian outer shelf and slope lithostratigraphy of the Franklinian basin in central and western North Greenland, based on sections measured by the authors in the 1984 and 1985 field seasons. Simplified copies of these hitherto unpublished section logs are presented in an appendix, together with fossil identifications.

ABSTRACT

The Early Cambrian to Early Silurian sequence exposed in anticlinal fold cores and thrust slices between northern Nyeboe Land and Adolf Jensen Fjord represents outer shelf, slope and basin fringe environments along the southern margin of the Franklinian basin. Four formations are distinguished. Regional variations in development of each formation are described based on numerous measured sections, and reflect the transition between outer shelf and trough. Fossil determinations (mainly of trilobites and graptolites) demonstrate that the boundary between the third and fourth formation (Kap Stanton Formation/new formation of the Amundsen Land Group) is markedly diachronous, whereas the top of the Amundsen Land Group is everywhere Upper Llandovery.

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INTRODUCTION

The Lower Palaeozoic Franklinian basin extended from northern Ellesmere Island in the Canadian Arctic eastwards across North Greenland, the segment of the basin exposed in North Greenland being up to 800 km long and 200 km wide; the total thickness of the sedimentary column is up to 8 km.

A distinction can be made throughout North Greenland between a southern shelf sequence and a northern deep-water sequence. Two main facies belts characterise the shelf, a southern shallow-water carbonate-dominated platform, and a northern shale-dominated outer shelf. The boundary between these two regimes fluctuated greatly; in some periods the platform was almost drowned, while in others the platform prograded and the platform margin coincided with the shelf slope break. A deep-water basin, or trough, characterised by deposition of fine-grained sediments, sand turbidites and carbonate conglomerates was situated north of this zone.

The evolution of the North Greenland Lower Palaeozoic basin and its differentiation into a southern shelf and a northern trough was interpreted in terms of control by tectonic lineaments by Surlyk et al. (1980), a model elaborated by Surlyk & Hurst (1983, 1984). Facies boundaries along the south margin of the trough trend approximately E-W, parallel to the trough axis. Sedimentation was brought to a close in the latest Silurian or earliest Devonian by the Ellesmerian orogeny, which led to formation of the E-W trending North Greenland fold belt essentially on the site of the trough. Facies variations to some extent controlled the style of deformation, and some of the tectonic lineaments which originally controlled sedimentation were reactivated to form part of the network of thin-skinned low-angle thrusts and associated folds which characterise the south margin of the fold belt (Soper & Higgins, 1987, 1990).

This paper describes some aspects of the lithostratigraphy of the late Early Cambrian to Early Silurian sequence which outcrops in a series of anticlinal fold cores and thrust slices between northern Nyeboe Land and Adolf Jensen Fjord (Map 1). The outcrops occur within a strip of country about 280 km long from west to east and up to 25 km wide, separated from carbonate shelf rocks of equivalent age to the south by a 20-60 km wide zone of younger rocks; coeval deep-water clastic rocks outcrop in Amundsen Land, 20 km north-east of the mouth of Adolf Jensen Fjord. The sequence found within this narrow strip of country was apparently laid down in outer shelf, slope and basin fringe environments. A four unit subdivision was distinguished in the provisional description of Higgins & Soper (1985). Of these the lower two units are now recognised as formations of the Brønlund Fjord Group, the third a new formation (Kap Stanton Formation) of the Tavsens Iskappe Group and the fourth a new (unnamed) formation of the Amundsen Land Group. The general development of the sequence shows a striking resemblance to that of the Hazen Formation of northern Ellesmere Island (Trettin et al., 1991), which occupies an equivalent geological setting within the Franklinian basin.

The descriptions in this paper are based largely on field observations, including 24 complete or partial measured sections whose variations in thickness and lithology graphically illustrate the shelf-slope-basin transition. Field data has been supplemented by fossil identifications, mainly of trilobites and graptolites, which permit sufficiently precise age definition to demonstrate diachronous boundaries between some formations. Rich graptolite faunas demonstrate that the base of the Peary Land Group, marked by thick sequences of massive sandstone turbidites which abruptly overlie the Amundsen Land, is everywhere Upper Llandovery.

The locations of measured sections through the North Greenland sequence are shown in Fig. 1, and simplified section logs are presented in the Appendix together with fossil identifications.

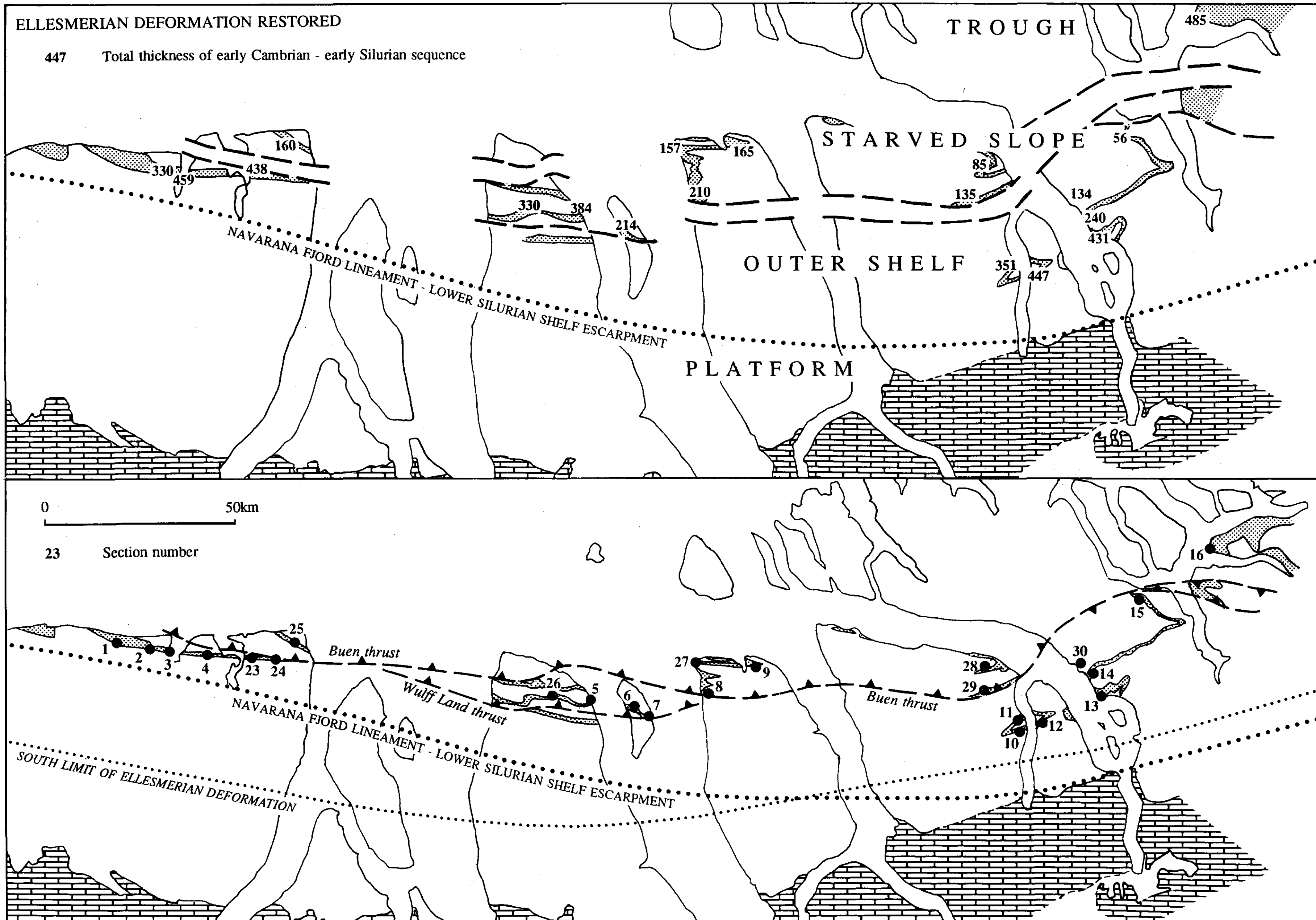


Fig. 1. Lower map shows outcrop of Lower Palaeozoic platform sequence (brick ornament) and equivalent outer shelf/slope succession (dot ornament). Locations of sections measured in the outer shelf/slope sequence are shown, and also the main Ellesmerian thrusts. Upper map depicts present land areas and outcrop after restoration of Ellesmerian deformation, as well as the total measured thickness of the outer shelf/slope sequence at different sites. See Map 1 for place names.

STRATIGRAPHICAL SETTING

The stages of development of the Franklinian basin in North Greenland have been described by Surlyk & Hurst (1983, 1984), and in more detail by Higgins et al. (1991a, b). Evolution of the basin is considered to have been controlled by tectonic lineaments, with the basin expanding in several episodes by southward shift of the southern margin to new E-W trending lineaments. Some of the lineaments responsible for control of sedimentation during the Early Palaeozoic are easily defined, but the identity of others is no longer clear as they have been reactivated as elements of Ellesmerian thin-skinned thrust zones.

The earliest stage of the Franklinian basin recognised in North Greenland (Skagen Group) is thought to be Early Cambrian by comparison with equivalent deposits in Ellesmere Island (Dawes & Peel, 1984). Later in the Early Cambrian it is possible to define a facies boundary between the shelf carbonates of the Portfjeld Formation and the equivalent trough carbonates of the Paradisfjeld Group; this boundary appears to have run westwards from outer J. P. Koch Fjord to north of Nyeboe Land, although its exact location is obscured by Ellesmerian thrusting. The present distribution of the succeeding deposits of the Buen Formation (shelf sandstones and shales) and Polkorridoren Group (trough turbidites) suggests that the shelf margin was at this time located slightly further south.

Carbonate accumulation resumed on the platform in the late Early Cambrian and continued through the Ordovician, while shale deposition dominated in the slope area which can be characterised as 'starved'. This paper is concerned with the outer shelf and slope sequences of this stage, where the total thickness deposited may be less than 100 m, but is more normally 300-450 m. The trough sequence, up to 1200 m thick, is only known from northern Peary Land (including Amundsen Land, Map 1) where it includes the thickly developed turbiditic units of the Vølvedal Group and shales and cherts of the Amundsen Land Group. Two lineaments seem to have determined the boundaries between shelf and trough deposition during this period. The northern of these, running through the northern ends of the peninsulas of Freuchen Land, Nares Land, Wulff Land and Nyeboe Land, may have marked the north margin of the shelf during the first part of this period and approximately coincides with the line of the Buen thrust (Fig. 1); the southern lineament is the Navarana Fjord lineament (Fig. 1), exposed as a platform margin scarp in the Navarana Fjord - J. P. Koch Fjord area, and extending westwards beneath younger cover to northern Nyeboe Land (Escher & Larsen, 1987; Surlyk & Ineson, 1987).

In the latest Ordovician and Early Silurian the Navarana Fjord lineament was the facies boundary separating shelf carbonate deposition to the south from turbidite deposition of the Peary Land Group to the north. The lineament took the form of a pronounced escarpment and the lowest formation of the turbiditic Peary Land Group (Merqujoq Formation) occurs only to the north. The base of the Merqujoq Formation marks the abrupt upper boundary of the outer shelf and slope sequences described in this report.

In the Upper Llandovery the outer platform foundered, and turbidite deposition expanded southwards to cover most of what is now North Greenland. The succession of formations of the Peary Land Group reflect facies variations governed by the supply of detritus from source areas in the east, principally the rising mountains of the East Greenland Caledonides (Hurst & Surlyk, 1982; Hurst et al., 1983).

The outcrops of the main geological units throughout North Greenland are shown in Map 1. The relationships between the Lower Palaeozoic shelf, slope and trough successions are depicted in Table 1.

The late Early Cambrian to Early Silurian outer shelf and slope sequence now exposed in a series of anticlinal fold cores and thrust slices occurs within a zone only 25 km wide from north to south. However, the intensity of folding in the northern parts of Nares Land and Freuchen Land indicates the strata have suffered north-south shortening of up to 40%,

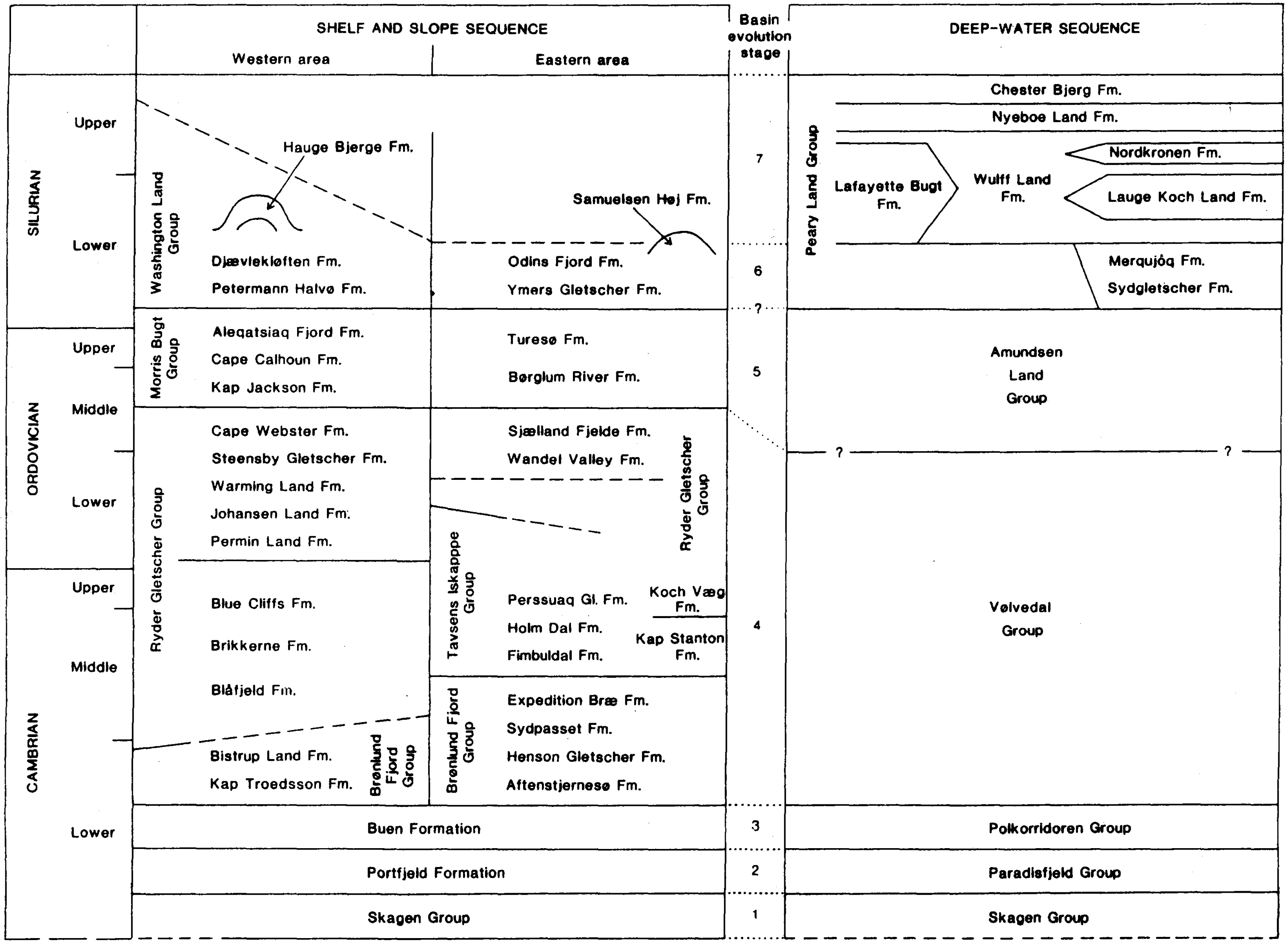


Table 1. Shelf, slope and trough lithostratigraphical divisions in North Greenland.

mainly accomodated by basement uplift north of the Navarana Fjord escarpment and displacement on two major thrusts (Buen thrust and Wulff Land thrust). In Fig. 1 (upper map) a provisional restoration for the effect of Ellesmerian deformation has been made, by extending the land masses north of the "south limit of Ellesmerian deformation" by an appropriate amount, and breaking the coast lines at the line of the Buen thrust.

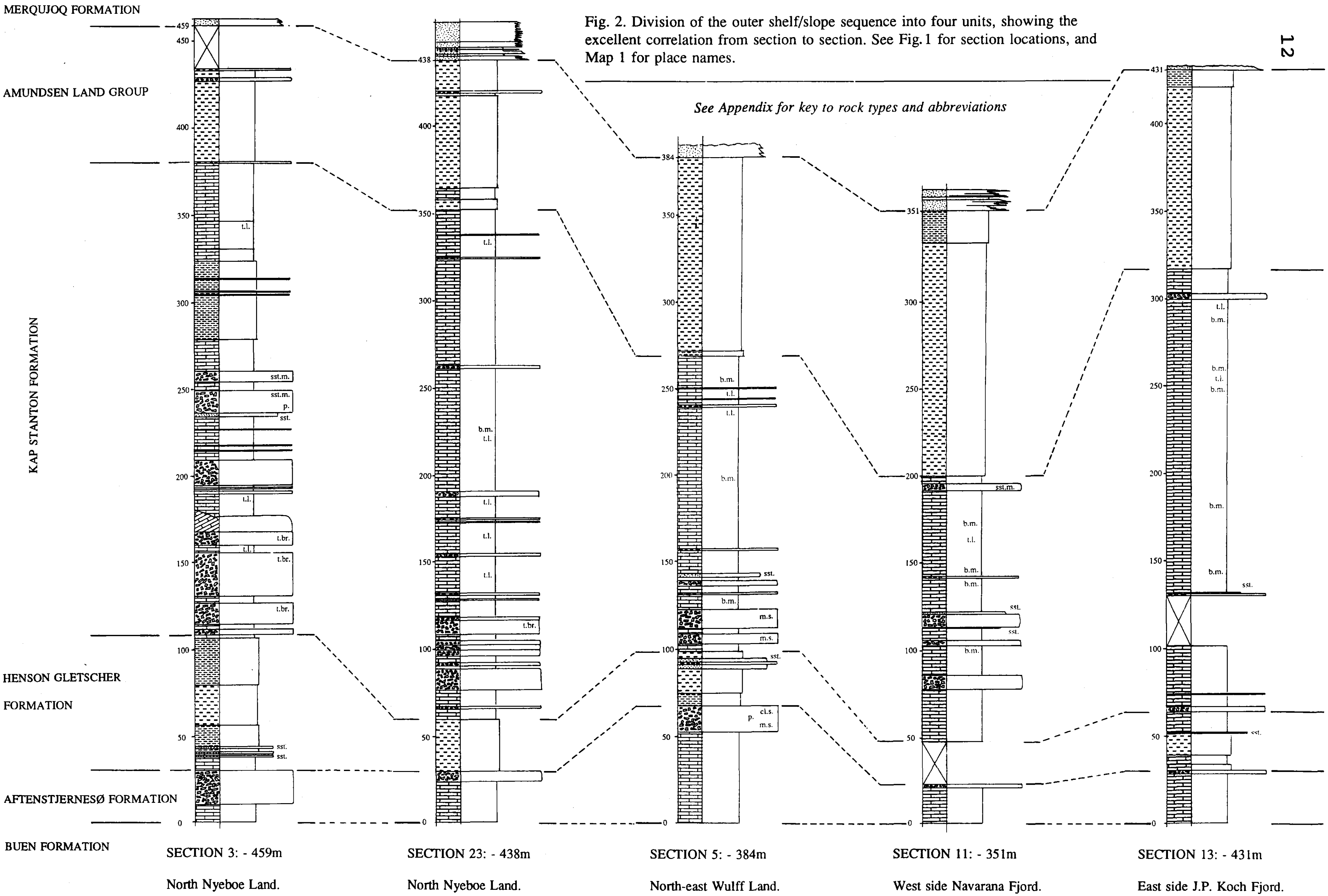
On this restored map (Fig. 1) the total thickness of the logged sections on which this stratigraphical description is based are given, and reflect the broad divisions into outer shelf, starved slope and trough. The line of the Buen thrust appears to coincide with a facies boundary. South of this thrust line the total thickness of the sequence ranges up to 459 m, and all four subdivisions are recognisable in almost every section (Fig. 2); the lower units are outer shelf facies and the upper units slope or basin fringe facies. North of this thrust the total thickness of the sequence is 56-210 m, and the environment is interpreted as starved slope or basin fringe; subdivision is sometimes possible here, but the thinnest sequences are not directly correlateable with the divisions erected farther south. Farther north again, the equivalent deep-water trough sequence, described by Surlyk et al. (in prep.), is represented by a 485 m composite section in westernmost Amundsen Land (section 16-17).

Comparisons of measured sections show clearly the northward decreases in total thickness along J.P. Koch Fjord and Navarana Fjord (Fig. 3), and between Wulff Land and north-west Nares Land (Fig. 4). Figure 3 also shows the dramatic contrast between the thin starved slope sequence (section 15) and the thick equivalent trough sequence (section 16-17).

The four part subdivision of the outer shelf sequence described by Higgins & Soper (1985) has been substantiated by further work. Their units 1 and 2 are interpreted as distal, outermost shelf correlatives of the Aftenstjernesø and Henson Gletscher Formations of the Brønlund Fjord Group (late Early Cambrian -Middle Cambrian). The third unit (Upper Middle

Fig. 2. Division of the outer shelf/slope sequence into four units, showing the excellent correlation from section to section. See Fig. 1 for section locations, and Map 1 for place names.

See Appendix for key to rock types and abbreviations



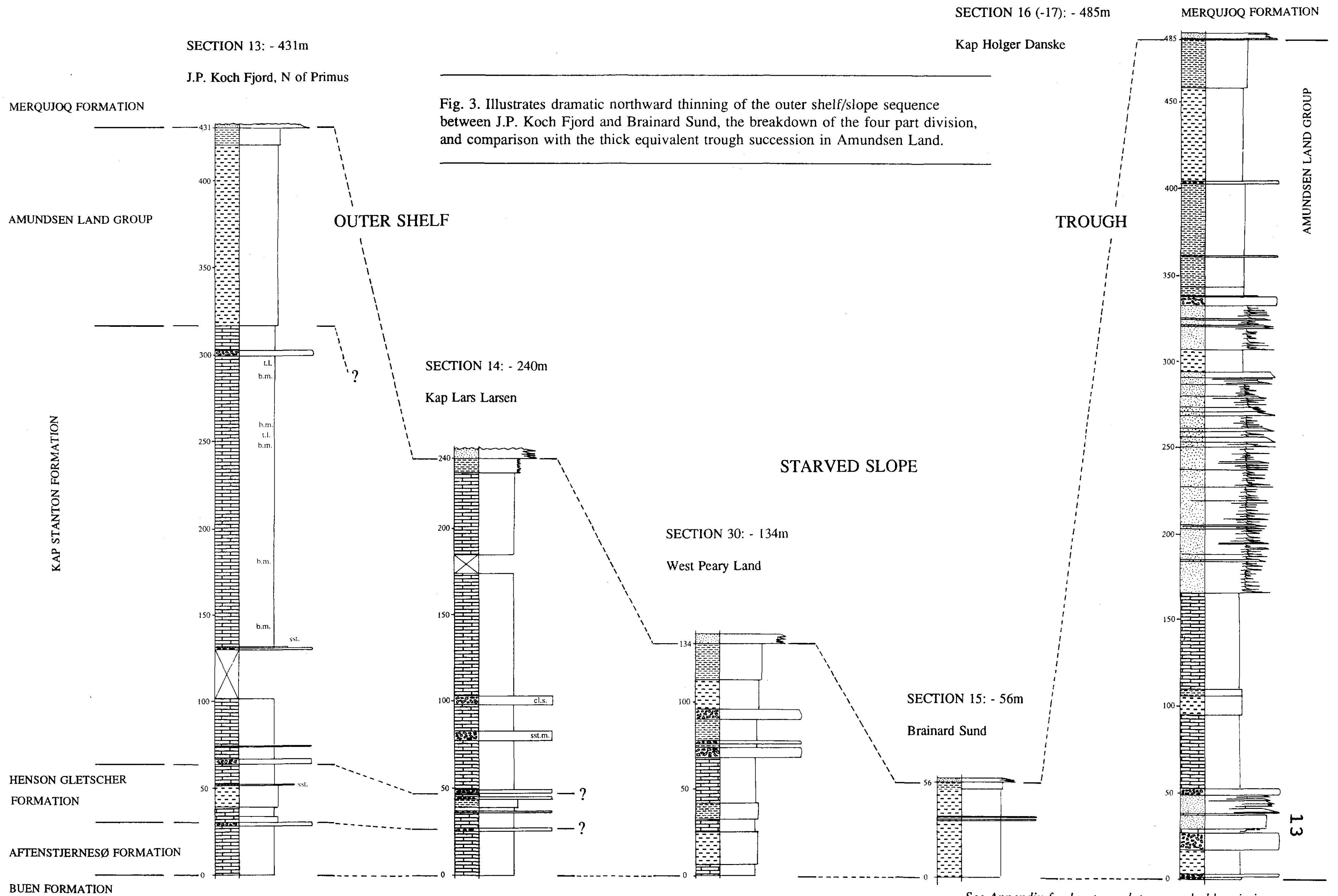


Fig. 3. Illustrates dramatic northward thinning of the outer shelf/slope sequence between J.P. Koch Fjord and Brainard Sund, the breakdown of the four part division, and comparison with the thick equivalent trough succession in Amundsen Land.

See Appendix for key to rock types and abbreviations

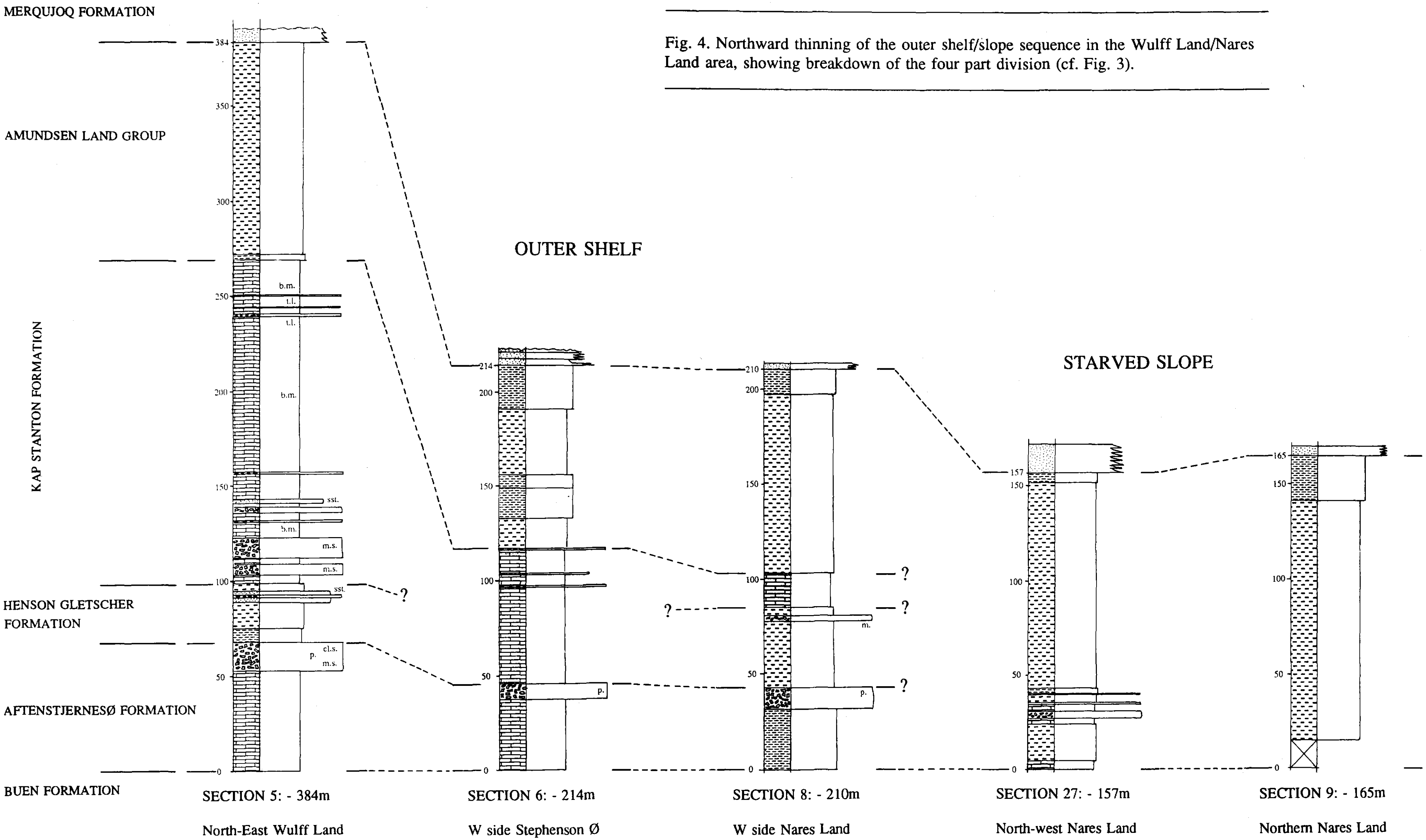


Fig. 4. Northward thinning of the outer shelf/slope sequence in the Wulff Land/Nares Land area, showing breakdown of the four part division (cf. Fig. 3).

See Appendix for key to rock types and abbreviations

Cambrian - lowermost Ordovician) is a new formation of the outer shelf Tavsens Iskappe Group, defined by Peel & Ineson (in press) as the Kap Stanton Formation. The fourth unit (lowermost Ordovician to lowermost Silurian) is largely ascribed to a new (unnamed) formation of the basinal Amundsen Land Group (Higgins et al., 1991a, b).

LITHOSTRATIGRAPHY

Buen Formation

The Buen Formation is a distinctive siliciclastic unit, uniformly developed over large areas of North Greenland, and forms a good marker at the base of the outer shelf/slope sequence. In Navarana Fjord and in northern Wulff Land the Buen Formation is about 400 m thick, the lower part characterised by coarsening upwards sandstone sequences, and the upper part by a monotonous sequence of mudstone and siltstone (Davis & Higgins, 1987). This development is closely comparable to that at the type area near Jørgen Brønlund Fjord, south Peary Land, 100 km east of the head of J.P. Koch Fjord (Map 1) (Jepsen, 1971). As the unit is traced northwards east of central J. P. Koch Fjord, in north Wulff Land and north Nyeboe Land, it thickens, passing into a sequence transitional between the typical shelf Buen Formation and the basinal Polkorridoren Group (Davis & Higgins, 1987). The upper siltstones and shales of the Buen Formation have a characteristic black or greenish grey colouration, and the contact with the base of the Aftenstjernesø Formation is often marked by a red or yellow rusty staining, most conspicuous in central Navarana Fjord (Fig. 5).

In southern Peary Land the Buen Formation has yielded a nevadiid trilobite associated with *Olenellus hyperboreas,* hyolithids, *Pelagiella* and ostracods, suggesting a Middle and late Early Cambrian age (Palmer & Peel, 1979). Upper levels of the formation in Navarana Fjord and east and west of central J. P. Koch Fjord have yielded Lower Cambrian fossils, including large specimens of the sponge *Choia hindei* (Rigby, 1986),

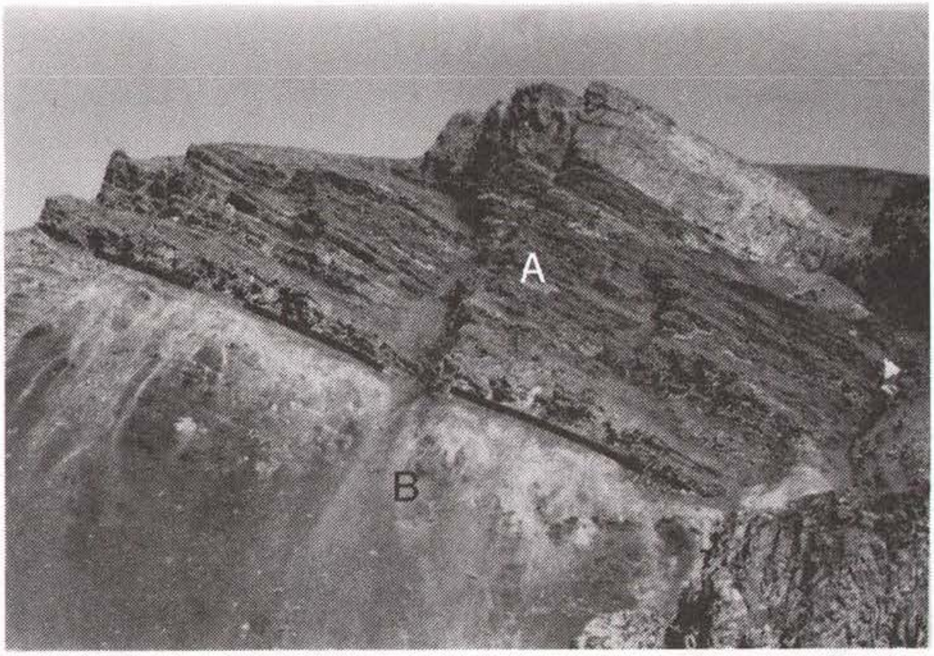


Fig. 5. Buen Formation (B) with rusty yellow staining at top derived from ferruginous marker bed at base of the Aftenstjernesø Formation (A). The latter comprises rubbly weathering bedded limestones and dolomites with a prominent carbonate breccia crag at the top. East side of Navarana Fjord (section 12).

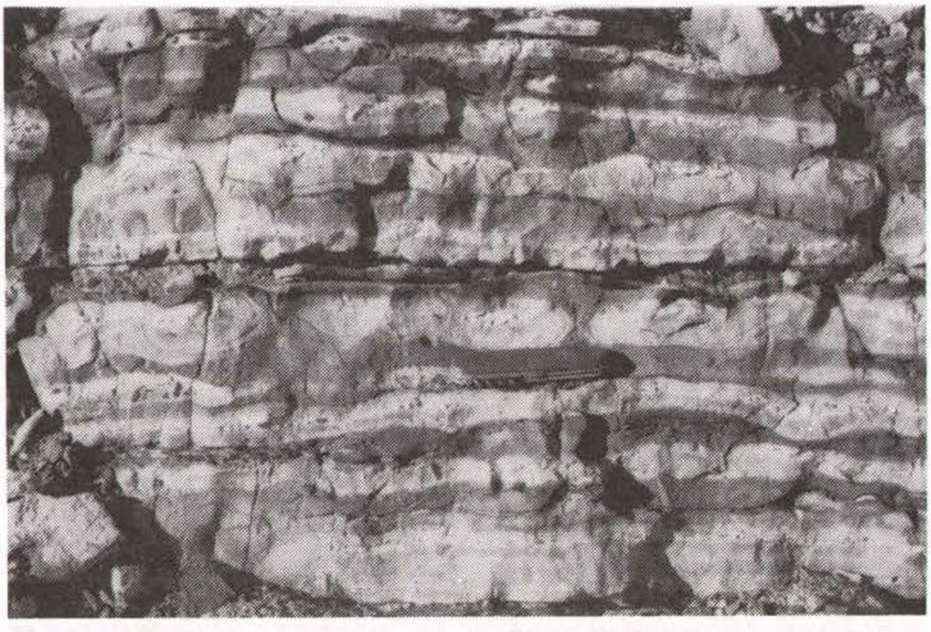


Fig. 6. Aftenstjernesø Formation showing characteristic nodular development of the limestone beds. West side of Navarana Fjord (section 11).

collections of non-trilobitic arthropods lacking mineralised skeletons comparable to Burgess shale faunas (Conway Morris et al., 1987; Conway Morris & Peel, 1990; Peel et al, 1992), a new navadiid trilobite, *Buenellus higginsi* (Blaker, 1988), bradoriid ostracods and brachiopod fragments.

Aftenstjernesø Formation

The Aftenstjernesø Formation and Henson Gletscher Formation, the lowest two formations of the Brønlund Fjord Group, were recognised by J. S. Peel in the Navarana Fjord anticline in 1984 (pers. comm. 1984), and correspond to units 1 and 2 of Higgins & Soper (1985) which they traced throughout the region between northern Nyeboe Land and central J. P. Koch Fjord. The correlation of these outer shelf developments with the better known shallow shelf sequences to the south-east was confirmed by Surlyk & Ineson (1987). In southern Peary Land the Brønlund Fjord Group together with the Tavsens Iskappe Group make up a complex diachronous array of carbonates with subordinate siliciclastics, characterised as the deposits of a regressive unstable shelf. The formations of the Brønlund Fjord Group were briefly characterised by Ineson & Peel (1980) and are defined by Ineson & Peel (in press).

Between central J. P. Koch Fjord and northern Nyeboe Land the outer shelf development of the Aftenstjernesø Formation comprises a sequence of rubbly weathering, often nodular, limestones and dolomites with a prominent dolomite breccia at the top (Figs 5, 6). The sequence is generally from 19 to 51 m thick (Fig. 7), but unusually thick developments were measured in north-east Wulff Land (section 5, 68 m) and north-east Nyeboe Land (section 25, ca 80 m). The boundary with the underlying Buen Formation is usually sharp, and often marked by a red or yellow weathering, pyritic hardground surface, also a feature of the same contact in south Peary Land (Frykman, 1980). The coloured staining is most conspicuous in the Navarana Fjord anticline, where it extends for up to 5 m into the uppermost Buen Formation shales (Fig. 5). In north-east Nyeboe Land (west of section 25) the contact between the Buen

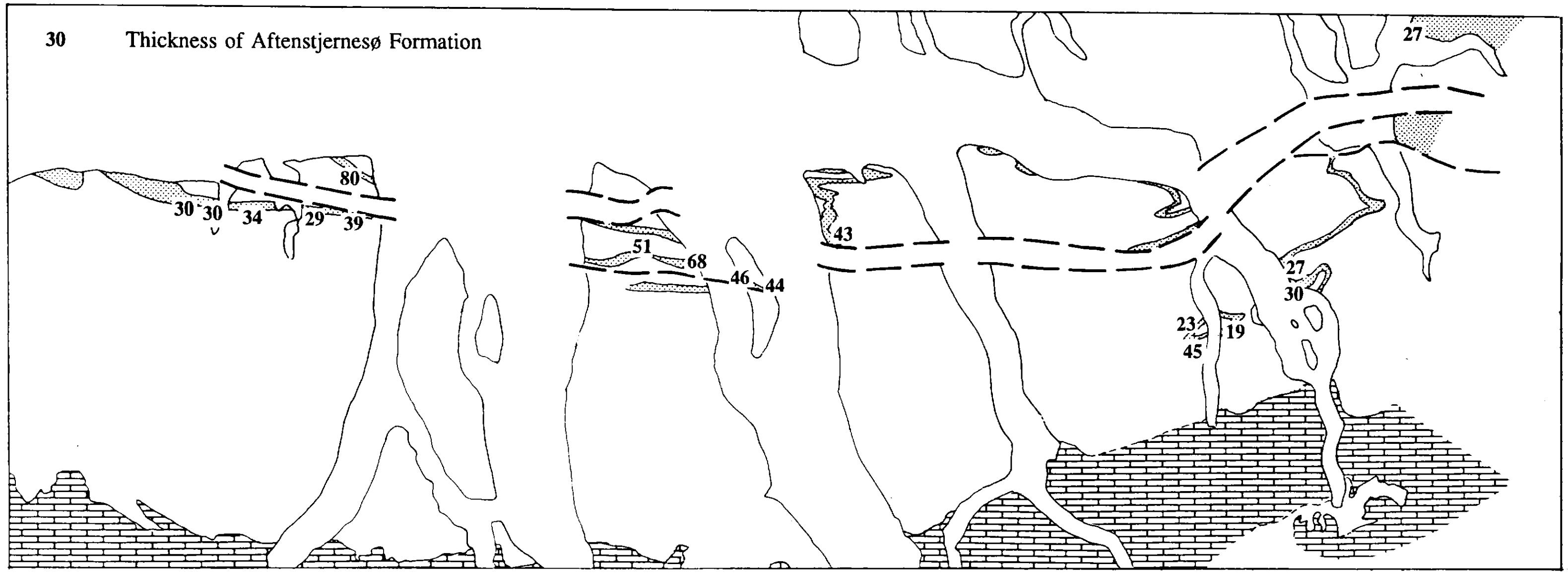
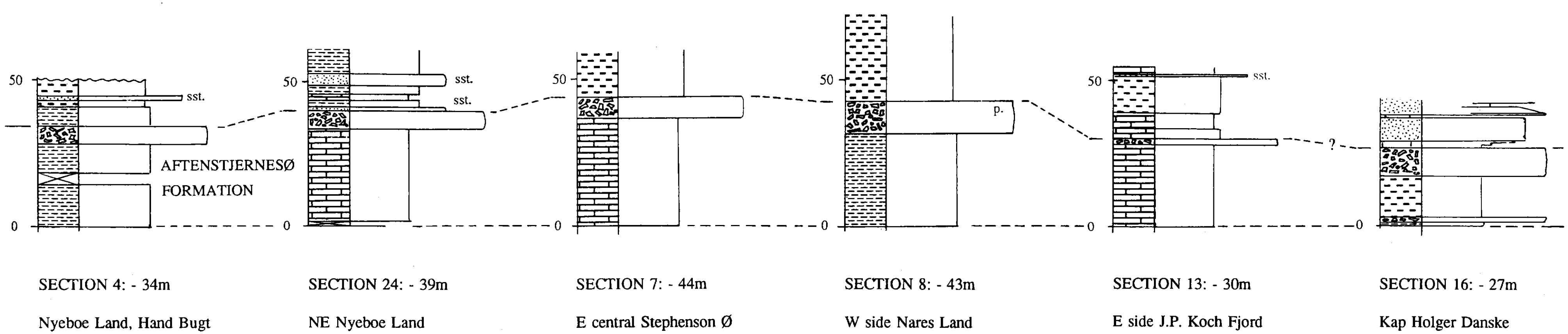


Fig. 7. Thickness variations and correlation of the outer shelf developments of the Aftenstjernesø Formation. Note comparison with the lowest levels of the trough sequence at Kap Holger Danske (section 16). Map base restored for effects of Ellesmerian deformation (see Fig. 1)



See Appendix for key to rock types and abbreviations

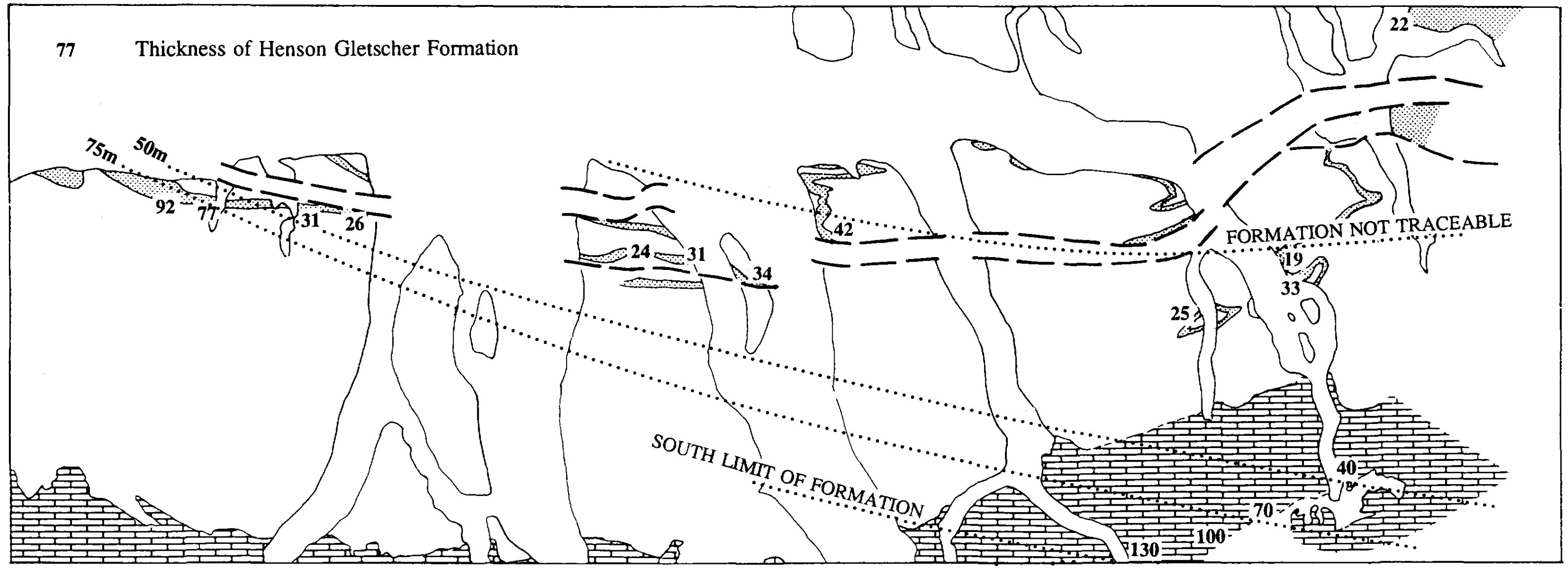
Formation and Aftenstjernesø Formation appears transitional over a distance of about 10 m.

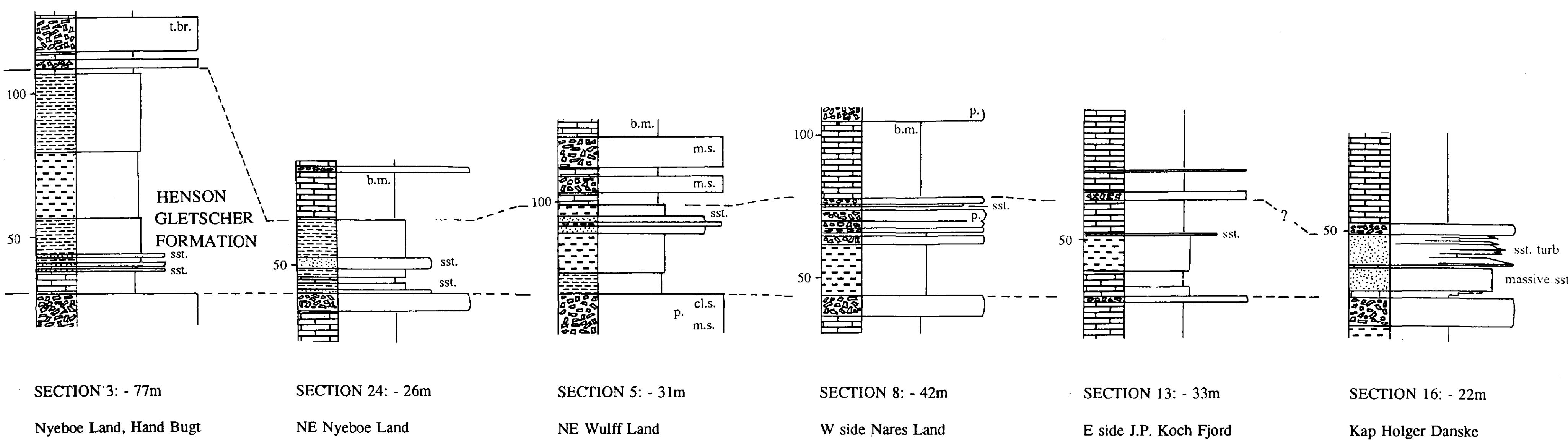
The lower part of the sequence comprises interbedded dark limestones or dolomites and dark calcareous shales or siltstones. The limestone beds are from a few cm to 30 cm thick, mainly parallel laminated, locally with grading, and typically with lens-like or nodular development (Fig. 6); the beds may contain isolated quartz sand grains. In some sections the proportion of shale decreases upwards. Apart from the locality near Kap Bryant (section 25) the sequence has yielded few fossils; *Chancelloria* and *Hyolithellus* were collected from the base of the formation in Navarana Fjord by J. S. Peel in 1984, an olenellid trilobite was recovered (loose) from near the base of the formation on Stephenson Ø, and in northern Nyeboe Land (section 24) several levels near the base are rich in hyolithids.

Section 25, south of Kap Bryant in north-east Nyeboe Land, is unusually thick and richly fossiliferous. Samples throughout the ca 80 m sequence have yielded *Olenellus sp.* and the eodiscid species *Serrodiscus speciosus* and *Serrodiscus daedalus*. This locality has previously yielded a late Early Cambrian fauna, including *Hadimopanella apicata*, *Serrodiscus bellimarginatus*, *Calodiscus*, *Chancelloria*, *Palagiella*, *Latouchella* and inarticulate brachiopods (Peel, 1974, 1979; Dawes & Peel, 1984; Peel & Larsen, 1984).

Between central J.P. Koch Fjord and northern Nyeboe Land the uppermost unit of the Aftenstjernesø Formation is a conspicuous dolomite breccia. Around J. P. Koch Fjord and Navarana Fjord it is 2-4 m thick, in northern Nyeboe Land generally 6 m thick, whereas in northern Wulff Land and Nares Land more variable thicknesses were encountered, between 2 m and 15 m (Fig. 7). The 15 m thick breccia in north-east Nyeboe Land comprises: 2 m rubbly weathering breccia with silicified tabular clasts in a black dolomite matrix; 10 m of very coarse breccia, containing angular dolomite clasts up to 1 m in length, quartzite clasts up to 40 cm across and occasional chert clasts; 2 m of limonite stained breccia; and a 1 m breccia bed extensively replaced by

Fig. 8. Thickness variations and correlation of outer shelf developments of the Henson Gletscher Formation, with 50m and 75m isopachs. Thicknesses in platform area from Christiansen *et al.* (1987). Map base restored for effects of Ellesmerian deformation (see Fig. 1).





See Appendix for key to rock types and abbreviations

pyrite. In general the breccias may be either monomict or polymict, and partial silicification at the top and base is not uncommon. The wide extent of this particular breccia level (more than 200 km from east to west) indicates a debris flow of regional extent, perhaps triggered by a significant tectonic event.

As noted above, as outer shelf sequences are traced northwards into slope sequences, the clear division into units breaks down. The Aftenstjernesø Formation thus cannot with any confidence be delineated in the thin, starved sequences of sections 9, 30 and 15. Higgins & Soper (1985) suggested an interdigitation between the four part outer shelf sequence and the turbiditic trough sequence of Amundsen Land (cf. Fig. 3), although in view of tectonic complexities and the distance between measured sections this idea should be viewed with reservation. There is, however, a resemblance between the basal 28 m of section 16 in the trough sequence of Amundsen Land (cherty shales capped by a breccia) and the normal Aftenstjernesø Formation development (Fig. 7).

Henson Gletscher Formation

The Henson Gletscher Formation was recognised by J. S. Peel in the Navarana Fjord anticline in 1984, and corresponds to unit 2 of Higgins & Soper (1985) and Davis & Higgins (1987); it is traceable throughout the region between central J. P. Koch Fjord and northern Nyeboe Land (Fig. 8). It is characteristically a recessive unit (Fig. 9), comprising dark dolomitic mudstones and siltstones, black cherty shales and occasional massive sandstone beds. It weathers easily, and was for this reason often not logged in detail. Measured thicknesses range from 19-42 m over most of the region, but west of Hand Bugt in northern Nyeboe Land 77 m was measured in section 3, 92 m in section 2, and comparable, greater than normal thicknesses were also noted at Blackhorn Cliff farther to the north-west (Fig. 10). The formation overlies the dolomite breccia of the Aftenstjernesø Formation, and is overlain in many sections by another dolomite breccia at the base of the Tavsens Iskappe

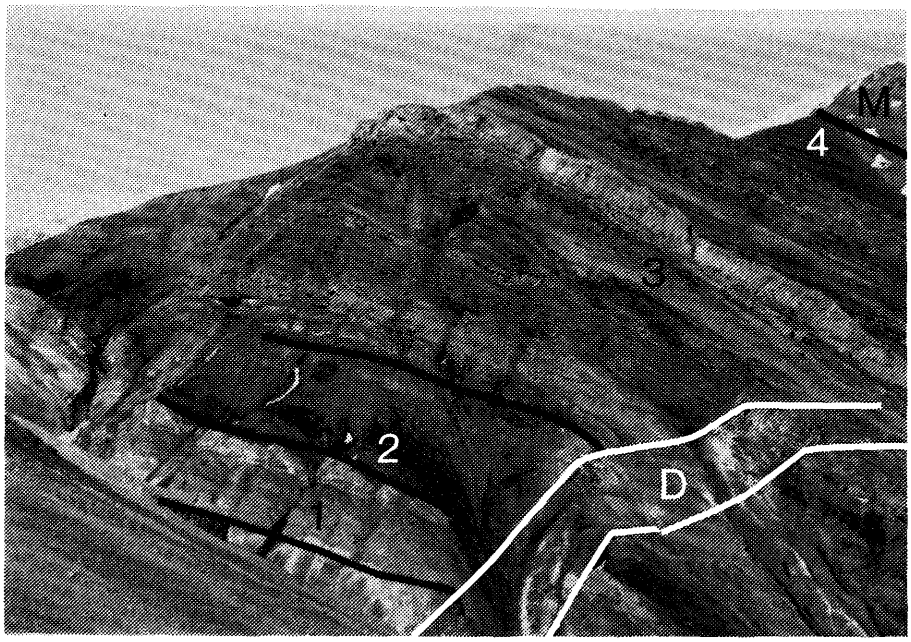


Fig. 9. Part of section 12 on the east side of Navarana Fjord. 1: Aftenstjernesø Formation (cf. Fig. 5); 2: dark coloured, recessive, Henson Gletscher Formation; 3: banded carbonate mudstone and carbonate conglomerate crags of the Kap Stanton Formation; 4: black shale and chert of the Amundsen Land Group; M: Silurian Merqujoq Formation turbidites; D: Tertiary dyke.

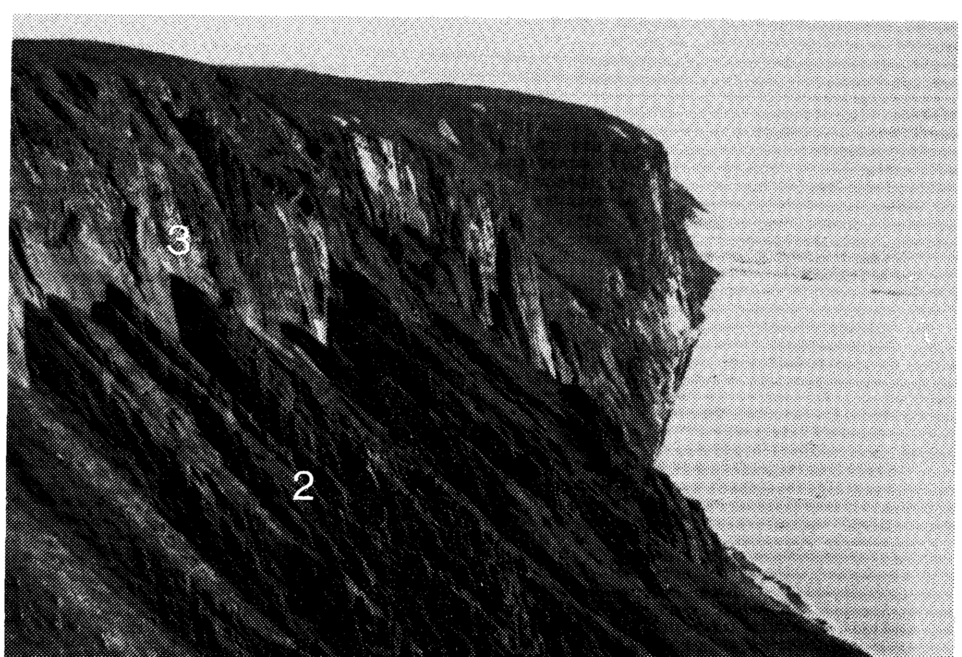


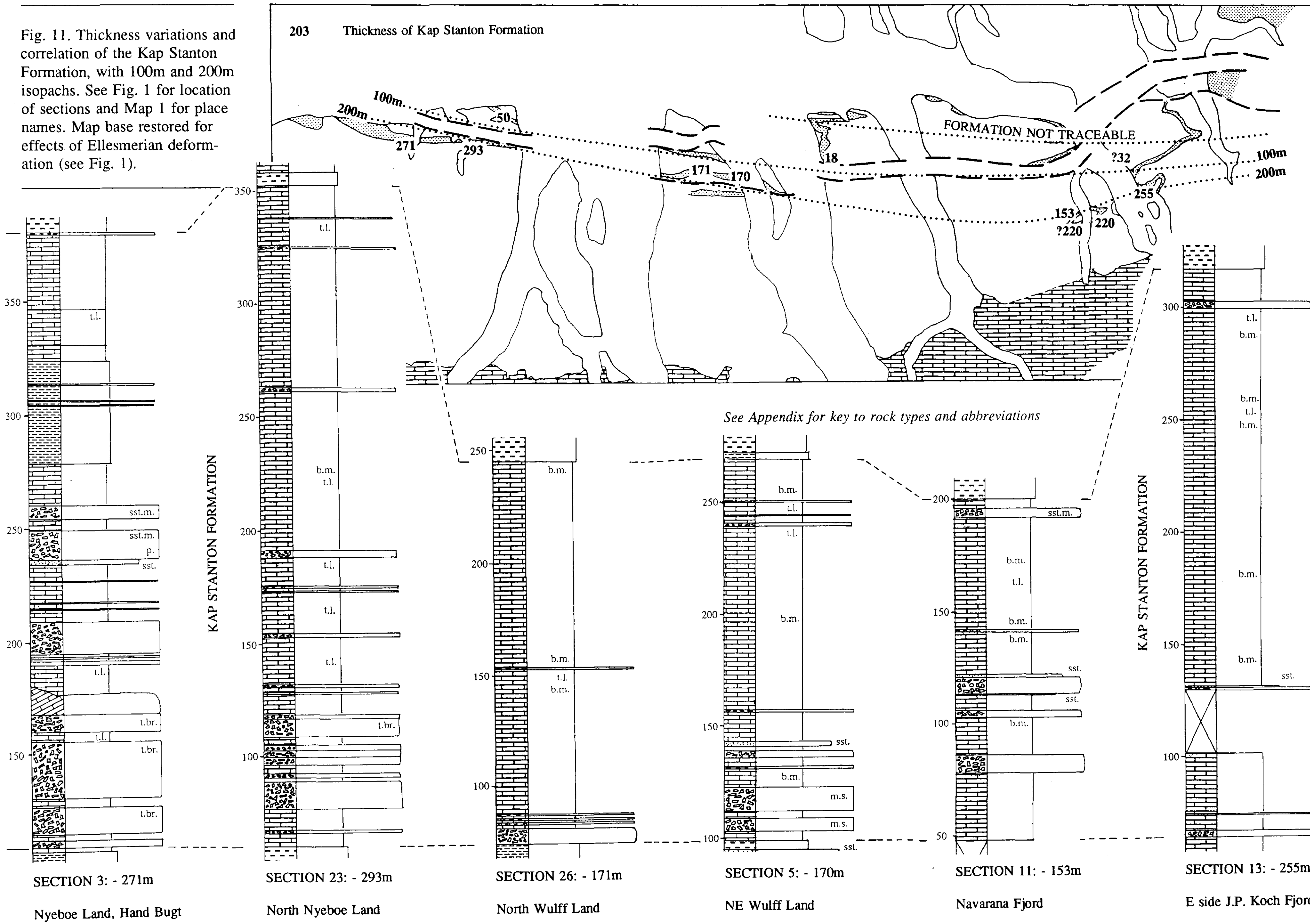
Fig. 10. Vertically dipping unusually thick development of dark coloured Henson Gletscher Formation (2) overlain (at left) by light coloured carbonate mudstone of the Kap Stanton Formation (3). Blackhorn Cliff, northern Nyeboe Land.

Group. In the type area around Henson Gletscher, at the head of J. P. Koch Fjord, the sequence has a very similar development (Ineson & Peel, 1980, in press), and here an evaluation of its potential as a hydrocarbon source rock has been carried out by Christiansen (1989); here there is a systematic south-west increase in thickness from 40 to 130 m (Fig. 8).

Massive sandstone beds are a conspicuous, although subordinate, feature of the Henson Gletscher Formation in many sections. They are white, grey or pale yellow in colour, usually structureless, rather pure quartzites, and form beds up to 4 m thick. Several beds can be traced in the lower part of the sequence throughout northern Nyeboe Land (sections 3, 24) (Fig. 8). In Wulff Land two beds occur high in the sequence (section 5). Sandstones are absent or insignificant in sections measured in Nares Land, Freuchen Land and around central J. P. Koch Fjord. Similar sandstones are also conspicuous in the type area, where they make up the central siliciclastic unit (Ineson & Peel, 1987; Christiansen et al., 1987): this unit is persistant, up to 124 m thick, and has been traced for over 300 km from east to west and 40 km from south to north The sandstones are interpreted as storm sands, and each bed probably represents a single shelf-wide storm event.

Rich fossil faunas have been collected from six levels of the Henson Gletscher Formation west of Hand Bugt (section 3) (see Appendix). The two lowest collections are assigned to the early Middle Cambrian (*Glossopleura* zone), and include the Polymeroid trilobites *Glossopleura walcotti, Kootenia hedosa*, *Syspacephalus spinifera* and *Ogygopsis kiotzi* (Babcock, 1990) and articulate and inarticulate brachiopods. The third collection is from the Middle Cambrian *Ptychagnostus gibbus* zone, and the upper three collections from the *P. atavus* zone; species identified include numerous Polymeroid and Agnostoid tribolites (Babcock, 1990) and inarticulate brachiopods. Two collections from the basal strata of the overlying Tavsens Iskappe Group in northern Nyeboe Land (section 23) contain species similar to the upper two collections from section 3 noted above, and are assigned to the *Ptychagnostus atavus*

Fig. 11. Thickness variations and correlation of the Kap Stanton Formation, with 100m and 200m isopachs. See Fig. 1 for location of sections and Map 1 for place names. Map base restored for effects of Ellesmerian deformation (see Fig. 1).



interval zone (Babcock, 1990).

The Henson Gletscher Formation cannot be distinguished in sections 9, 15, 27, 28, 29 and 30, although equivalent strata may be present. Correlation farther north with the trough sequence of Amundsen Land is highly speculative, although it is worth noting that section 16 at Kap Holger Danske contains near the base a 9 m sequence of massive, clean sandstone beds of non-turbiditic appearance. Like those in the Henson Gletscher Formation, they may represent storm sand deposits.

Isopachs based on thickness changes noted in Nyeboe Land, and those observed in the Henson Gletscher region by Christiansen et al. (1987), run approximately ESE-WNW (Fig. 8). The isopach trends diverge slightly from the trend of the later Navarana Fjord lineament (cf. Fig. 1).

Kap Stanton Formation

The sequence of limestones, dolomites, dolomitic mudstones and intraformational conglomerates which make up unit 3 of Higgins & Soper (1985) and Davis & Higgins (1987), has been defined by Ineson & Peel (in press) as the Kap Stanton Formation of the Tavsens Iskappe Group. The sequence is traceable between northern Nyeboe Land and central J. P. Koch Fjord and is generally 150-300 m thick (Fig. 11). It overlies the recessive Henson Gletscher Formation, and is overlain by dark cherts and cherty shales of the Amundsen Land Group. The lower boundary is usually clearly defined, and in many sections is marked by a conglomerate bed. The upper boundary is in some sections abrupt, in others transitional over several metres. In section 14 the upper boundary is undefinable as yellow weathering dolomitic mudstones identical to those of the Kap Stanton Formation also make up the entire overlying sequence equivalent to unit 4 (Amundsen Land Group) of other sections.

The dominant rock types in eastern sections are laminated dolomites and dolomitic mudstones. Parallel lamination is the dominant sedimentary structure, and while cross-lamination and starved ripples have been recorded, they are rare. Banding on a scale of 30-50 cm, often up to 1 m, is common in many

Fig. 12. Rhythmically banded carbonate mudstones of the Kap Stanton Formation; dark grey silty mudstone passes upwards into compact, yellow weathering dolomite. West side of Navarana Fjord.

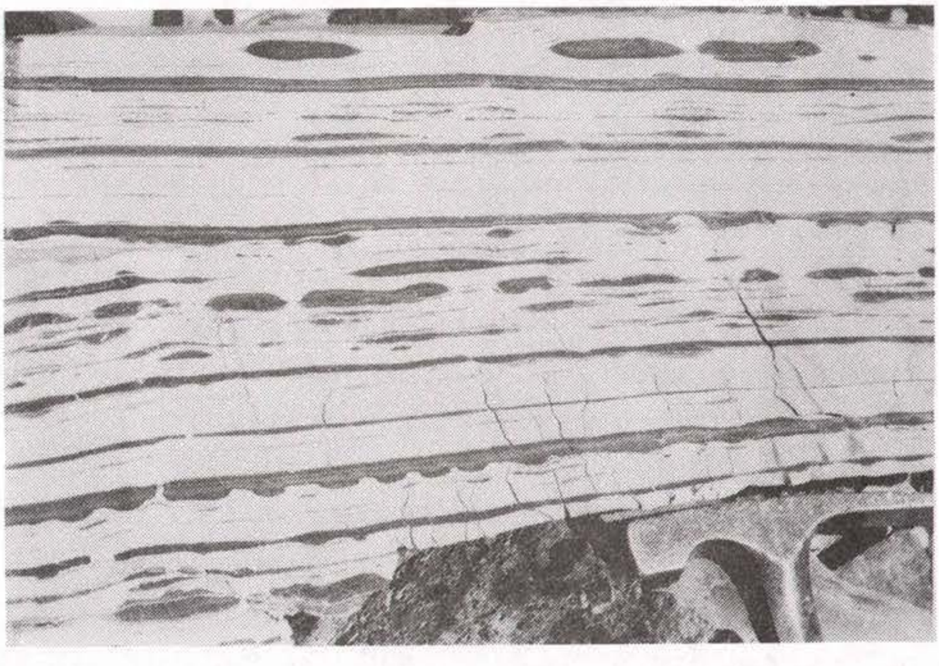


Fig. 13. Dark grey layers and lenses of limestone interbanded with yellow weathering laminated dolomite, the "tiger limestone" of Dawes (1976) - see also Fig. 14. Northern Wulff Land.

sections (Fig. 12). The lower part of each banded unit is generally dark in colour, laminated and silty to the touch. It grades upwards to a yellow weathering compact dolomite. Under the microscope the only recognisable mineral is fine-grained carbonate, but associated always with much indeterminate dark "dust". Chemical analyses of some of the dolomitic mudstones in the Navarana Fjord area reveal a total MgO plus CaO content of only 20 to 35%, and a corresponding total for SiO_2 plus Al_2O_3 of 60 to 35% (A. Steenfelt, pers. comm.); the "dust" is thus presumed to be very fine-grained quartz and feldspar. The rhythmic banding of much of the sequence and the presence locally of cross-lamination and starved ripples suggests sedimentation by dilute, "starved" turbidity currents. Current directions measured in the well exposed section 26 (north Wulff Land) were mainly to the north-west, some to the west.

In western sections the most characteristic lithologies are the "tiger limestones" of Dawes (1976). They comprise alternate layers of grey limestone and orange-weathering dolomitic mudstone, each layer from a few cm to 10-15 cm thick (Fig. 13). The grey limestone layers appear to be an early diagenetic replacement, as shown by a common lens-like development of the grey limestone (Figs 13, 14), whose laminae are continuous with those in adjacent dolomitic mudstone. The enveloping laminated dolomite muds have undergone 80% compaction during dewatering, calculated from observations of distortion of laminae about the limestone lenses (N.J.S., 1984).

The proportion of banded limestone/dolomite units ("tiger limestones") in measured sections decreases eastwards, units of laminated and banded dolomitic mudstones alternating with banded limestone/dolomite units in many sections. The easternmost sections contain only a few metres of banded limestone/dolomite lithologies (sections 11, 13), although blocks of these characteristic rocks are recorded in the highest conglomerate bed of most sections (see also below). The preferential formation of one or other type of carbonate lithology may relate to position on the shelf, the eastern

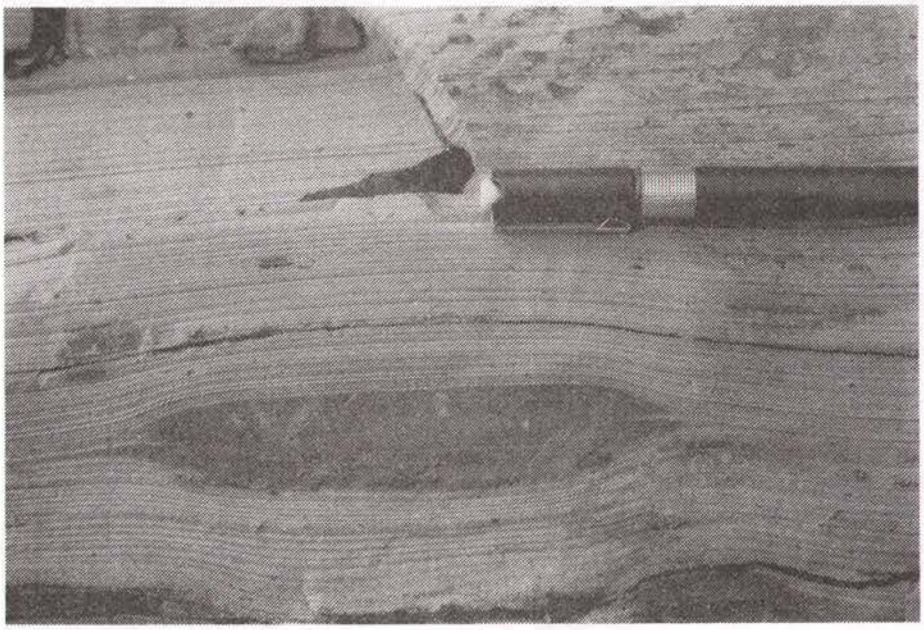


Fig. 14. Lens of early-formed grey limestone in laminated yellow dolomite. Note distortion of lamination around the lens, and continuation of laminae from limestone lens into dolomite.

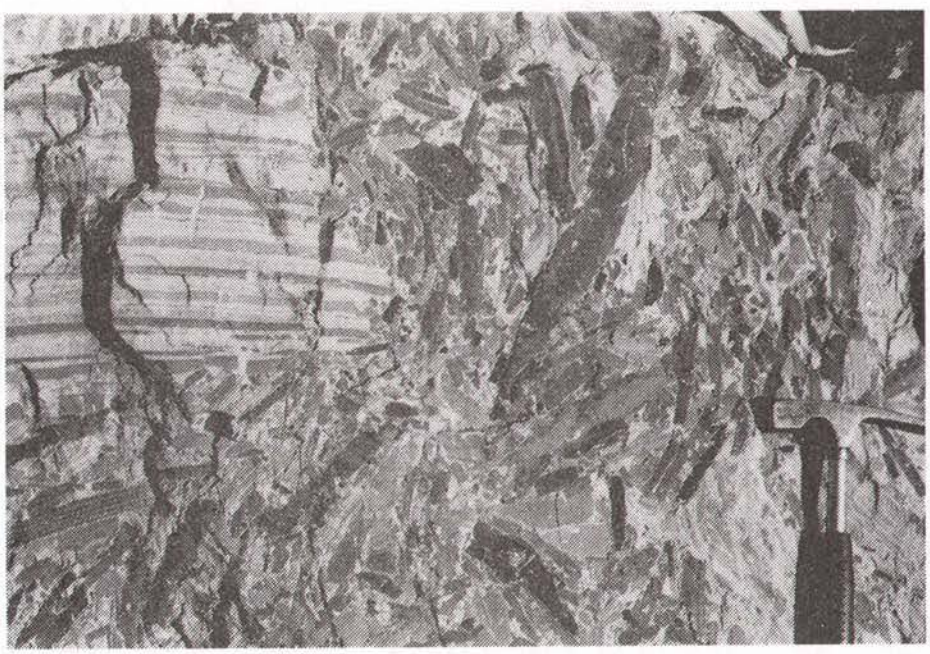


Fig. 15. Clast-supported intraformational carbonate breccia ("tiger breccia"), comprising light and dark grey limestone clasts in yellow dolomite matrix. Note large block of banded limestone and dolomite ("tiger limestone") at upper left. Northern Nyeboe Land.

localities being perhaps farther north, and thus more distal.

Intraformational conglomerates formed by flow or slumping of the banded limestone/dolomite lithologies are particularly conspicuous in western areas, notably in Nyeboe Land where the lowest 90 m of the formation in section 3 is dominated by this rock type. It seems that they develop as a consequence of movement of sediment after the early diagenetic formation of the grey limestone layers or lenses, but before lithification of the enveloping dolomite mudstone. All stages in the break-up of the limestone layers are recorded, from very slight disruption where adjacent angular limestone fragments were clearly part of the same limestone layer to more complete mixing of clasts where such relationships are no longer discernable (Fig. 15). Their general characteristics are closely comparable to the carbonate breccias of the Tavsens Iskappe Group described by Ineson (1980) and Ineson & Peel (in press). These chaotic conglomerates may form units up to 25 m thick, sometimes massive slumped units with disconformities at the base, sometimes interbedded with undisturbed limestone/ dolomite units with unconformable basal contacts.

Other types of carbonate conglomerates (or breccias), occur in all sections (Fig. 11). Some are monomict, with pale limestone or dolomite clasts in a dark coloured dolomite mudstone matrix or dark-weathering clasts in a light coloured matrix. Others are polymict, with mixtures of clasts; different coloured dolomite or limestone, and occasional blocks of sandstone or black chert (Fig. 16). The conglomerate beds are generally up to 5 m thick, but some units show dramatic variation in thickness, from a few metres to 15 or even 25 m; bases of units may show channelling. The largest clasts are usually from 30 cm to 1 m, occasionally up to 2 m in length. Some of the conglomerate beds are persistent, and can be traced over distances of 10 to 20 km. A regionally persistent conglomerate near the top of eastern sections is traceable from central Navarana Fjord (section 11) to the east side of J.P. Koch Fjord, and is characterised by the occurrence of large blocks of the banded limestone/dolomite lithology, whose

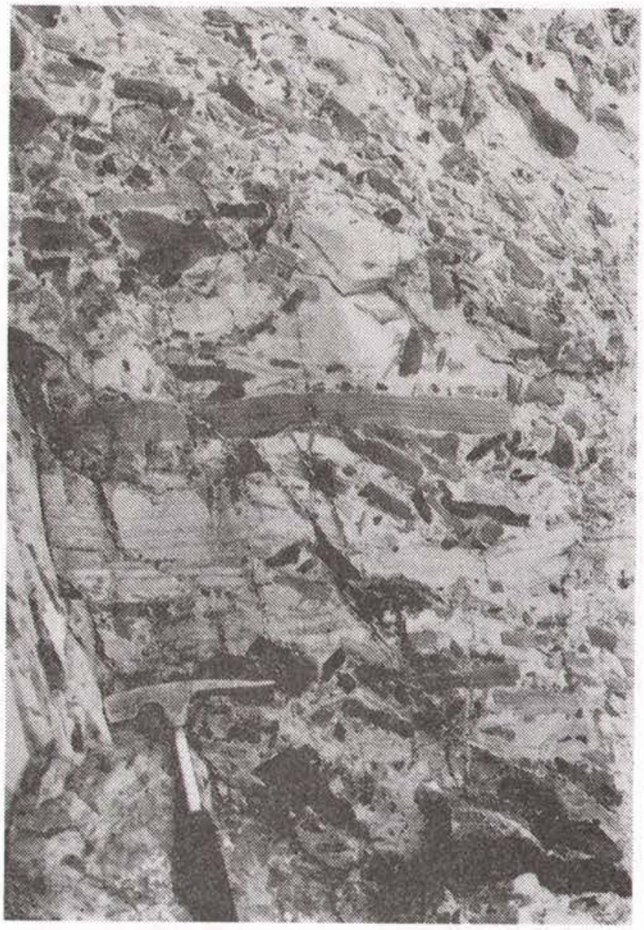


Fig. 16. Chaotic breccia, dominated by yellow dolomite matrix supporting variety of sizes and types of clast. Northern Nyeboe Land.

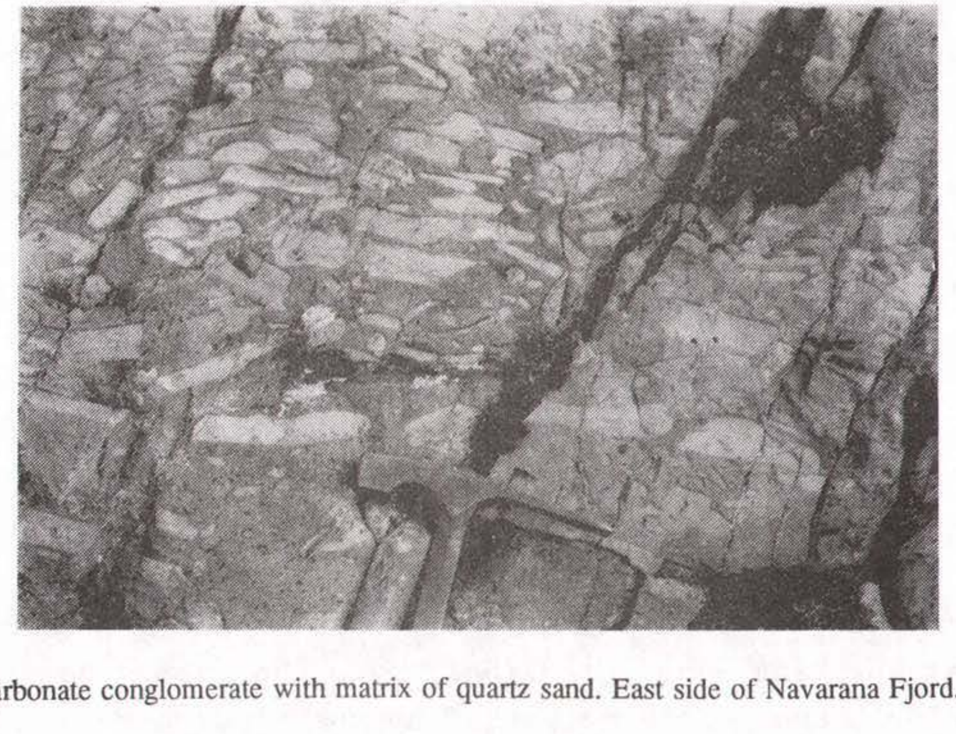


Fig. 17. Carbonate conglomerate with matrix of quartz sand. East side of Navarana Fjord.

distorted edges indicate the sediment was not then completely lithified.

Sandstones are rare, but there are usually one or two thin beds of grey quartzite in most sections. Some of the conglomerate beds have a quartz sand matrix where individual sand grains are recognisable (Fig. 17); in other conglomerates the matrix seems to have been replaced by grey quartzite, or more rarely black chert.

Northwards correlation is sometimes uncertain, but in many of the starved outer shelf slope sections (sections 25, 8, 27, 29, 28) there are sequences of dolomite mudstones and carbonate conglometates, which probably correspond to the Kap Stanton Formation. In the well exposed coastal sections of north-west Nares Land, this light coloured central sequence can be seen to thin from about 18 m (section 8) to about 10 m (section 27), and it is not represented in northernmost Nares Land (section 9). Similarly, the formation is not evident in sections 28 and 29 in north-east Freuchen Land. East of J.P Koch Fjord there is a spectacular decrease in thickness between section 13 (255 m) and section 30 (? 32 m) and the formation is not traceable in section 15.

Farther north, the thick trough succession dominated by sandstone turbidites of the Vølvedal Group contains near the base at Kap Holger Danske (section 16) about 100 m of banded dolomitic mudstones (Fig. 3). These grade upwards into sandstone turbidites. The similarity of these dolomitic mudstones with those of the Kap Stanton Formation led Higgins & Soper (1985, Fig. 2) to suggest an interdigitation between the trough and outer shelf developments. Higher levels of the Amundsen Land Group contain limestone conglomerate beds resembling the similar beds in the Kap Stanton Formation; clasts in the Amundsen Land Group conglomerates also include large blocks of the characteristic banded limestone/dolomite ("tiger limestone") type, presumably derived from the shelf to the south.

P.R. Dawes collected a suite of Middle Cambrian tribolites in northern Nyeboe Land from near the base of the formation in 1966 (Poulsen, 1969). These include *Ptychagnostus sp.* and *Onymagnostus* (Robinson, 1984; Dawes & Peel, 1984). Also in Nyeboe Land, the basal few metres of section 23 contain a rich late Middle Cambrian fauna of Polymeroid and Agnostoid trilobites referable to the *Ptychagnostus atavus* interval zone (Babcock, 1990). About 40 m above the base of the formation in section 13, on the east side of J.P. Koch Fjord, an extensive Middle Cambrian fauna of Polymeroid and Agnostoid trilobites was collected (Babcock, 1990), all from the lower part of the *Lejopyge laevigata* interval zone; there is a close correspondance with species typical of the Andarum Limestone of Sweden. Middle Cambrian "Atlantic" faunas appear widespread in outer shelf sequences along the north coast of Greenland, whereas "Pacific" faunas charactise inner shelf sequences more to the south (Fletcher et al., 1988).

There are few fossils in upper parts of the formation, apart from occasional Ceratiocarids. However, the uppermost strata of the formation in section 11 on the west side of Navarana Fjord contain Llanvirn graptolites, including *Loganograptus sp.*, *Glossograptus hincksi, Isograptus victoriae ?divergens*, *Glyptograptus sp.* and *Caryiocaris* (M. Bjerreskov, pers. comm., 1987). In other sections graptolites from strata overlying the Kap Stanton Formation are Arenig (sections 4, 23), suggesting the boundary between the Kap Stanton Formation and the Amundsen Land Group is diachronous. In the westernmost sections of Nyeboe Land (sections 1, 2, 3) the top of the Kap Stanton Formation appears to become progressively younger at the expense of the cherts of the Amundsen Land Group. Between sections 3 and 4, the uppermost bed of the Kap Stanton Formation is conglomeratic, and contains large blocks of crinoidal limestone of probable Upper Ordovician age; it is overlain by only 15 m of Amundsen Land cherts. West of section 1, near Repulse Havn, there are no cherts and the Silurian Merqujoq Formation appears to rest directly on the Kap Stanton Formation.

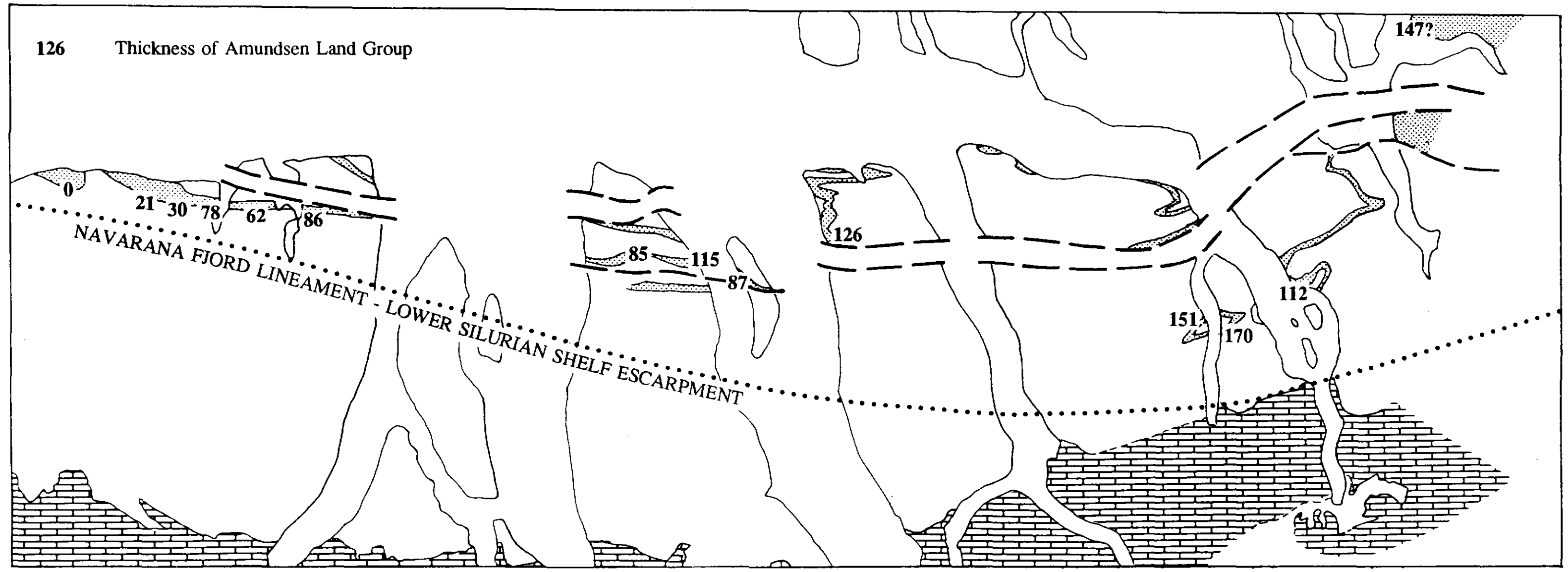
Amundsen Land Group - new unnamed formation

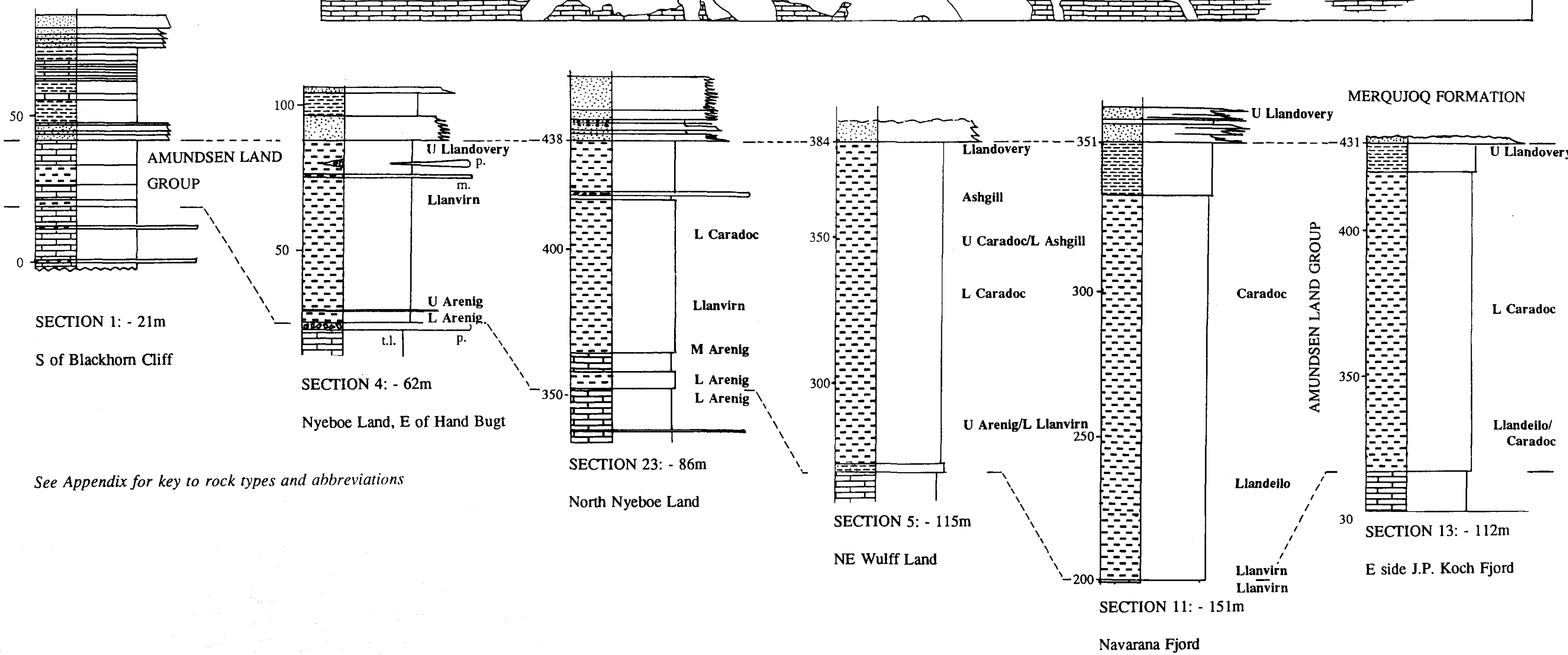
The light coloured dolomitic mudstones and limestone conglomerates of the Kap Stanton Formation give way upwards to a dark coloured mapping unit dominated by cherts and cherty shales (Figs 18, 19, 20). This dark cherty sequence is assigned to a new, currently unnamed formation of the Amundsen Land Group, and corresponds to unit 4 of Higgins & Soper (1985) and Davis & Higgins (1987). The formation is overlain by pale orange weathering sandstone turbidites of the Silurian Merqujoq Formation (Larsen & Escher, 1985, 1987, 1991).

The dark cherty sequence of the new formation varies in thickness from a maximum of 170 m in Navarana Fjord (Fig. 18) to only 62 m in northern Nyeboe Land (section 4). Graptolite collections indicate that most of the Ordovician is represented in both areas, and the systematic thickness decrease from east to west may largely be a reflection of sediment supply. However, between sections 3 and 4 only 15 m was recorded, and section 1 comprised a 21 m sequence of which only part was black cherts; at a locality west of Repulse Havn no cherts were observed (see also Kap Stanton Formation above). In general, no subdivision of the formation has proved possible. In the field rock types encountered were described as black cherts, dark cherts, cherty shales, silty shales etc. Occasional thin beds, lenses or pods of yellow weathering dolomitic mudstone within the cherts suggest that much of the chertification may be secondary (Fig. 20). A measured section at Kap Lars Larsen (section 14) on the east side of J.P Koch Fjord comprised entirely dolomitic mudstone, although graptolites within the sequence show the upper part is equivalent to Amundsen Group cherts nearby; both southwards and eastwards from Kap Lars Larsen these upper dolomitic mudstones can be seen in the field to pass laterally into dark cherts and cherty shales.

Other rock types encountered include thin conglomerate beds, thin beds of black or grey limestone, rare quartz sandstones and nodular shales. The conglomerate beds contain a variety of limestone and dolomite clasts, and in some cases the matrix is

Fig. 18. Thickness variations and correlation of the Amundsen Land Group. Ages from graptolite determinations by M. Bjerreskov. See Fig. 1 for locations of sections and Map 1 for place names. Map base restored for effects of Ellesmerian deformation (see Fig. 1).





See Appendix for key to rock types and abbreviations

replaced by black chert. The thin limestone beds found mainly towards the top of the sequence often contain fossil debris, chiefly crinoids. The locality between sections 3 and 4 in northern Nyeboe Land where a conglomeratic limestone bed about 1 m thick at the base of the formation contained large, articulated Upper Ordovocian crinoids has been mentioned above. Limestone beds 20-30 cm thick with and without fossil fragments were noted in sections in Nyeboe Land, Wulff Land, Stephensen Ø and east of J.P. Koch Fjord. Similar beds occur interbedded with the Silurian sandstone turbidites in the lowest levels of the Merqujoq Formation (Fig. 21). The fossil debris is probably derived from the shelf to the south, and the beds themselves may be compared to the more substantial carbonate conglomerates of the Kap Brevoort Member (Larsen & Escher, 1987) and Navarana Fjord Member (Surlyk & Ineson, 1987). Thin beds of nodular shales are found towards the top of many sections in Nyeboe Land (see also below), and are characterised by closely packed centimetre-size nodules.

Graptolites are common in most sections, and more than 80 rich collections have been made from 14 sections. Identifications by Merete Bjerreskov (personal communications, 1985, 1986, 1987; Bjerreskov, 1989) demonstrate that most of the internationally recognised Ordovician graptolite zones are represented, but there is currently no evidence in the graptolite sequence for the lowermost and uppermost Ordovician zones. The graptolite faunas of North Greenland are most similar to those described from the Canadian Cordillera region, especially northern Yukon (Bjerreskov, 1989). In sections 4 and 23 in Nyeboe Land graptolites at the base of the formation and spanning the lower boundary are Arenig. In the Navarana Fjord area Llanvirn faunas have been found in the lowermost levels, transitional with the Kap Stanton Formation. These, and the Upper Ordovician crinoids at the base in one section suggest the lowest boundary of the formation is diachronous. Graptolites from the uppermost levels of the formation are Upper Llandovery (sections 4, 5, 9, 13, 27), and Upper Llandovery graptolites also occur in the lowermost strata of

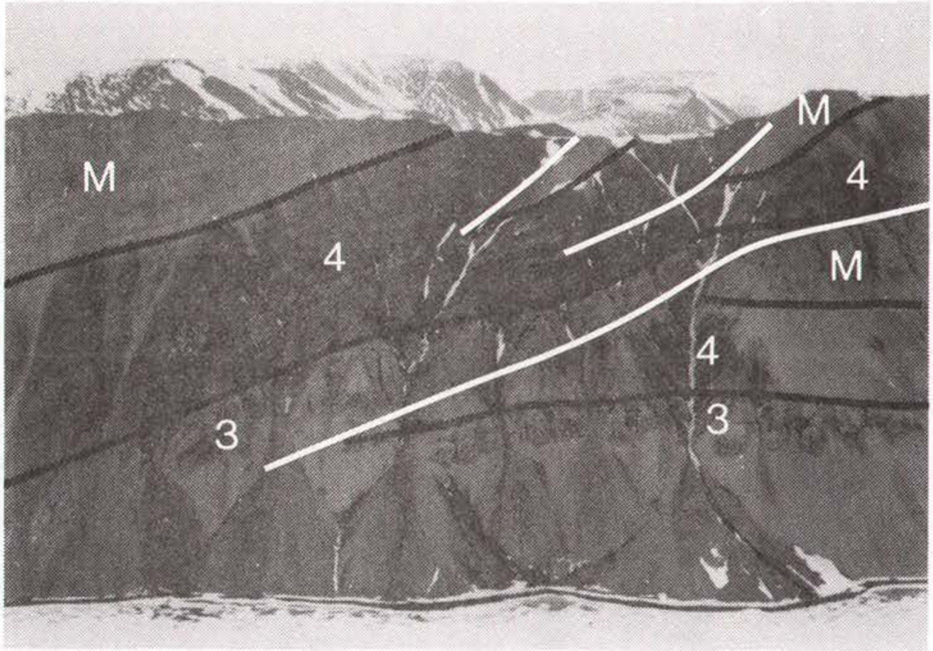


Fig. 19. Interleaving of Kap Stanton Formation (3), Amundsen Land Group (4) and Merqujoq Formation (M), due to low angle Ellesmerian thrusting. Formation/Group boundaries shown by black lines, thrusts in white. Thrusts dip gently northwards and have a southward sense of displacement (towards right of photograph). East side of J.P. Koch Fjord (section 13).

Fig. 20. Lens of yellow weathering dolomitic mudstone within Amundsen Land Group chert sequence. Looking along strike. West side of J.P. Koch Fjord, north-east Freuchen Land.

the overlying Merqujoq Formation (e.g. section 11). The onset of Silurian turbidite deposition in the western half of North Greenland, represented by massive sandstone turbidites at the base of the Merqujoq Formation, can thus be dated as Upper Llandovery (Higgins & Soper, 1987). This is in broad agreement with the dating of the corresponding event in northern Ellesmere Island, where graptolite collections from close to the top of the Hazen Formation give late Ashgill ages to early late Llandovery ages; the lowest collections from the overlying Danish River Formation (= Merqujoq Formation) give latest Llandovery ages (Trettin et al., 1979, 1991).

Over most of the region the upper boundary of the Amundsen Land Group is abrupt, and marked by the incoming of massive sandstone turbidite beds of the Merqujoq Formation. However, at sections 1 and 4 in northern Nyeboe Land a first phase of 5 to 10 m of orange-yellow sandstone turbidites was followed by a return to deposition of shales, thin black limestones and nodular shales perhaps more characteristic of upper levels of the Amundsen Land Group (Fig. 21). Higgins & Soper (1985) reported this feature as an interdigitation of the two units.

The starved slope successions to the north represent something of a problem, as the four-unit subdivision into formations cannot be recognised, and the greater part of many of the sections comprises cherts and cherty shales indistinguishable from those of the Amundsen Land Group. Sections 9 (165 m), 27 (157 m), 28 (85 m), 29 (135 m), 30 (134 m) and 15 (56 m) (Fig. 1 & Appendix) are examples of such developments, although in some of these sections possible equivalents of the Aftenstjernesø Formation have been noted at the base. Graptolites have been recorded in several sections in the upper levels, and on the basis of graptolite collections about half of section 27 (70 m) is thought to be equivalent to the Amundsen Land Group elsewhere. In many of these sections the uppermost levels comprise yellowish silty shales and siltstone (5-25 m thick), which Higgins & Soper (1985) reported as transitional to the Merqujoq Formation. Their development appears similar to descriptions of the Harder Fjord Formation

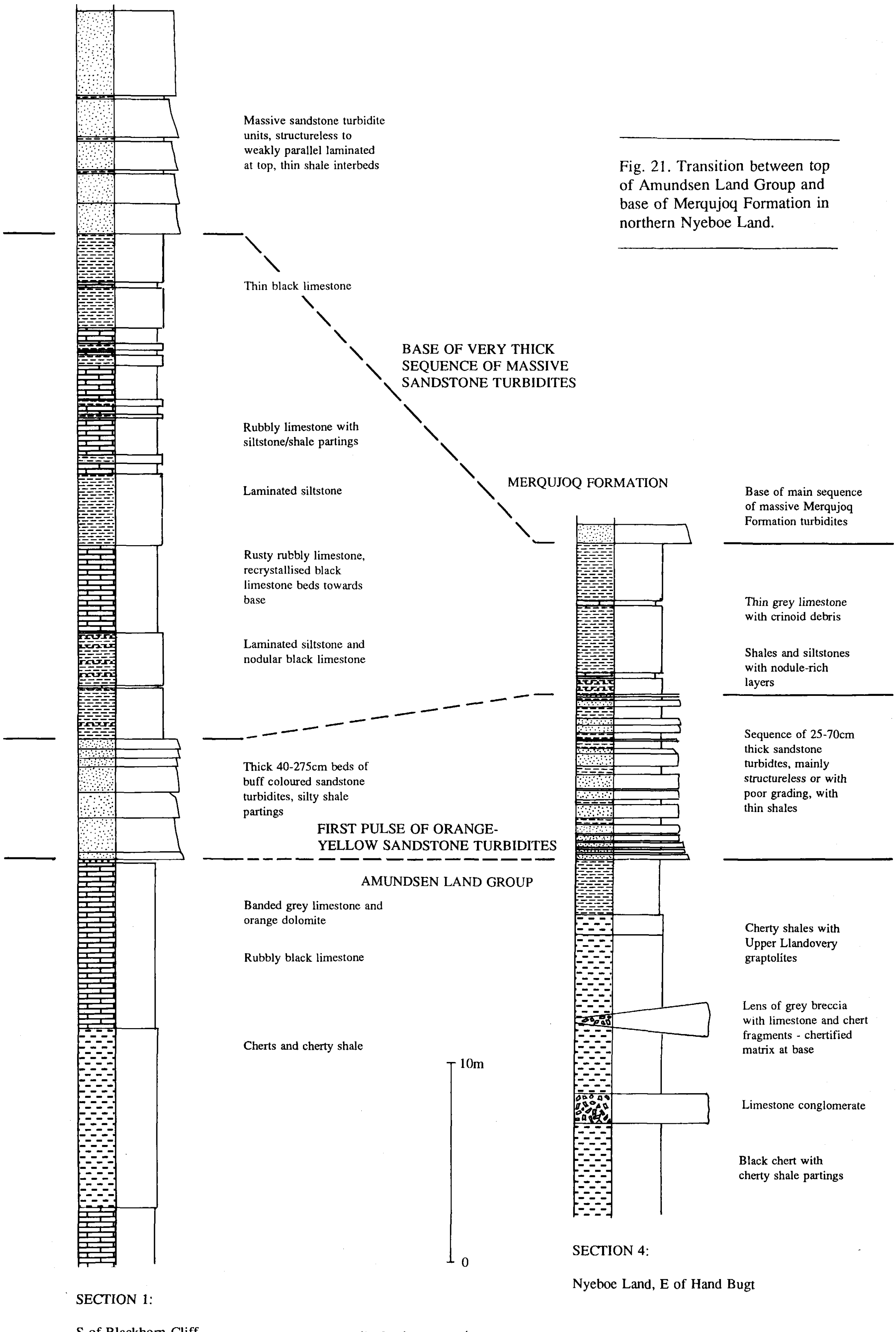


Fig. 21. Transition between top of Amundsen Land Group and base of Merqujoq Formation in northern Nyeboe Land.

See Appendix for key to rock types

of the Amundsen Land Group in the Amundsen Land region (Surlyk et al., in prep). This unit has yielded Llandovery graptolites at several localities.

Acknowledgements

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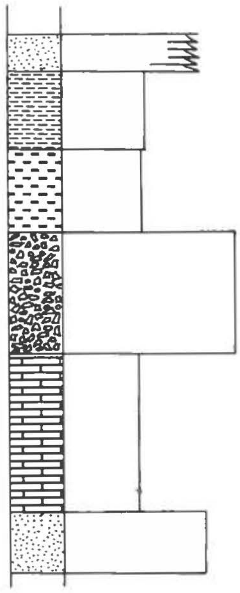
APPENDIX

Simplified measured sections of the early Cambrian - early Silurian outer shelf and slope sequence.

Sections 1-16(-17): measured 1984.
Sections 23-30: measured 1985.



Sandstone turbidites and siltstones

Shale and siltstone - in places yellow weathering and dolomitic

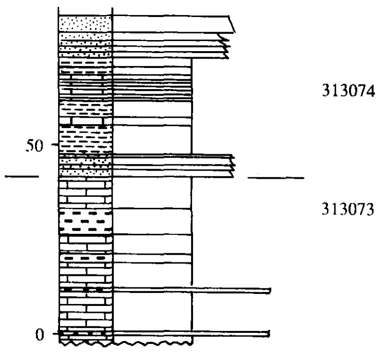
Chert dominated - bedded cherts, cherty shale, cherty siltstone

Conglomerate, debris flows, dominated by angular carbonate mudstone clasts
m.: monomict; p.: polymict; t.br.: "tiger breccia" - grey calcareous clasts in yellow dolomitic mudstone matrix; cl.s.: clast supported; m.s.: matrix supported; sst.m.; sandstone matrix.

Carbonate mudstone, calcareous shale
b.m.: regularly banded "turbiditic" carbonate mudstone, grading from silt to mud;
t.l.: "tiger limestone" - alternations of grey limestone (calcareous mudstone) and yellow dolomitic mudstone.

Sandstone, quartzite - mainly in Henson Gletscher Formation interpreted as storm sands
sst.: sandstone.

313074 Six figure numbers are GGU sample numbers

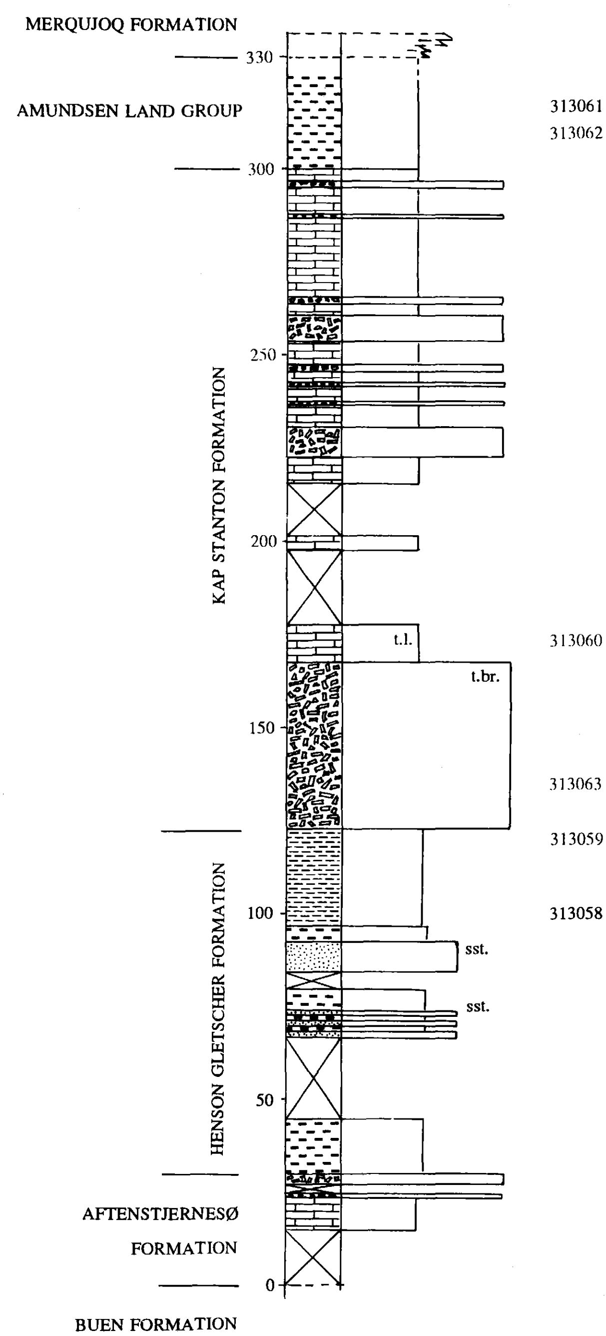


SECTION 1:

Nyeboe Land, south of Blackhorn Cliff, locality 84.22, measured 23 July 1984 by AKH & NJS.

Transition between Amundsen Land Group and Merqujoq Formation.

See Fig. 21 for more detailed log.

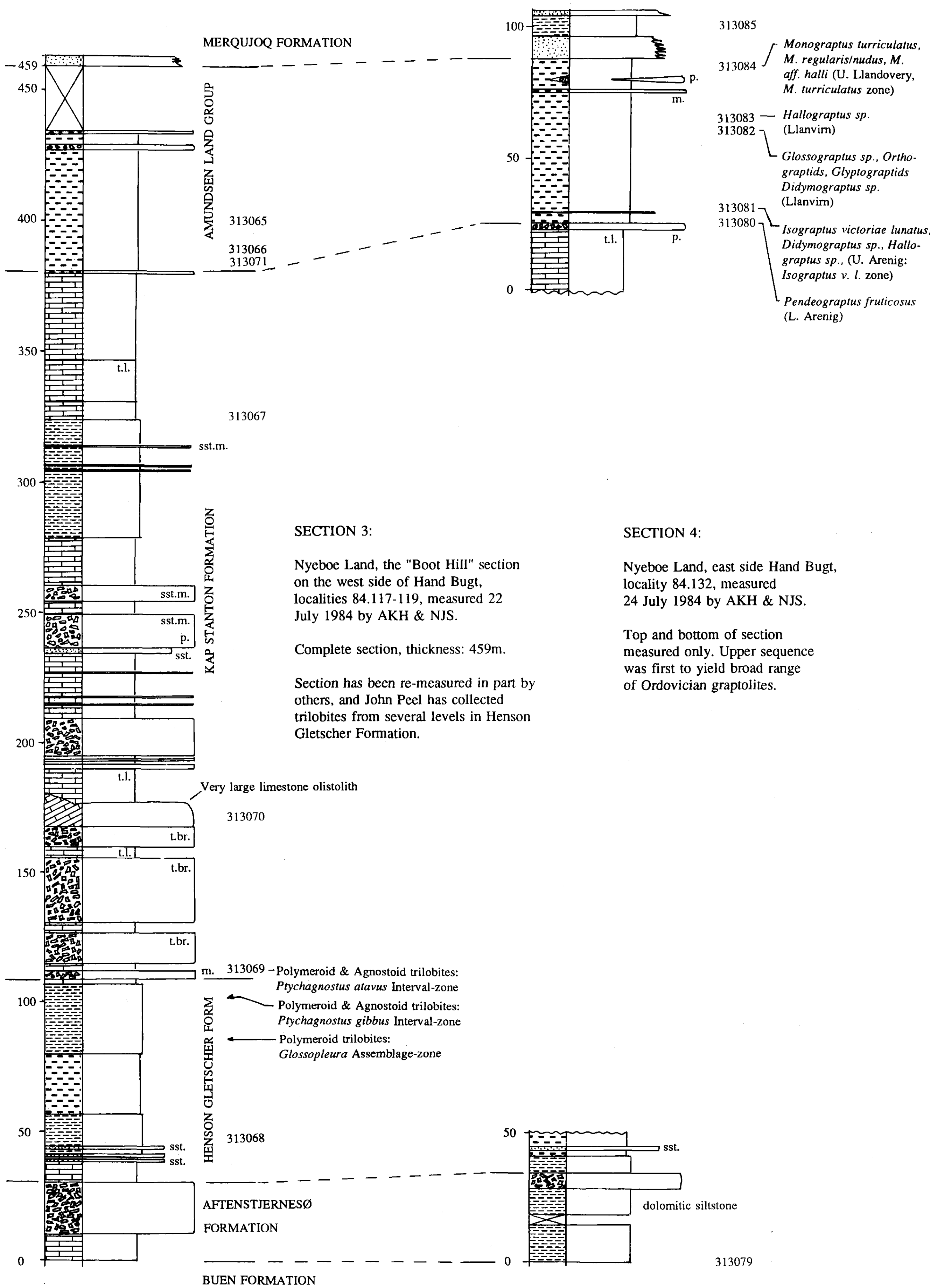


SECTION 2:

Nyeboe Land, east side Stanton Gorge, localities 84.110-112, measured 21 July 1984 by AKH & NJS.

Complete section, but pronounced folds hinder measurement here, and parts of sequence are covered by debris.

Estimated section thickness: 330m.



SECTION 3:

Nyeboe Land, the "Boot Hill" section on the west side of Hand Bugt, localities 84.117-119, measured 22 July 1984 by AKH & NJS.

Complete section, thickness: 459m.

Section has been re-measured in part by others, and John Peel has collected trilobites from several levels in Henson Gletscher Formation.

SECTION 4:

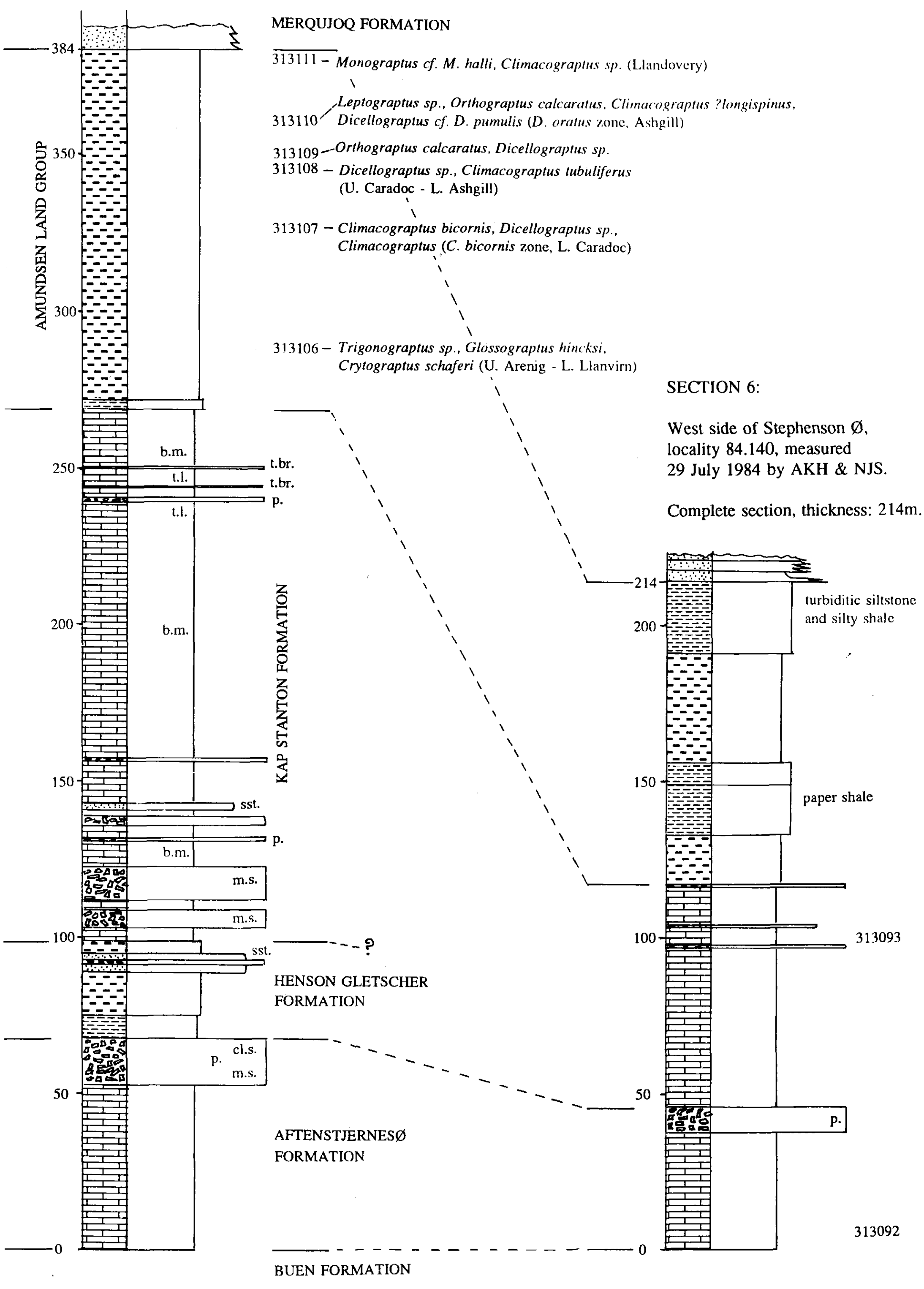
Nyeboe Land, east side Hand Bugt, locality 84.132, measured 24 July 1984 by AKH & NJS.

Top and bottom of section measured only. Upper sequence was first to yield broad range of Ordovician graptolites.

SECTION 5:

North-East Wulff Land,
locality 84.152, measured 03
August 1984 by AKH & NJS.

Complete section, thickness: 384m.



SECTION 8:

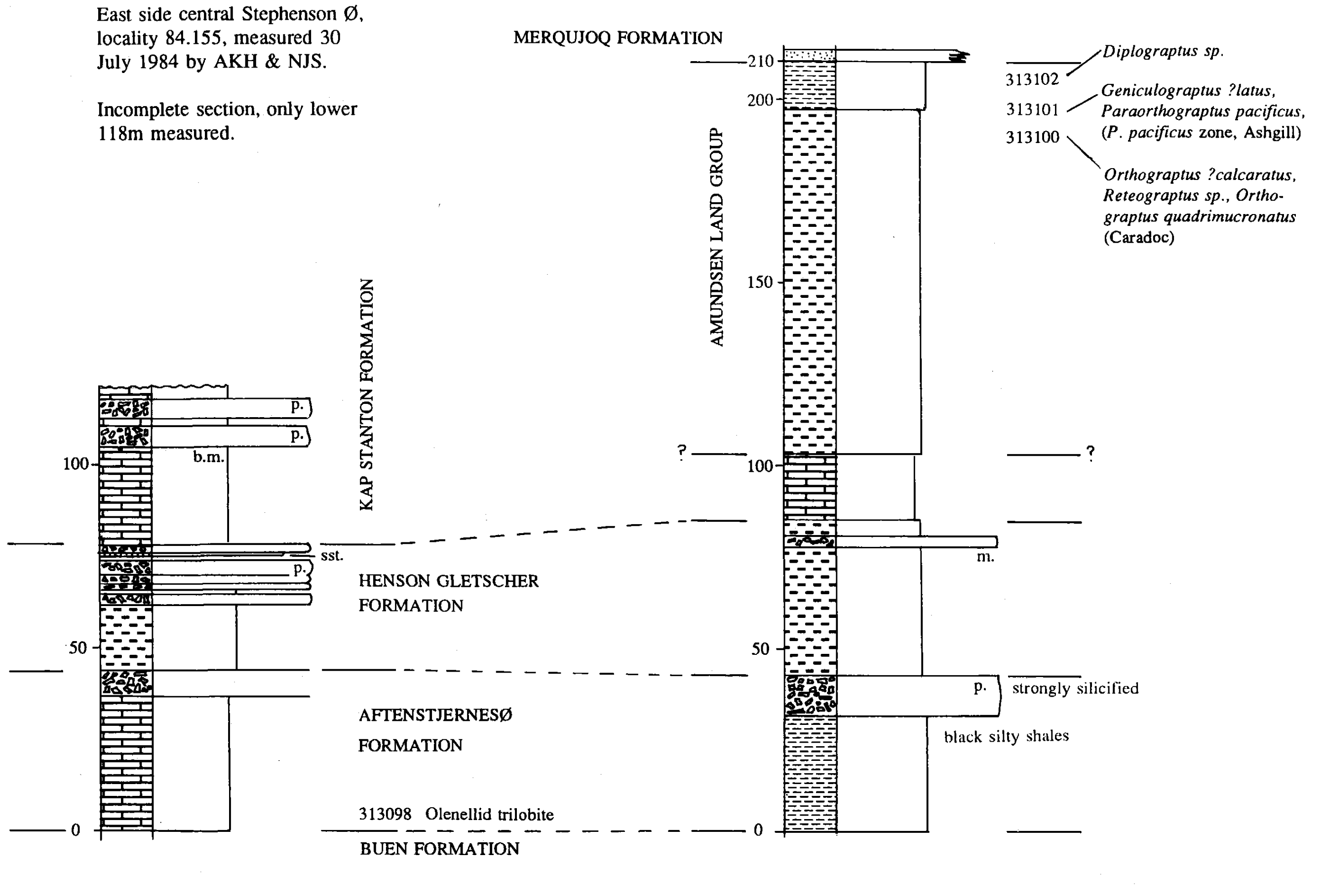
West side of Nares Land,
localities 84.147-148, measured
01 August 1984 by AKH & NJS.

Complete section, thickness: 210m.

SECTION 7:

East side central Stephenson Ø,
locality 84.155, measured 30
July 1984 by AKH & NJS.

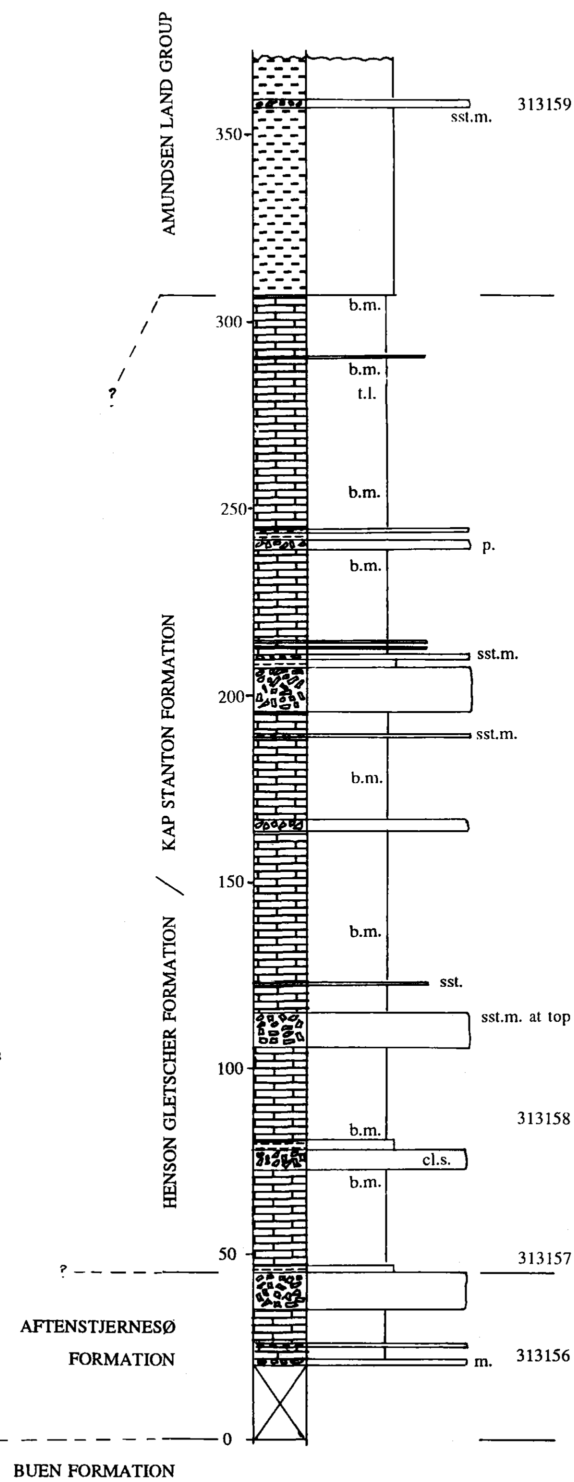
Incomplete section, only lower
118m measured.



SECTION 10:

West side of Navarana Fjord, localities 84.183, measured 13 August 1984 by AKH & NJS.

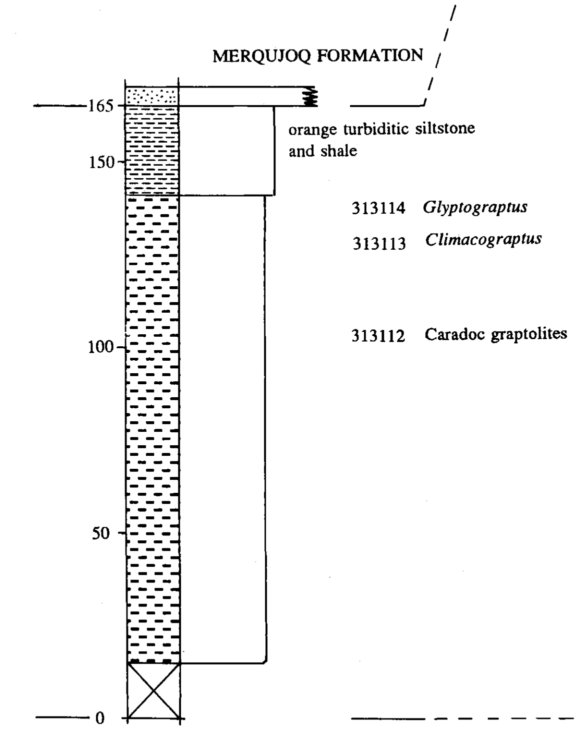
Incomplete section, missing lower 20m and uppermost cherts.



SECTION 9:

Northern Nares Land locality 84.154, measured 04 August 1984 by AKH & NJS.

Complete section of starved sequence, total thickness: 165m.



SECTION 12:

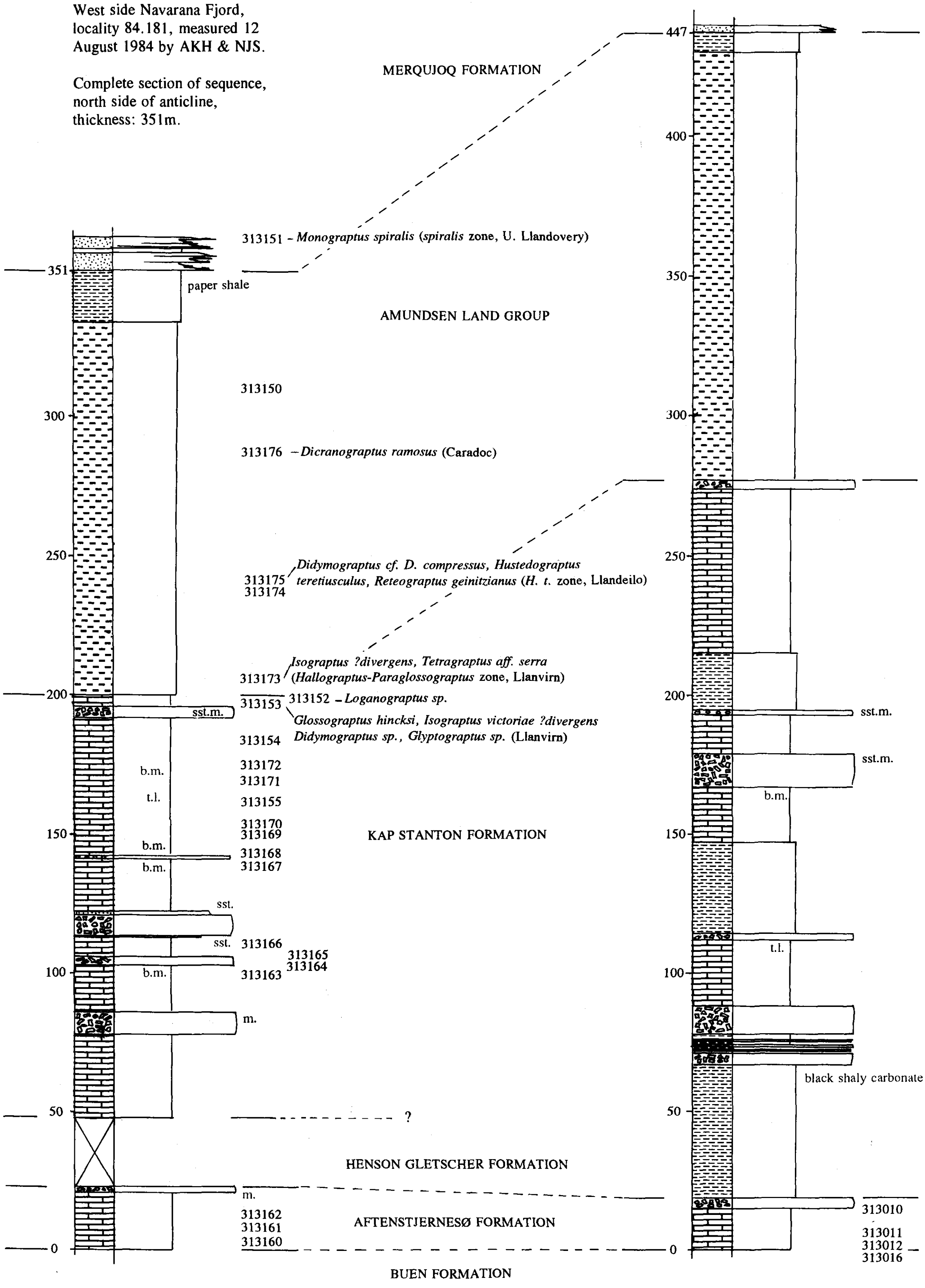
East side of Navarana Fjord, localities 84.011-014, measured 26 June 1984 by AKH & NJS.

Complete section, thickness: 447m.

SECTION 11:

West side Navarana Fjord, locality 84.181, measured 12 August 1984 by AKH & NJS.

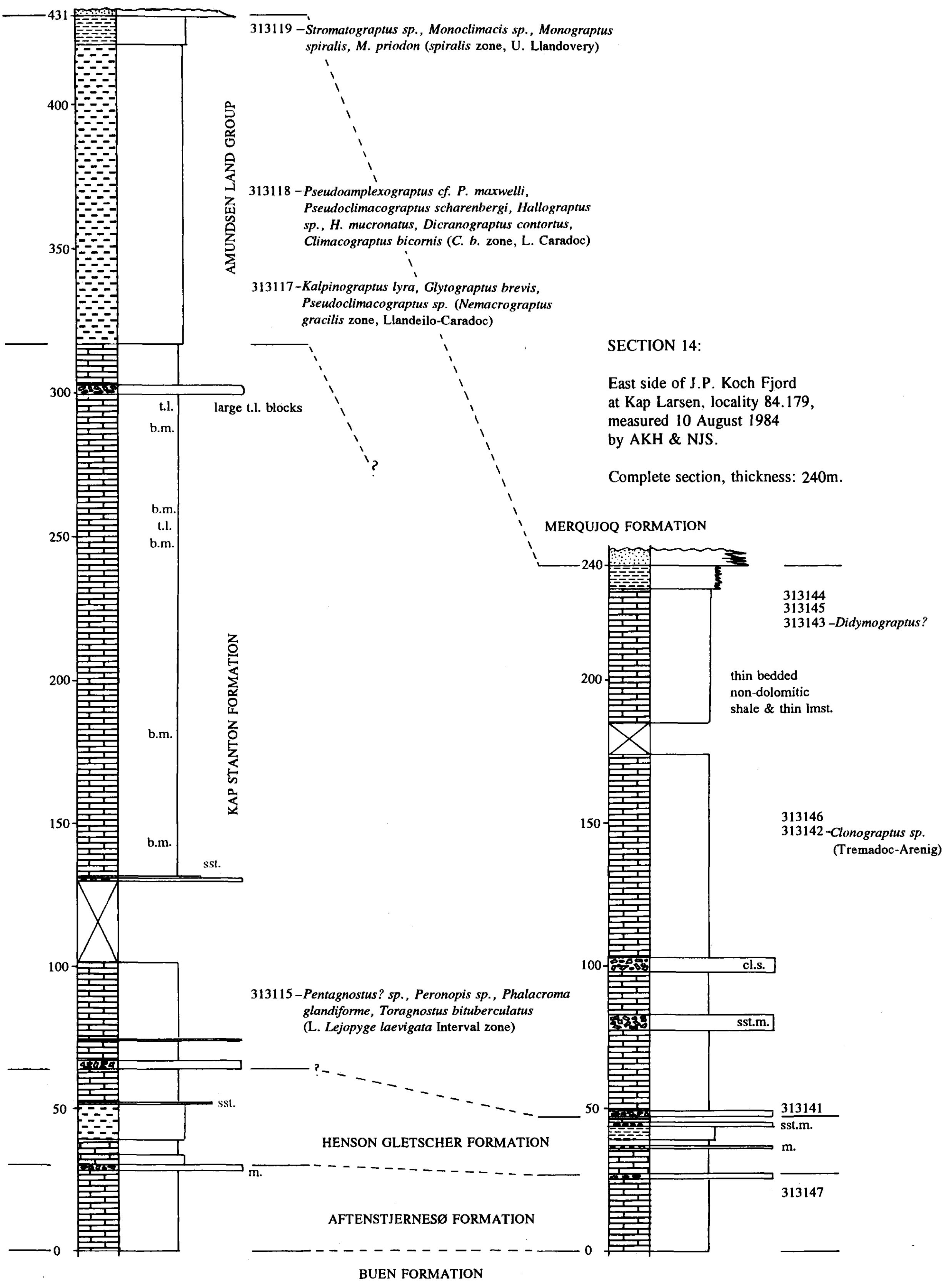
Complete section of sequence, north side of anticline, thickness: 351m.



SECTION 13:

East side J.P. Koch Fjord, north of Primus, locality 84.155, measured 04 August 1984 by AKH & NJS.

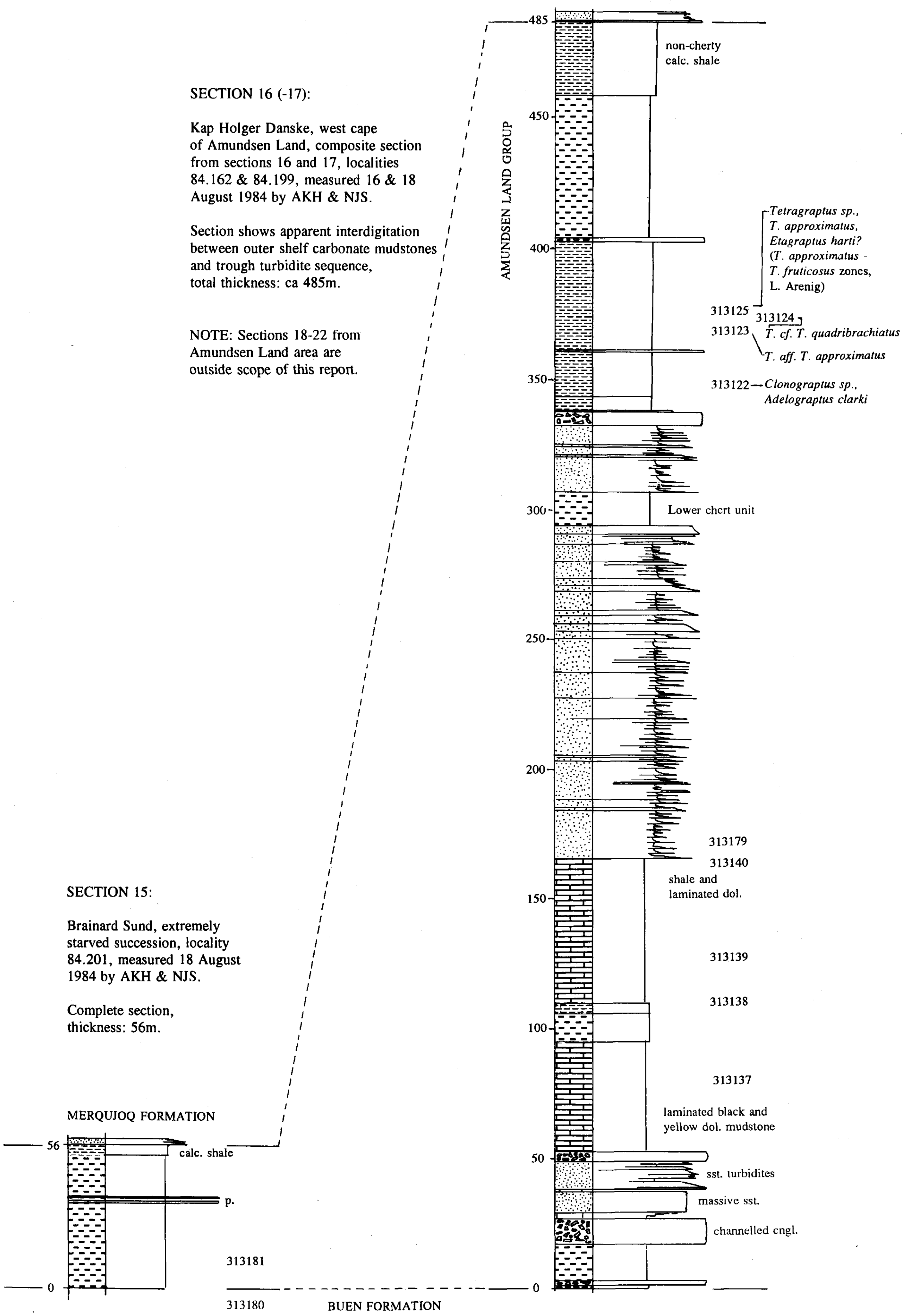
Complete section of sequence, thickness: 431m.



SECTION 14:

East side of J.P. Koch Fjord at Kap Larsen, locality 84.179, measured 10 August 1984 by AKH & NJS.

Complete section, thickness: 240m.

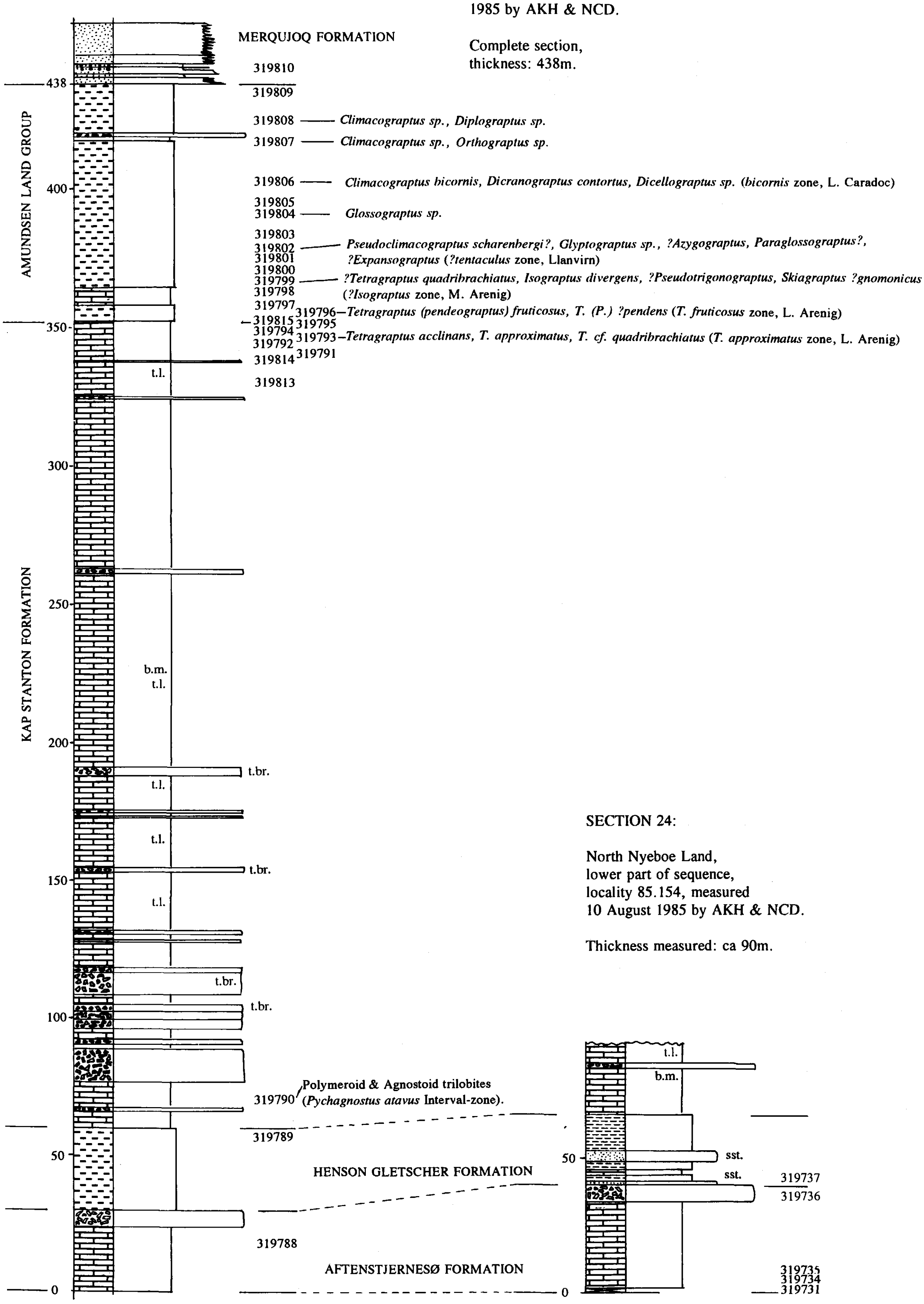

SECTION 16 (-17):
Kap Holger Danske, west cape of Amundsen Land, composite section from sections 16 and 17, localities 84.162 & 84.199, measured 16 & 18 August 1984 by AKH & NJS.
Section shows apparent interdigitation between outer shelf carbonate mudstones and trough turbidite sequence, total thickness: ca 485m.
NOTE: Sections 18-22 from Amundsen Land area are outside scope of this report.
SECTION 15:
Brainard Sund, extremely starved succession, locality 84.201, measured 18 August 1984 by AKH & NJS.
Complete section, thickness: 56m.
MERQUJOQ FORMATION
AMUNDSEN LAND GROUP
BUEN FORMATION
485
450
400
350
300
250
200
150
100
50
0
56
0
non-cherty calc. shale
Tetragraptus sp., T. approximatus, Etagraptus harti? (T. approximatus - T. fruticosus zones, L. Arenig)
313125
313124
313123
T. cf. T. quadribrachiatus
T. aff. T. approximatus
313122—Clonograptus sp., Adelograptus clarki
Lower chert unit
313179
313140
shale and laminated dol.
313139
313138
313137
laminated black and yellow dol. mudstone
sst. turbidites
massive sst.
channelled cngl.
calc. shale
p.
313181
313180

NOTE: Sections 18-22 from Amundsen Land area are outside scope of this report.

SECTION 23:

North Nyeboe Land, east of Frankfield Bugt, locality 85.185, measured 15 August 1985 by AKH & NCD.

Complete section, thickness: 438m.



SECTION 24:

North Nyeboe Land, lower part of sequence, locality 85.154, measured 10 August 1985 by AKH & NCD.

Thickness measured: ca 90m.

SECTION 26:

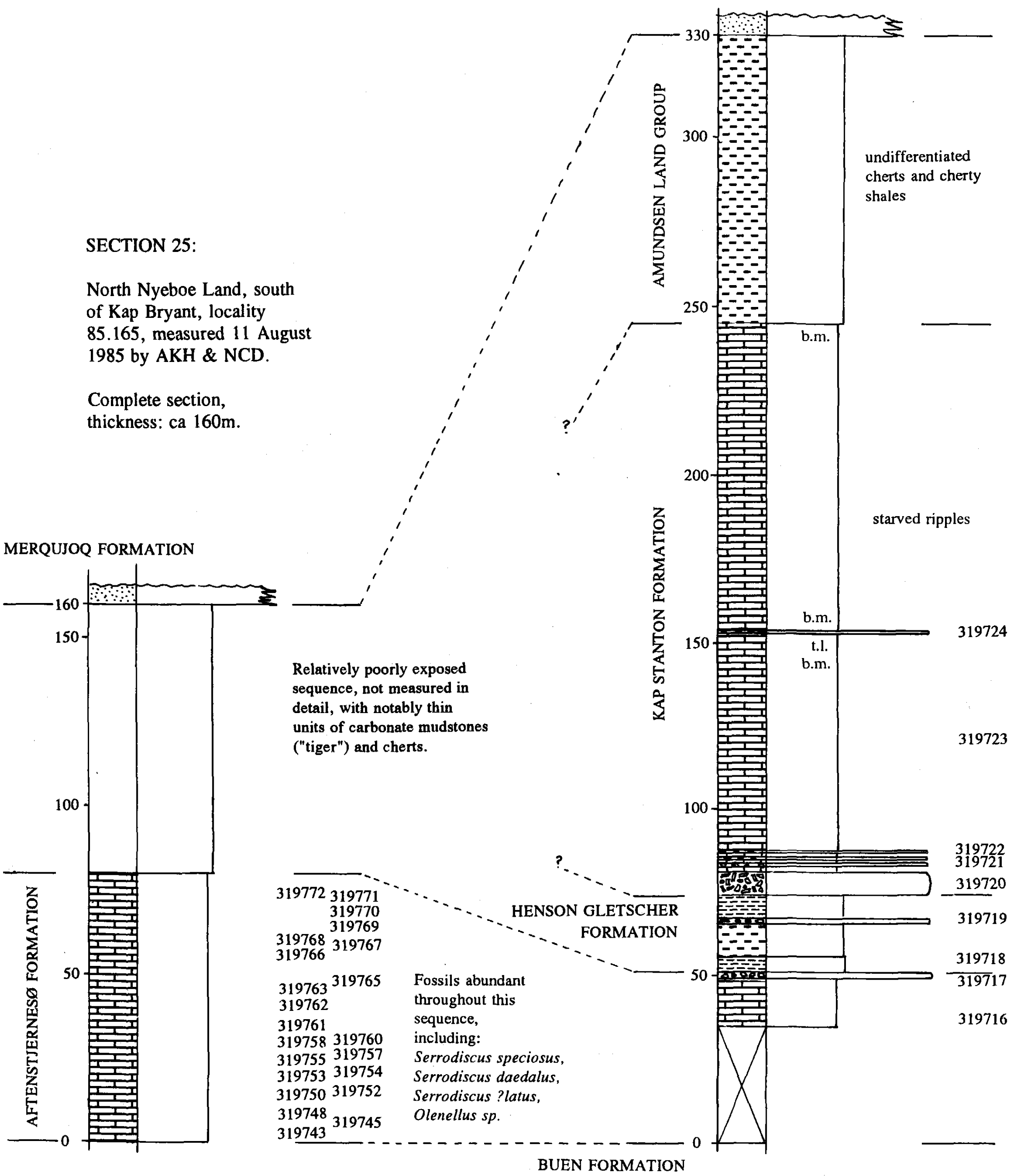
North Wulff Land,
locality 85.142, measured
07 August 1985 by AKH & NCD.

Almost complete section,
missing only lowest part of
Aftenstjernesø Fm,
thickness: ca 330m

SECTION 25:

North Nyeboe Land, south
of Kap Bryant, locality
85.165, measured 11 August
1985 by AKH & NCD.

Complete section,
thickness: ca 160m.



SECTION 27:

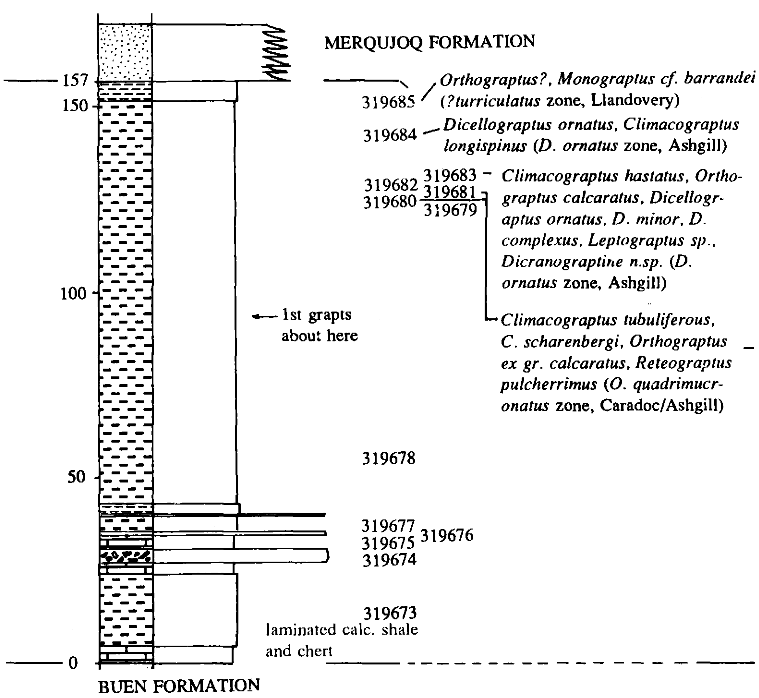
West coast of north Nares Land, locality 85.118, measured 31 July 1985 by AKH & NCD.

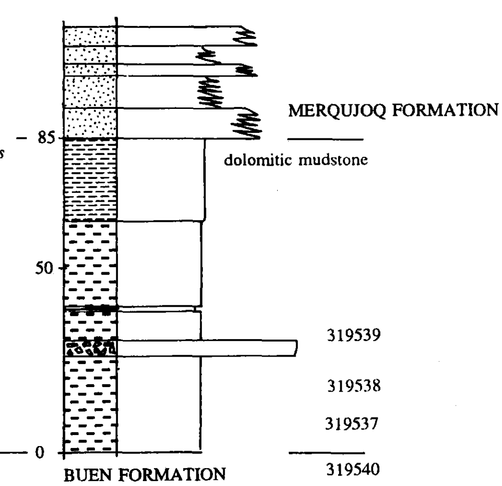
Complete section, thickness: 157m.

SECTION 28:

North Wulff Land, locality 85.22, measured 04 July 1985 by AKH & NCD.

Complete section, thickness: 85m.





SECTION 29:

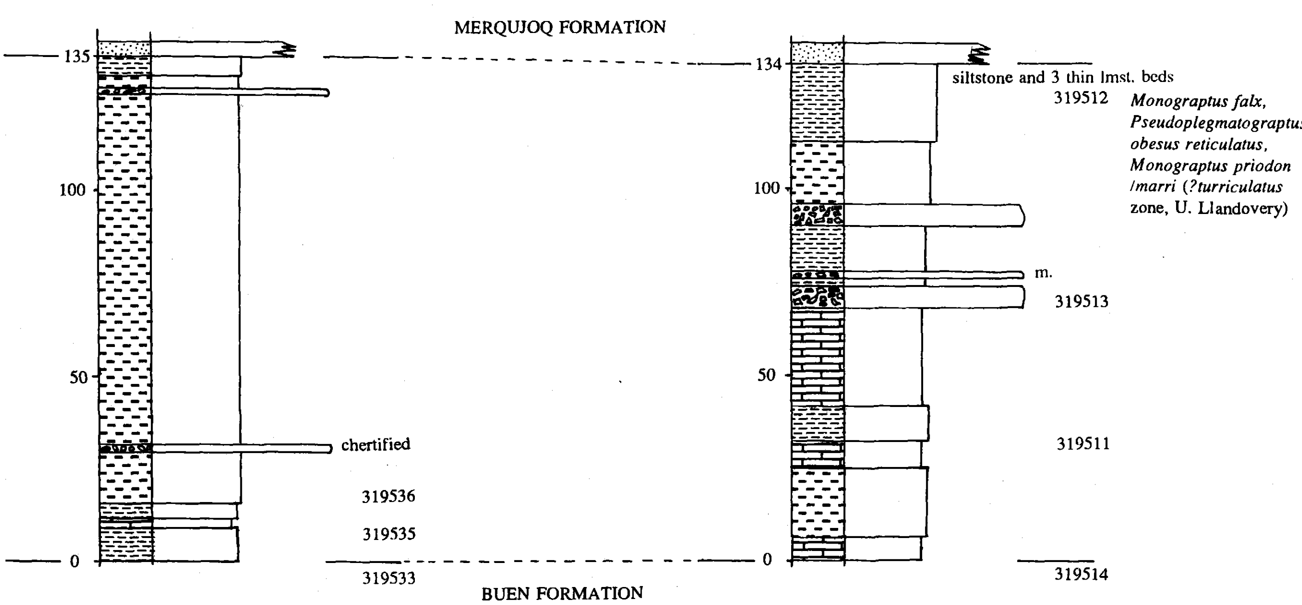
North-East Freuchen Land,
locality 85.21, measured
03 July 1985 by AKH & NCD.

Complete section,
thickness: 135m.

SECTION 30:

West Peary Land, east
side J.P. Koch Fjord,
locality 85.10, measured
01 July 1985 by AKH & NCD.

Complete section,
thickness: 134m.



GEOLOGICAL MAP OF NORTH GREENLAND

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