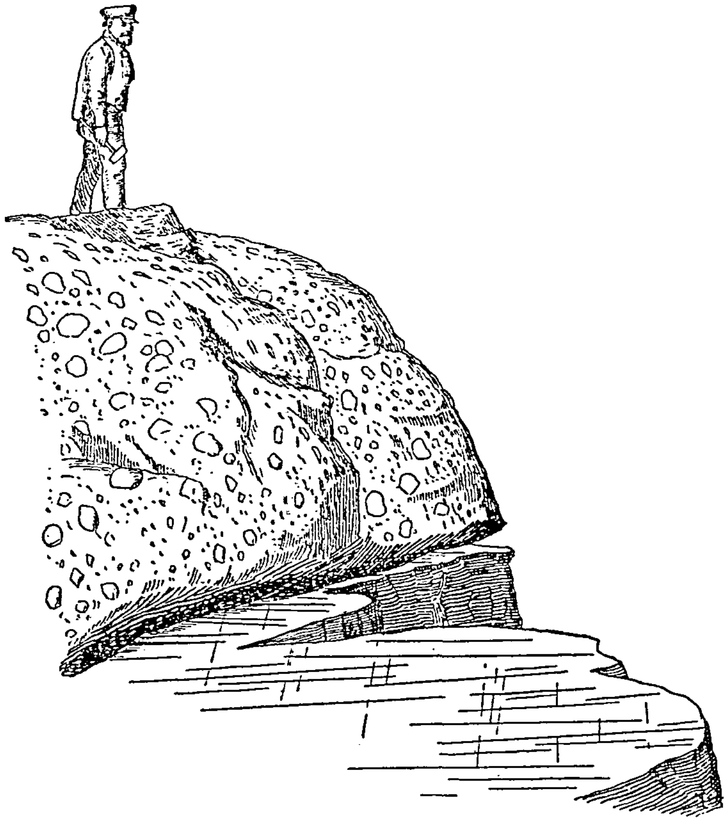
TERMINAL PROTEROZOIC SYSTEM

IGCP PROJECT 320
NEOPROTEROZOIC
EVENTS AND RESOURCES

IUGS WORKING GROUP
ON THE TERMINAL
PROTEROZOIC SYSTEM



FIELD GUIDE TO THE WORKSHOP IN EASTERN FINNMARK, NORTH NORWAY, 1-8 AUGUST 1994

by

Anna Siedlecka

Geological Survey of Norway, Report no. 94.065

Cover illustration: Drawing of the conglomerate at Bigganjargga from Reusch's paper published in 1891. Reusch identified glacial scours on the surface of the sandstone subjacent to the conglomerate and interpreted the conglomerate as a moraine. In subsequent literature the locality has often been referred to as 'Reusch's moraine' or 'Bigganjargga tillite'.

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RAPPORT

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Sammendrag:
Kort beskrivelse av litostratigrafi og facies utvikling av den øverste proterozoiske lagrekken i Øst-Finnmark med særlig vekt lagt på glasjale avsetninger og plasseringen av prekambrium-kambrium grense.

Ekskursjonsfører med beskrivelse av utvalgte lokaliteter og snitt i Varangerfjorden og Tanafjorden områdene.

Rapporten er skrevet for feltkonferansen av IGCP prosjekt 320 i Øst-Finnmark 1.- 8. august 1994.

Emneord: berggrunnsgeologi	stratigrafi	sedimentologi
proterozoikum		

PREFACE

The main phase of stratigraphic and sedimentological research on the Neoproterozoic record in East Finnmark started in the sixties and was largely completed in the eighties. This research was carried out mainly by postgraduate students from the University of Oxford under the leadership of Harold G.Reading and by Anna Siedlecka and Stan Siedlecki from the Geological Survey of Norway. During the last few years some additional research has been carried out in connection with the collaboration programme between the Geological Survey of Norway and the Russian Academy of Sciences. This research, as well as the mapping programme, is now completed and at the present time the Geological Survey of Norway does not have any projects operating in this area.

The main results of research carried out on the Neoproterozoic record of East Finnmark were published during the years 1965 - 1985. In this field guide I have chosen to enclose copies of the papers, or abstracts, which present results of research relevant to the objectives of the IGCP project 320 and IUGS Working Group on the Terminal Proterozoic System, and have written a brief introduction to the geology of the area to be visited with reference to the published results.

Marc B.Edwards, who has carried out an extensive research on the Varangerian glacial record in East Finnmark, agreed to join the excursion as co-leader and has provided valuable comments on the introductory notes and the proposed itinerary included in this guide.

I wish to thank my colleagues, Reidulf Bøe and David Roberts for their assistance during organisation of the workshop in East Finnmark and in the course of preparation of the excursion guide. I am also thankful to Brian A.Sturt, Research Director at the Geological Survey of Norway, for his support.

I acknowledge the economic support provided by the Geological Survey of Norway, Norges forskningsråd, Norsk Hydro and Statoil.

Trondheim, July 1994.

Anna Siedlecka

Contents:

INTRODUCTION

Upper Proterozoic successions of Late Riphean and Vendian age and strata of Early Cambrian age occur in northern and southern Norway. These Upper Riphean to Lower Palaeozoic strata, both in the southern 'sparagmite' region and in Finnmark, northern Norway, occur either autochthonously, resting unconformably on the older Precambrian rocks of the Fennoscandian Shield, or in nappes of the Lower and Middle Allochthons of the Scandinavian Caledonides (Fig.1). In both regions there are Varangerian tillites and there is a transition into Lower Cambrian strata. The most complete record in the south is found in the Osen-Røa Nappe Complex. The record in the north is more complete than in the south and the successions may be best studied in the autochthon of the Tanafjorden - Varangerfjorden Region, in the Gaissa Nappe Complex and in the Barents Sea Region of the northern Varanger Peninsula (Figs.1 and 2). The successions of the Barents Sea Region do not include tillites and are in many respects different from the main Upper Proterozoic sequences in Scandinavia. They will not be treated here. Information may be found in the enclosed papers by Siedlecka (1985) and Siedlecka & Roberts (1992).

The objectives of the workshop in northern Norway, 1-8 August 1994, are to examine and discuss:-

1) **the stratigraphy and facies of the Terminal Proterozoic sections, starting with the Varangerian glacial record;**
2) **the transition into the Cambrian and the location of the Precambrian - Cambrian boundary; and**
3) **The location of the lower boundary of the TPS and GSSP.**

In the text which follows I will therefore concentrate on this particular part of the Upper Proterozoic stratigraphy in East Finnmark, i.e. **the Vestertana Group** (Figs. 2 & 3).

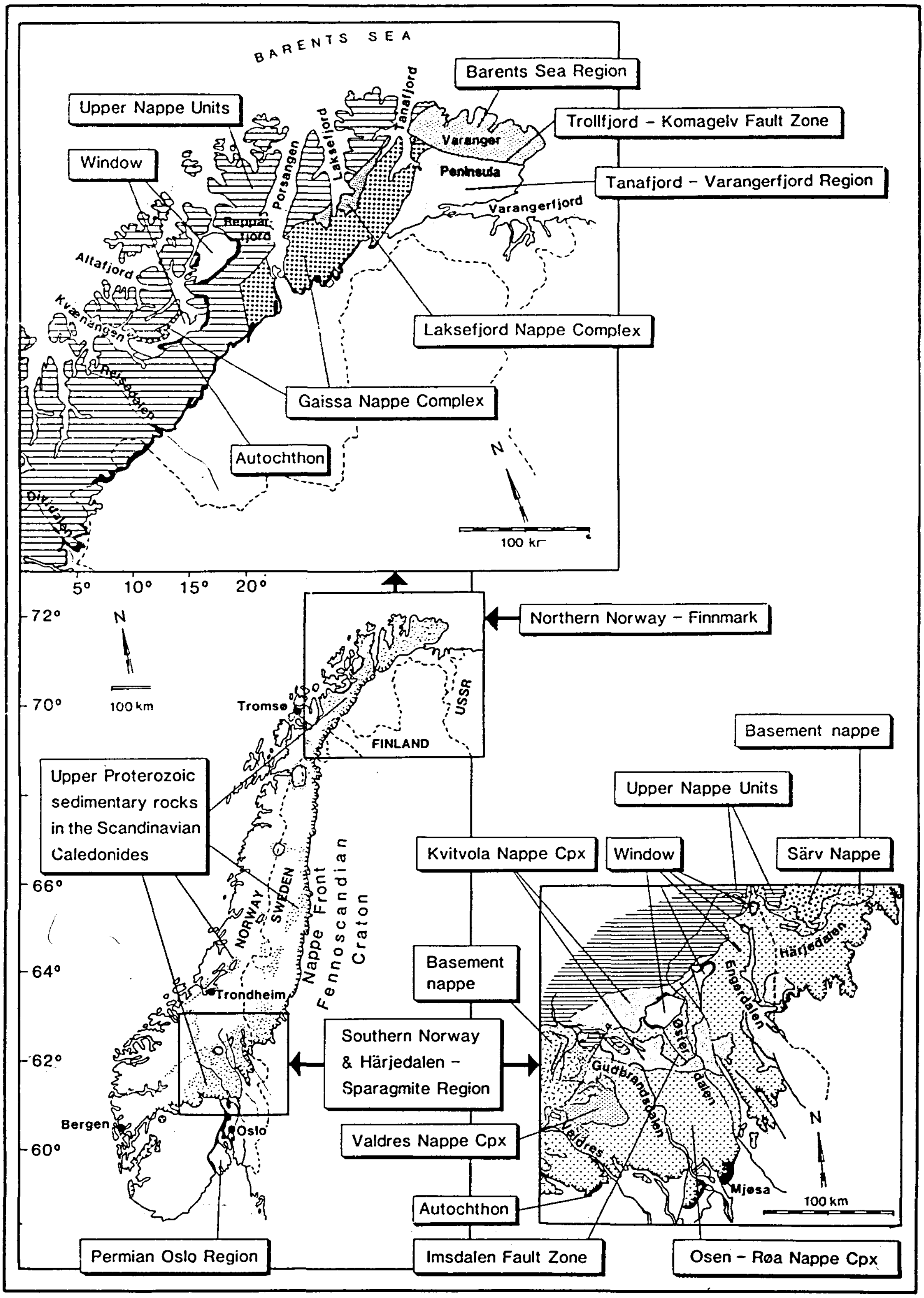


Fig. 1. Key maps showing occurrence of Upper Proterozoic to Lower Cambrian sedimentary rocks in the Scandinavian Caledonides (central map), in the sparagmite region, South Norway and Härjedalen, Sweden (lower right map), and in Finnmark, North Norway (upper left map). The key maps are modified from Gee *et al.* (1985).

(from Nystuen & Siedlecka 1988)

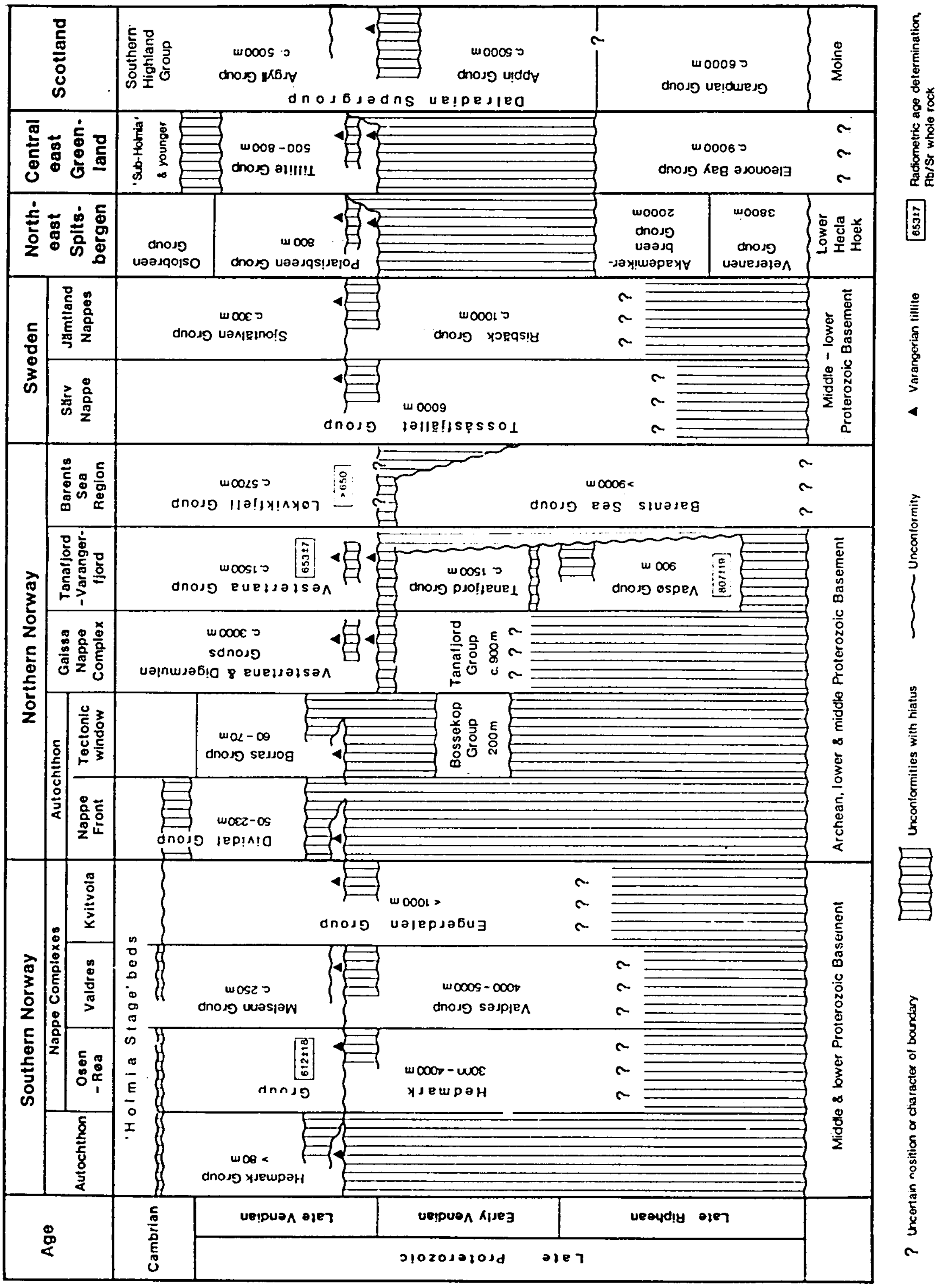


Fig. 2. Correlation diagram for Upper Proterozoic to Lower Cambrian sequences in the North Atlantic region. Sources: southern and northern Norway: Tables 18.1-18.5 of present chapter and Vidal (1981*a*); Sweden: Gee *et al.* (1974), Kumpulainen (1980, 1982); NE Spitsbergen: Harland (1959, 1985), Knoll (1982*a,b*); central East Greenland: Henriksen and Higgins (1976), Henriksen (1985); Scotland: Harris and Pitcher (1975), Johnson (1983).

(from Nystuen & Siedlecka 1988)

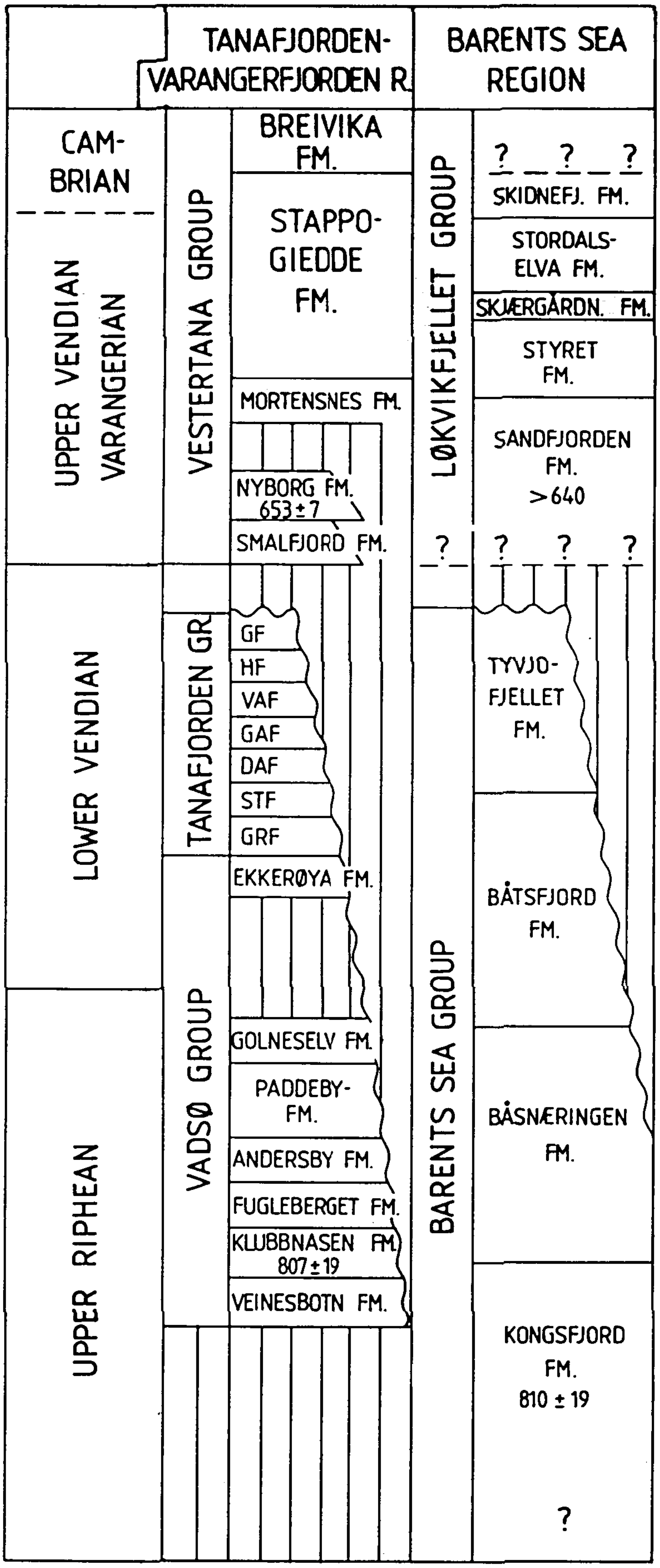


Fig. 3. Stratigraphy and correlation of the Neoproterozoic record in East Finnmark, northern Norway.

LOWER VESTERTANA GROUP: THE VARANGERIAN GLACIAL RECORD

The lower Vestertana Group consists of three formations (in descending order):-

Mortensnes Formation, commonly informally called the 'upper tillite',

Nyborg Formation,

Smalfjord Formation, commonly informally termed the 'lower tillite'.

A major, low-angle unconformity separates the Smalfjord Formation and the younger units from the substratum. The erosional hiatus increases southwards: in the north, on the eastern side of Tanafjorden, the Smalfjord Formation rests with an erosive contact upon the uppermost known portion of the Tanafjorden Group, the Grasdalen Formation, while in the south it overlies the lowermost Vadsø Group or older crystalline basement of the Fennoscandian Shield. This means that in the south (southern side of Varangerfjorden) up to 2500 m of the pre-tillitic succession has been removed successively to the south.

The sedimentology of the Varangerian record, including the postglacial Lillevatn Member of the overlying Stappogiedde Formation, has been studied by Reading & Walker (1966) and Edwards (1972, 1984). The Varangerian tillites were interpreted by Reading & Walker (1966) as glacio-marine, while Edwards (1972, 1984) forwarded the hypothesis that the glacial accumulations were predominantly of a terrestrial character. A substantial part of the information which follows in this guide is based on Edwards' observations and interpretation, and only to a lesser extent on the ideas of Reading & Walker (1966). Reference to pre-1984 literature is to be found in Edwards' (1984) paper. A useful summary on the tillite-bearing succession of Finnmark is that of Edwards & Føyn (1981). (Enclosed).

The **Smalfjord Formation** is widespread at the head and on the northern side of Varangerfjorden, and also at the head and inland from Tanafjorden in the Vestertana area (Fig.1). Another area where the Smalfjord Formation is extensive is that of Laksefjordvidda, on the plateau west of the area to be visited. I have chosen to highlight the most important characteristics of the Smalfjord Formation; details may be found in Edwards (1984).

The deposits of the Smalfjord Formation in the Varangerfjorden area and on Laksefjordvidda accumulated in two distinct palaeovalleys, the **Varangerfjorden Palaeovalley** and the **Krokvatnet Palaeovalley,** respectively. The deposits of the Tanafjorden area are considered to be younger than those infilling the valleys and were deposited by ice sheets.

The **Varangerfjorden Palaeovalley** coincides closely with the inner part of Varangerfjorden (Bjørlykke 1967). Sandstones and conglomerates deposited by water predominate in the Smalfjord Formation in this area, while diamictites, interpreted as glacial, are subordinate. Observed thicknesses of the palaeovalley infill reach c.125 m. Palaeocurrents record a transport direction towards the northwest and indicate ice movement in the same direction and its retreat southeastwards. The sequence of events suggested by Edwards (1984, pp.12-13)) is as follows:-

1) Glacial scouring of the palaeovalley,
2) Retreat of the glacier leaving behind ice-cored moraine ('Reusch's moraine', see further in this guide),
3) Rise of water level, turning the valley into a lake or fjord,
4) Continued deglaciation, progradation of deltas and coastlines,
5) Slumping of sediment down the valley sides, or subsequent glacial episodes, producing diamictites.

In the **Tanafjorden area** the Smalfjord Formation is characterised by an alternation of diamictite (tillite) and mudstone. Two chcracteristic features may be pointed out:-

1) The predominance of massive lodgement tillite, and
2) Repetitive sequences of an erosional surface -> glacial

lodgement till -> proglacial laminated mudstones (cf. summary sequence in Edwards 1984, p.15, his fig. 14).

Some tillites exhibit a pronounced banding or lamination which bring to mind glacimarine deposition. These tillites were interpreted as lodgement till in which mixing of local and far-transported debris by glacial shearing produced the banding (Edwards 1984). The repetitive sequences (cf.2 above) were interpreted as reflecting at least five advances and retreats of the ice sheet.

The **Nyborg Formation** rests upon the Smalfjord Formation with an unconformity and is unconformably overlain by the Mortensnes Formation; and there is a hiatus between the Nyborg and the Mortensnes formations (Vidal 1981). Deposition of the Nyborg Formation commenced with a post-glacial transgression, and at several localities a 'cap dolomite' occurs above the glacials. The carbonate facies varies from algal-laminated dolomite to mudstone-dolomite interbeds to edgewise conglomerate. It is usually just a few metres thick and represents a subordinate deposit of the Nyborg Formation, and is interpreted as having accumulated in a peritidal environment.

The Nyborg Formation is up to 400 m thick. However, as it is a structurally incompetent unit it is usually tightly folded, in contrast to the subjacent and overlying strata. Continuous sections therefore cannot be measured. Both thickness and facies distribution vary considerably, suggesting that the depocenter of the developing basin was located in the Vestertana area.

Interbedded grey sandstone and greenish-grey or purple shale in varying proportions constitute the predominant facies of the formation. This facies exhibits characteristics of turbidites with grain size decreasing from the Varangerfjorden to the Tanafjorden area. It was interpreted by Edwards (1984) in terms of a submarine fan model to basin plain with considerable detritus supply from the south and the presence of a significant palaeoslope along the southern margin of the basin. The stratigraphically higher facies include sandstones and shales which accumulated in high-energy coastal conditions preceded by deposits indicative of a transitional regressive phase in basin development. The uppermost strata are indicative of a return to transgressive conditions (Reading & Walker 1966). The shallow-marine sediments are preserved only in the north. To the south they were progressively removed by the Mortensnes tillite.

The **Mortensnes Formation** differs from the Smalfjord Formation in being:-

1) fairly homogeneous lithologically with tillite as the predominant facies,
2) less variable in thickness, and
3) much more widespread, extending from the eastern Varanger Peninsula to the Altafjord area in West Finnmark, i.e. a distance of more than 300 km (cf. Edwards & Føyn 1981).

The formation is thickest in the Vestertana area where it reaches c. 50 m. In brief, the formation consists in its lower part of lodgement tillite which was accumulated by piedmont glaciers advancing from the south. It may contain rafts of sandstones of the Nyborg Formation up to several metres in length. The middle part of the formation comprises both proglacial subaqueous diamictite and a more common subglacial lodgement tillite which accumulated during an ice advance from the north. It is easy to recognise by its reddish-brown weathering colour and an abundance of dolomite clasts. The upper part of the formation consists of dark-grey lodgement tillite and subordinate laminated mudstone with dropstones. It marks the second advance of ice, but from an unknown direction. The formation terminates with a widespread lag conglomerate.

Clasts in glacigene deposits of the Smalfjord and Mortensnes Formations include predominant fragments of crystalline rocks of the Fennoscandian Shield, as well as dolomite and chert clasts deriving from the uppermost Tanafjorden Group. Sandstone clasts from the subjacent Upper Proterozoic succession are subordinate. Some tillite horizons in both the Smalfjord and the Mortensnes Formation are dominated by either dolomite clasts or fragments of crystalline rocks. This feature has a stratigraphic importance only in some parts of the glacial record, e.g. the middle part of the Mortensnes Formation.

UPPER VESTERTANA GROUP: THE POST-GLACIAL RECORD

The upper Vestertana Group consists of two formations: the **Stapogiedde Formation,** overlying the glacial deposits, and the **Breivika Formation,** grading upwards into the Duolbasgaissa Formation of the Digermulen Group.

The upper Vestertana Group is of stratigraphic importance because it contains the first undoubted <u>trace fossils,</u> the fossils V<u>endotaenia, Sabellides</u> and <u>Platysolenites antiquissimus</u> and a poor assemblage of <u>Ediacaran fauna</u> in addition to an assemblage of acritarchs (Føyn 1967, Vidal 1981, Farmer et al. 1992). The upper Vestertana Group represents a continuous succession of shallow-marine to basinal terrigenous deposits. The Precambrian - Cambrian boundary may be defined within this succession and alternative locations of this boundary have been proposed (Føyn & Glaesner 1979, Vidal 1981, Farmer et al.1992, Vidal & Moczydlowska in press).

The **Stapoggiedde Formation** is more than 500 m thick and extends from the eastern Varanger Peninsula westwards to the Laksefjorden area. In addition, it is lithostratigraphically correlatable with the Dividal Group south of Porsangerfjorden, and this correlation enlarges considerably the geographic extent of deposits analogous to the Stappogiedde Formation.

The lowermost mudstones of the Stappogiedde Formation rest sharply and conformably on the Mortensnes Formation. These mudstones are interpreted as marking a post-glacial transgression and their greater thickness in the south suggests that the depocenter was located there. The lowermost mudstones are overlain by fine-grained conglomerate, coarse-grained feldspathic sandstone and mudstone with a distinct fining upwards motif, and with evidence for transport of detritus towards the north. This interval of the lower Stappogiedde Formation is interpreted as a delta prograding from the south with the development of a braided delta plain. In this context, the underlying mudstones probably represent prodelta deposits (Edwards 1984). Higher up, there are indications of a new deepening episode which resulted in long-lasting deposition of shelf muds which constitute the bulk of the middle Stappogiedde Formation. The total thickness of the lower part of the formation, **the Lillevatnet Member,** is c. 100 m while the overlying shelf muds are c.200 - 300 m thick in the Tana area thinning southwestwards to c.70 m (Banks 1973).

The middle Stappogiedde Formation, or the **Innerelva Member** (in the older literature called a blue-green and red-violet shale), is easily recognisable in the field because of this conspicuous coloration and is well exposed in several localities including good road-cuts. The red-violet coloration is primarily in the lower and upper parts of the member and these may be taken for Nyborg Formation in poorly exposed areas. Although exposure is generally good, there are few easily accessible, fairly complete and well exposed sections of the Innerelva Member. Banks (1973) measured two sections in the Tana area and these will be treated in more detail later on in this guide.

The Innerelva Member was interpreted as having been deposited in a quiet marine shelf environment. West of Tanafjorden the member comprises two coarsening-upwards sequences, interpreted by Banks (1973) as two shallowing-up episodes. East of the fjord, the entire member is finer grained and no distinct coarsening sequences have been observed. The section in the easternmost part of the Varanger Peninsula exhibits a somewhat coarser grain size compared to that in Austertana (eastern side of the Tana river). Thicknesses, facies distribution and palaeocurrent patterns suggest that land areas were located to the southeast of Varanger Peninsula and to the west of the Tana area which was the site of the deeper part of the basin.

The shallow-marine upper part of the Stappogiedde Formation, the Manndraperelva Member, is c.190 m thick in the Tana area and thins considerably towards the southwest. The contact against the Innerelva Member is gradational (Banks et al.1971). In the Tana area the member consists of three intervals of red sandstones separated by two bands of grey greywackes and mudstones (Reading 1964, Beynon et al.1967). There are two coarsening-upwards cycles from greywacke and mudstone to red sandstone interpreted as a shallowing from offshore turbidites to shallow-marine accumulations. Transport of the material was primarily towards the southwest (Banks et al. 1971).

The **Breivika Formation** is the uppermost formation of the Vestertana Group and is of Early Cambrian age. The thickness of the formation is approximately 600 m and there is a gradual transition between the Stappogiedde and the Breivika Formations. The boundary between the formations has been placed by Reading (1965) at the top of the uppermost red sandstone. According to Banks (1971, p.82) this was not a good choice since another red sandstone occurs a short distance above what Reading clearly mapped as the base of the Breivika Formation. Banks (1971) therefore redefined the boundary as located between the red and white sandstone of the second coarsening-upwards sequence (in the Manndraperelva Member) and an interbedded sandstone - mudstone interval (lower Breivika Formation). The Breivika Formation is subdivided into two informal members. The upper member is preserved only on the Digermulen Peninsula.

The **lower Breivika member,** at least 264 m thick in the type section at Breivika (SE coast of Digermulen), consists of alternations of sandstones and shales with an abundance of sedimentary structures, common bioturbation and trace fossils (Phycodes pedum). It was also in this member that the Platysolenites antiquissimus was found (Føyn 1967, Hamar 1967). The member has been interpreted as a deposit from a tidal current influenced shelf environment, tens of metres deep (Banks 1971).

The **upper Breivika member** rests with a sharp planar contact on the white quartz arenite of the lower member and consists predominantly of greenish-grey mudstone and subordinate thin sandstone. The sediments are heavily bioturbated and Phycodes palonatum and Teichichnus are present. The upper Breivika member was deposited in quieter conditions and in deeper water than the lower member (Banks 1971).

THE NATURE OF IMPORTANT LITHOSTRATIGRAPHIC BOUNDARIES - A SUMMARY

1. Bottom of the Smalfjord Formation: low-angle unconformity,major hiatus. Incised valleys.
2. Interface Smalfjord - Nyborg Fms.: (?) transition (Reading & Walker 1966); unconformity (Edwards 1984). 'Cap dolomite' Interpretation: transgression, post-glacial eustatic SL rise.
3. Interface Nyborg - Mortensnes Fms.: unconformity. The tillite progressively cuts down through the Nyborg Formation and rests on the Smalfjord Fm. or on the Vadsø Group (Banks et al.1971, Siedlecki 1980, Edwards 1984). Hiatus (Vidal 1981). Regression due to the eustatic SL fall.
4. Interface Mortensnes Fm. - Lillevatnet Mbr.: sharp, transgressive (Banks et al. 1971, Edwards 1984). Post-glacial eustatic SL rise. Possible GSSP?
5. Interface Lillevatnet - Innerelva Mbrs.: gradational, interpreted as transgression.
6. Interface Innerelva - Manndrapselva Mbrs.: gradational, regressive, hypothetical unconformity in the west (Kunes) (Banks et al.1971).

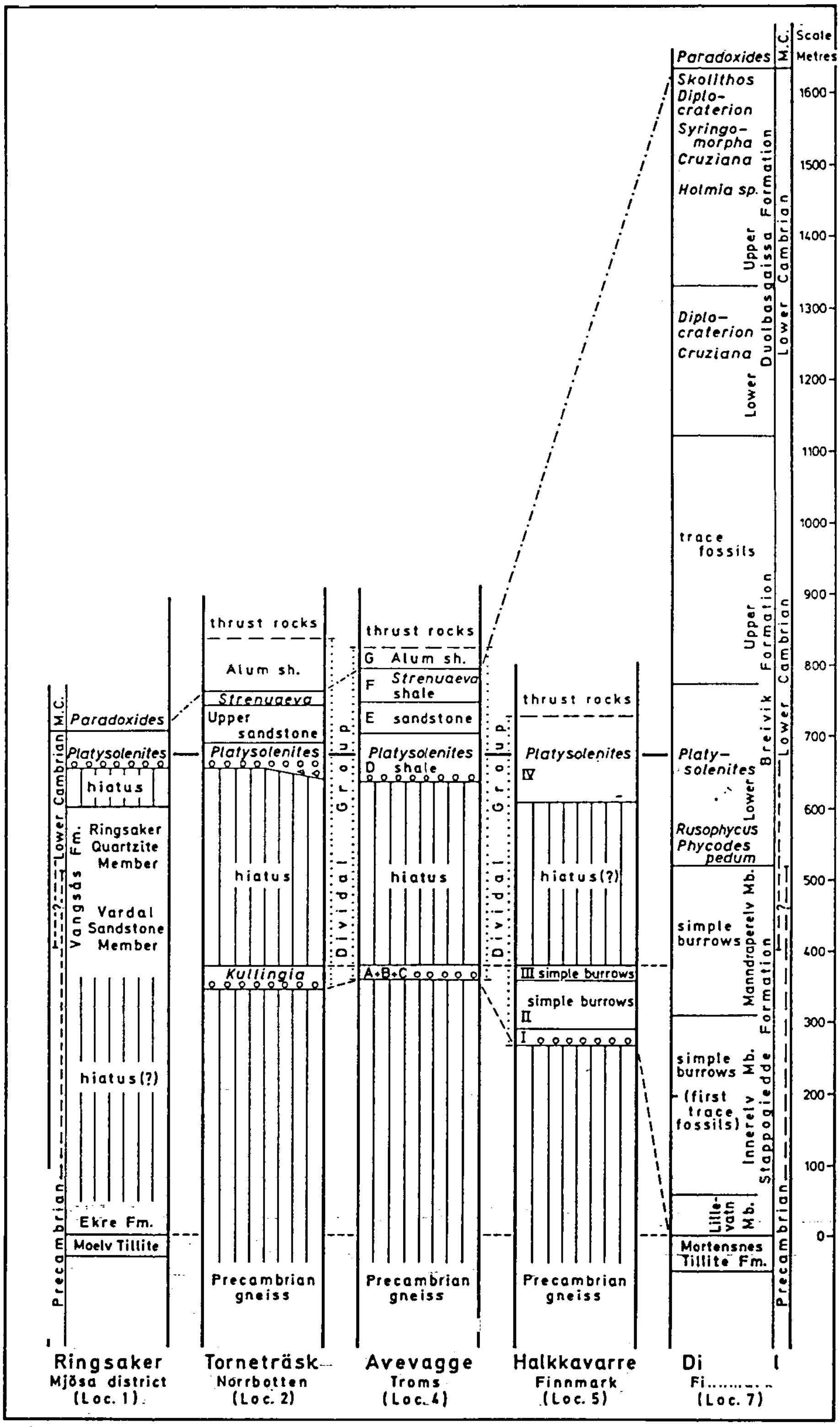


Fig. 4. Correlation table and the proposed location of the Precambrian - Cambrian boundary.

7. Interface Manndrapselva - L.Breivika Mbrs.: gradual transition (Banks 1971).
8. Interface L.Breivika - U.Breivika Mbrs.: sharp planar contact (Banks 1971).

LOCATION OF THE PRECAMBRIAN-CAMBRIAN BOUNDARY - A SUMMARY

1. Føyn & Glaesner (1979): The authors reviewed several Upper Precambrian-Cambrian sections in Scandinavia and described fossils Platysolenites antiquissimus, Spirosolenites spiralis, Aldanella kunda and Sabellides cambriensis. They suggested location of the Precambrian-Cambrian boundary either within the Mandraperelva Member or at the bottom of the Breivika Formation (Fig.4).

2. Vidal (1981): The author described an acritarch assemblage from the Upper Proterozoic succession of the Tanafjorden - Varangerfjorden Region of the Varanger Peninsula and suggested location of the Precambrian-Cambrian boundary within the Manndraperelva Member (see enclosed paper, p.41).

3. Farmer et al.(1992): The authors described an Ediacaran fauna from the middle Stappogiedde Formation. They suggested location of the Precambrian -Cambrian boundary within the lower Breivika Formation.

4. Vidal & Moczydlowska (in press): The authors are suggesting a location of the Precambrian-Cambrian boundary within the lower Breivika Formation.

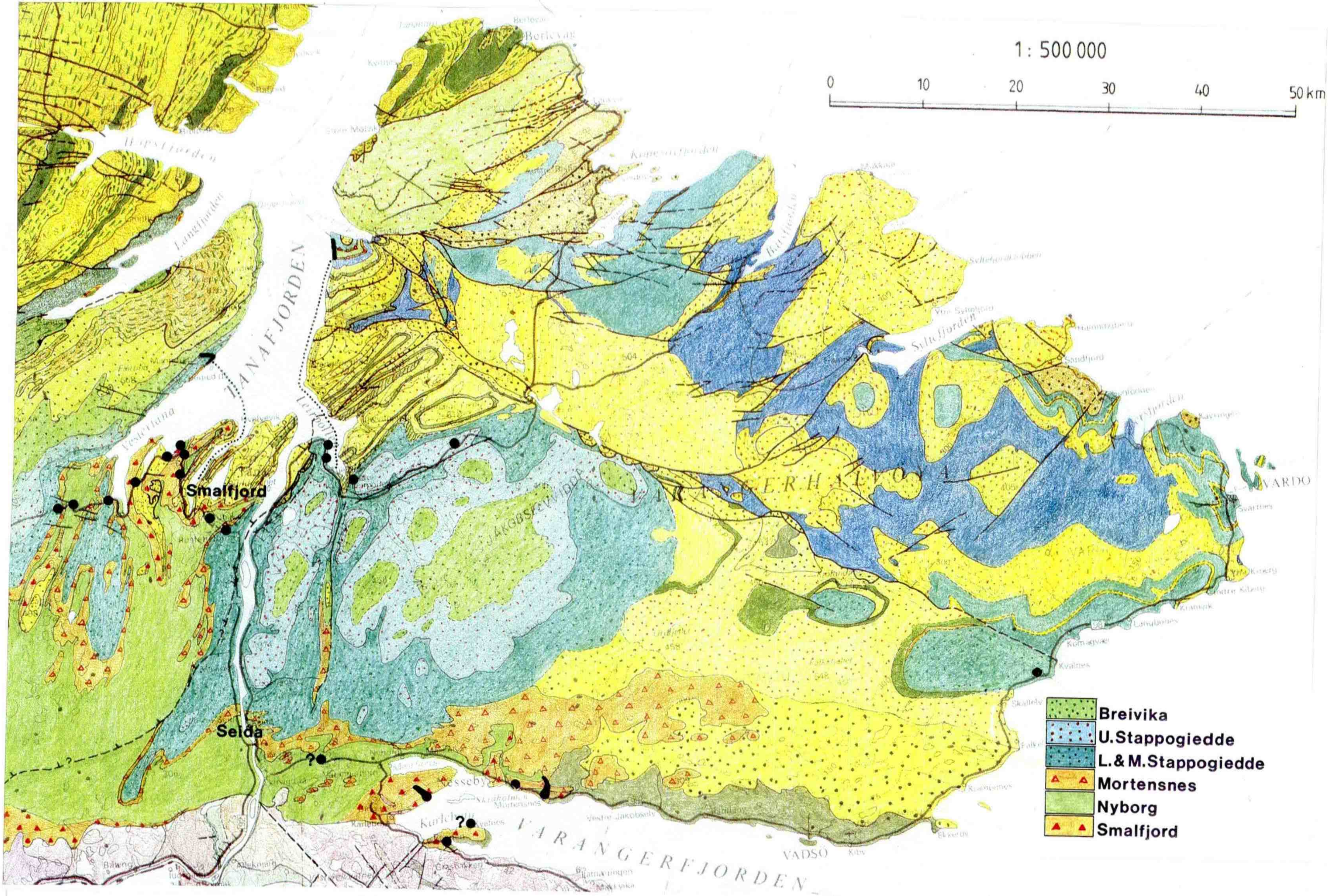


Fig. 5. Localities and sections proposed to be visited during the excursion

ITINERARY

Several localities and sections described below were previously referred to in some detail in Edwards (1984) and Siedlecka & Roberts (1992). For these localities the descriptions presented below are short and reference is given to the above-mentioned publications (enclosed).

Day 1: Monday, August 1st. Arrive at Vadsø. Afternoon/evening: Introduction and welcoming dinner.

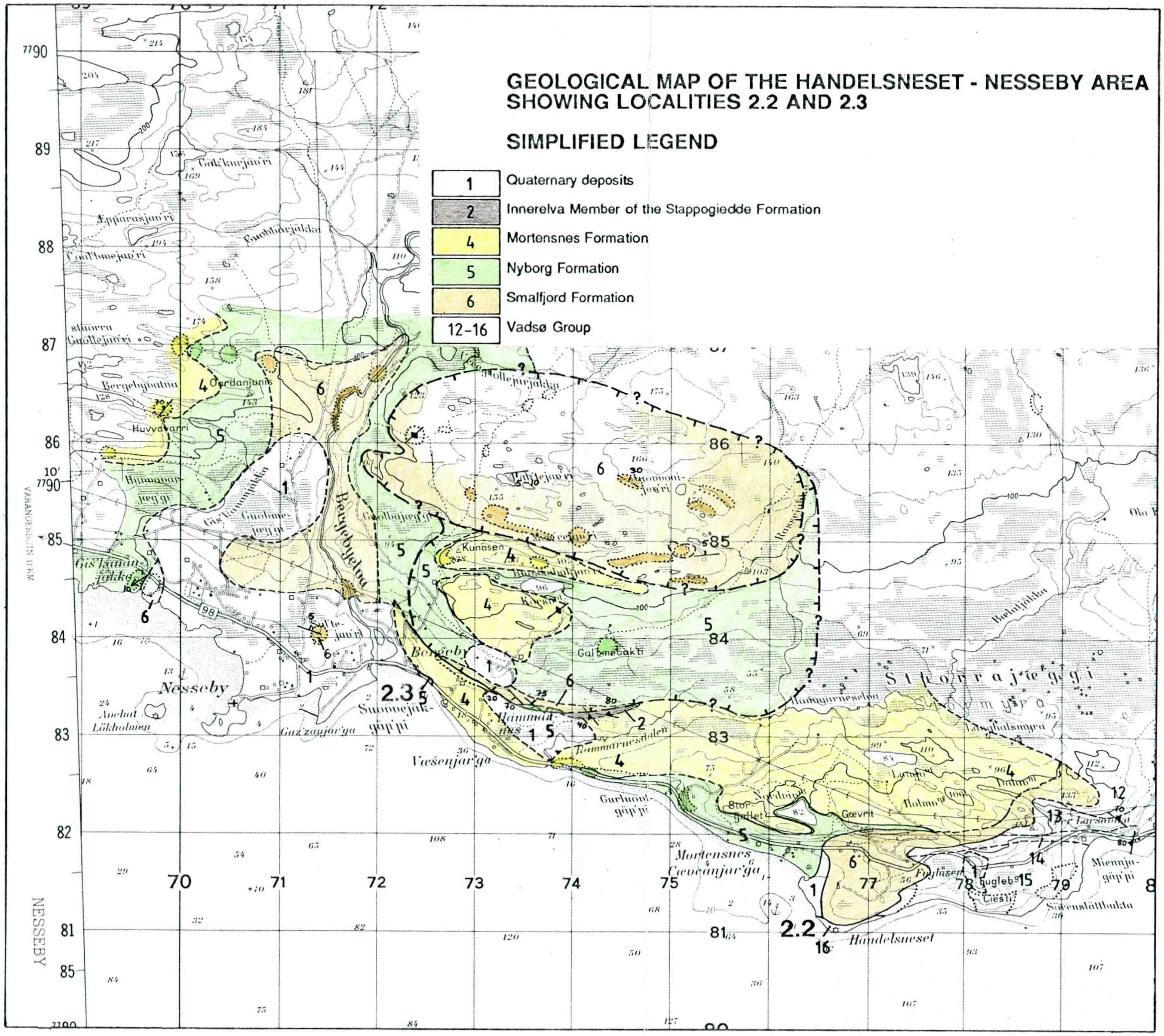
Day 2: Tuesday, August 2nd. Northern side of Varangerfjorden

2.1. Section of the **Innerelva Member** of the Stappogiedde Formation at Komagnes in the eastern part of Varanger Peninsula (described in Siedlecka & Roberts 1992 as loc.9, p.21 and their fig.18). This is the easternmost occurrence of the Stappogiedde Formation. About 100 m of the lower Innerelva Member is exposed on the south-facing slopes above the road (cf.Banks 1973, Kvalneset section, his fig.12). Neither the top nor the bottom of the member is exposed here and therefore a precise stratigraphic correlation with other sections is difficult. Blue-green, parallel laminated or ripple-cross stratified shales which are typical for this member crop out here. In contrary to the western occurrences these rocks are almost uncleaved and split easily along the bedding planes. Vertically oriented, burrow-like structures present in these rocks were first described by Banks (1970, 1971, 1973) as *Scolithos* and *Arenicolites*. These and other enigmatic structures were later reinterpreted as pseudofossils which originated by dewatering of sediment (Farmer et al. 1992). From this section Vidal (1981) described poorly preserved microfossils: *Bavlinella faveolata*, *Protosphaeridium cf.flexuosum*, *Trachysphaeridium levis* and vendotaenid algae.

2.2. The section at Handelsneset (Mortensnes), located about halfway between Vadsø and Varangerbotn (Fig.6). This is the easternmost section of the lower Vestertana Group exposed at the coast, close to the main road. The Smalfjord Formation at this locality has been described by Edwards (1984, pp.10-11, his fig.13) and the entire section is referred to in Siedlecka & Roberts (1992, p.18).

The section is located on the northern side of the deeply incised **Varangerfjord Palaeovalley** and the erosional contact, which shows considerable relief, is excellently exposed. The Smalfjord Formation rests on the lower-middle part of the Vadsø Group (a prograding deltaic sequence) and the unconformity is overlain by a variety of conglomerates and conglomeratic sandstones, representing on the whole a retrogradational - progradational set (Fig.7). The Nyborg Formation, underlying the slopes north of the highway, consists of interbedded purple clayey shale and sandstone. Lenses of dolomite and dolomite edgewise conglomerate are also present. These rocks are somewhat better exposed west of the Handelsneset section (Mortensnes - Hammarnes). Reddish-brown diamictite of the Mortensnes Formation forms a cliff several metres high above the Nyborg Formation. It represents a massive lodgement tillite (Edwards 1984).

2.3. Exposure in the slope on the northern side of the main road, c. 5 km west of the Handelsneset section. This locality is described as No.4 in Siedlecka & Roberts (1992, p.17, their fig.11). Turbidites of the Nyborg Formation, accumulated on a submarine fan (member B of Edwards 1984), are unconformably overlain by the massive tillite of the Mortensnes Formation. A c.300 m thick portion of the Nyborg Formation is probably missing here. The succession of events included a major regression followed by erosion, and by a subsequent deterioration of the climate and accumulation of lodgement tillite. The Nyborg - Mortensnes interface is a good candidate for a sequence boundary (type 1 ?).
The facies development of the Mortensnes tillite and



GEOLOGICAL MAP OF THE HANDELSNESET - NESSEBY AREA
SHOWING LOCALITIES 2.2 AND 2.3
SIMPLIFIED LEGEND
1 Quaternary deposits
2 Innerelva Member of the Stappogiedde Formation
4 Mortensnes Formation
5 Nyborg Formation
6 Smalfjord Formation
12-16 Vadsø Group
2.3
2.2
Nesseby
Handelsneset
Mortensnes
NESSEBY

Fig. 6

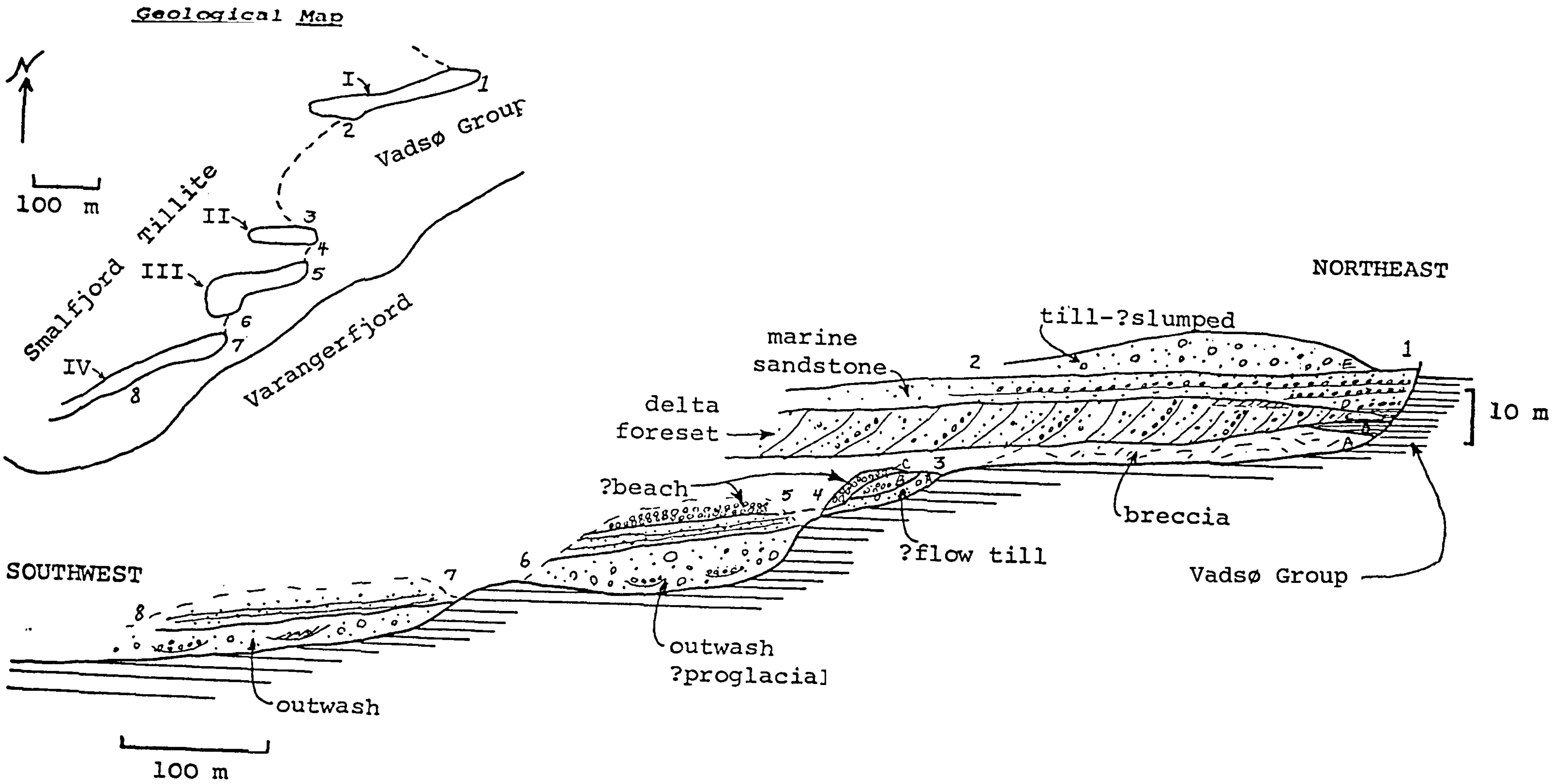


Fig. 7. Relationships between the four outcrops at Mortensnes. View between stations 2 and 3 is foreshortened. (From Edwards 1972)

composition of clasts may be conveniently studied along the coast immediately southeast of the main road.

2.4. (Optional). The road between Varangerbotn and the Tana River crosses the Nyborg Formation, primarily the member B sandstones and shales of Edwards (1984). These deposits are closely comparable to turbidites, most of them being thin-bedded and fine grained. Parts of the Nyborg section, deposited close to the basin margin, consist of thick, graded-bedded turbidites. One stop is proposed for an examination of these deposits.

Day 3: Wednesday, August 3rd. Grasdalen - Trollfjorden and Austertana.

Group A

The group will examine the coastal section south of Trollfjorden on the eastern coast of the Tanafjorden (Fig.5). We will commence with the uppermost formation in the Tanafjorden Group, the **Grasdalen Formation.** This terrigenous-carbonate unit is preserved only in this section, and comprises three stromatolite horisons (two of them with columnar stromatolites Minjaria tana and Parmites, Bertrand-Sarfati & Siedlecka 1980, Raaben et al. in press). The exposure of the stromatolitic strata is on a mountain slope and there is a rather exhausting, c.45 minute climb to this part of the section. The stratigraphically higher, terrigenous-dolomitic part of the Grasdalen Formation is exposed at the coast. Dolomitic sandstones and siltstones, thin dolomites, intraformational dolomitic breccias with imbricated pebbles, spectacular clastic dykes and synsedimentary faults may be observed both along the beach and in the coastal slopes. These strata grade upwards into finely laminated blackish-grey shale which is sharply overlain by tillite.

The **Smalfjord Formation** in this section, consists, of three units and has a total thickness of c.10 m (Edwards 1972, 1979, 1984). Only the lower c.6 m thick banded tillite is well exposed at the sea-shore while the remaining units and the contact with the substratum are continuously exposed in the coastal cliffs. Although the climb to this section (c.40 minutes) may be hard it is of importance because both the nature of the contact and the interpretation of the sedimentary facies of the Smalfjord Formation have been controversial. Reading & Walker (1966) interpreted the tillite as a glacimarine deposit resting conformably upon the Grasdalen Formation. Later, the contact has been reinterpreted as an unconformity (Siedlecka & Siedlecki 1971, Edwards 1972). Edwards (1972, 1979, 1984) suggested that the lowermost unit represents a basal till and that the overlying siltstone is a loessite (Fig.8).

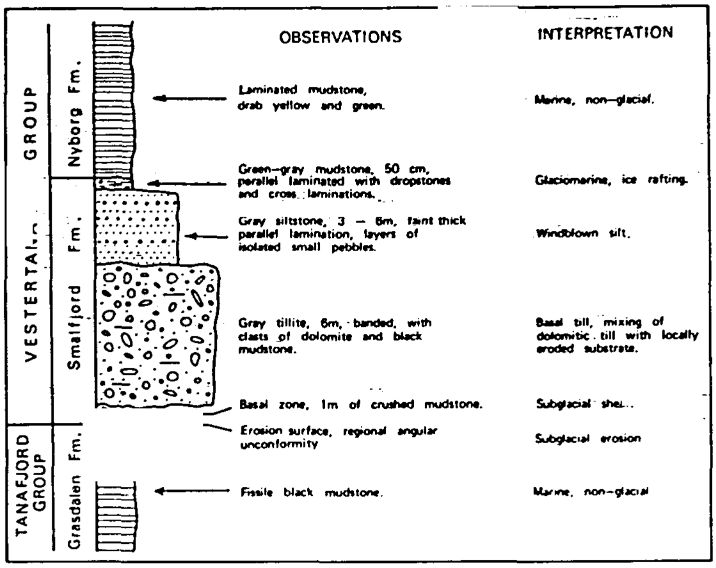


Fig. 8. Profile through the Smalfjord Formation at Grasdalen, Finnmark. From Edwards 1979.

The tillite is blackish-grey, distinctly banded and laminated, and exhibits a pronounced, steeply dipping cleavage. It contains dolomite fragments up to 15 cm across and, in its lower part, clasts of black shale. The tillite rests sharply on a blackish-grey shale, which is strongly sheared in the uppermost c.0.5 metres. Downwards, the shale becomes greenish-grey and contains yellow-weathering interbeds of impure dolomite. The thickness and number of the dolomite beds increase downwards. The upper part of the Smalfjord Formation, above the loessite, consists of grey-green laminated mudstone with dropstones (glacimarine). This is overlain by variegated (purple-green) laminated mudstone of the **Nyborg Formation.** In its lowermost part the formation contains three interbeds of dolomicrite, the thickest being about 20 cm (the 'cap dolomite', member A of Edwards 1984, p.27 and 40-41, and his figs.29 and 44). The exposure of the grey-greenish, muddy and arenaceous beds of the Nyborg can be followed northwards but is discontinuous. Interestingly, the highest (E) member of the Nyborg Formation is preserved only in this area and consists of clean sandstone and dolomite.

(The walk along the coast is time consuming and therefore at least a number of persons may proceed by boat to the upper part of the section which includes the Mortensnes Formation and parts of the Stappogiedde Formation).

The contact between the Nyborg and the **Mortensnes Formation** is erosional and in the latter there are clasts of tillite of the Nyborg sandstone. The tillite is about 10 m thick, and is overlain by a (transgressive) lag conglomerate which terminates the Mortensnes Formation (for more information, see Edwards 1984, pp.48-66, his fig.55).

The succeeding lower **Lillevatn Member** of the Stappogiedde Formation is c. 4 m thick and rests sharply upon the Mortensnes conglomerate. The silty and sandy parallel-laminated beds of this units were interpreted as marking a major post-glacial transgression (Reading & Walker 1966, Edwards 1984). The upper submember (c.40 m) consists of interbedded, grey, fluvial sandstones and muddy shales interpreted as parts of a prograding deltaic sequence.

There is a gradual upward transition into a thick, monotonous series of mudstones which constitute the **Innerelva Member.** The mudstones are purple in the lowermost part but over most of the section (which is some 200-300 m thick) the coloration is blue-green. This member was interpreted as a shelf deposit and the transgression as a result of a eustatic rise of sea level as the ice of the Varangerian glaciation finally melted away (Reading & Walker 1966, Banks 1971, 1973). These beds are extensively exposed in the coastal cliffs; however, climbing requires great care because the slopes are steep and may be slippery.

Group B

3.1. Stratigraphic section embracing the Smalfjord Formation and Lillevatn Member exposed in a gentle anticline along the road in Austertana on the western side of Leirpollen (Fig. 5). The section is described as locality 19 in Siedlecka & Roberts (1992, p.27). The lower part of the Vestertana Group is very condensed, each formation being only a few metres thick.

The section starts with the grey, massive **Smalfjord tillite** which contains a few fragments (< 1 cm) of dolomite (the thickness of the Smalfjord Formation in the Austertana area has been estimated to c. 8 m, Beynon et al. 1967). It is overlain by a c. 1 m thick grey mudstone which is sharply overlain by c. 25 cm of finely laminated dolomitic mudstone of the **Nyborg Formation** followed by about 1 m of stromatolitic dolomite. Some 350 - 400 m north of the dolomite (along the road), purple mudstones are exposed followed by brownish-grey **Mortensnes tillite** that contains fragments primarily of crystalline rocks.
At some distance towards the south (? c. 200 m) there are outcrops of grey mudstones of the **Lillevatn Member** (lower, c.45 m thick submember of Edwards 1984, his fig.45). This is

followed by grey, coarse-grained, feldspathic sandstone and conglomerate (upper submember, c.40 m thick, cf.Edwards 1984, his fig. 78-5 on p.68). The transition into the Innerelva Member, usually marked by a purple coloration of the shales, is not visible in this section.

3.2. The **Innerelva Member** is exposed in extensive road-cuts to the south of the previous locality (Siedlecka & Roberts 1992, locality 20). Here, blue-green mudstones and siltstones (to fine-grained sandstones) are parallel-laminated and ripple-cross stratified. In contrast to the same member at Komagnes, the rocks here split easily along subvertical joints and cleavage planes rather than along the bedding surfaces.

3.3. Section of the bulk of the Vestertana Group east of inner Leirpollen. As in the previous locality, the section of the lower Vestertana Group is condensed. The exposure is in the woods and is incomplete. However, critical contacts and the lithologies of all stratigraphic units may be found. The sharp erosional contact between the Hanglečærro Formation and the **Smalfjord tillite** is exposed in the southern part of this locality. The tillite contains fragments primarily of dolomite and is here not more than a few metres thick. Higher up, in the woods, there is a zone of scattered large blocks of algal-laminated dolomicrite marking the bottom of the **Nyborg Formation.** The shaly portion of this formation is not exposed; it is marked by a vegetated depression. Up sequence, across the depression, the **Mortensnes tillite** is exposed and exhibits a shaly parting just beneath the contact with the sandstones of the upper submember of the **Lillevatnet Member.** It thus looks as if the lower submember is missing here, although the relationships are not quite clear. The bottom of the **Innerelva Member** is marked by the purple coloration of mudstones which higher up in the section have a more common blue-green coloration. The slope above the woods exposes blue-green mudstones which are followed by red-coloured mudstones and sandstones of the **Manndraperelva Member.** The slope is rather steep, much of it is covered with scree and it may be somewhat dangerous to climb. However, as the complete Innerelva Member occurs here, climbing this section may be tempting.

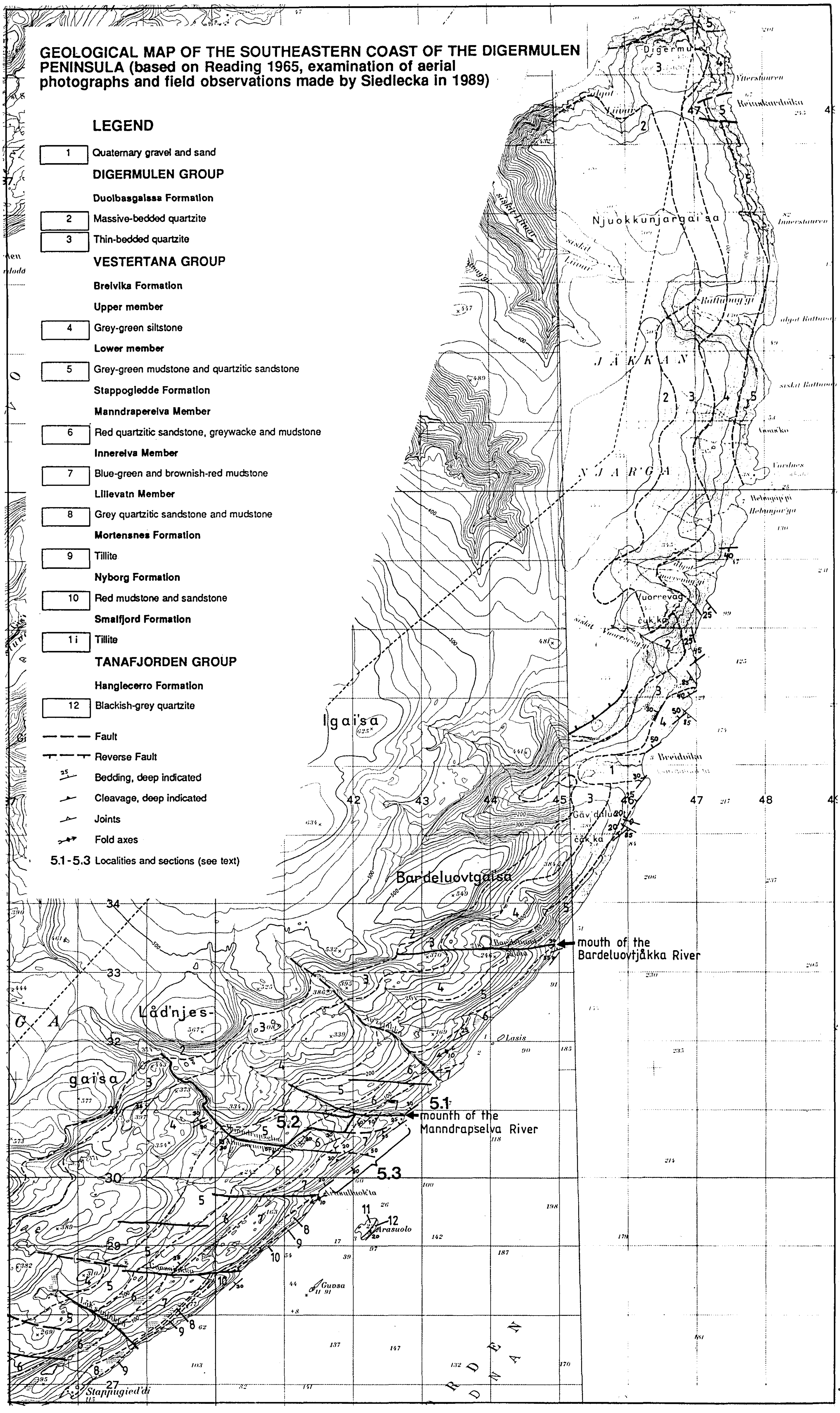
3.4. Red sandstones and clayey to muddy shales of the **Manndraperelva Member** occur in a creek and on slopes adjacent to the main road (Siedlecka & Roberts 1992, locality 22). These shallow-marine sediments, with evidence of subaerial exposure, represent the lower part of the member (the Lower Sandstone of Banks 1971).

Day 4: Thursday, August 4th

The programme of Day 3 will be repeated. Group A will examine sections in the Austertana area while Group B will go by boat to the coastal section along the eastern side of Tanafjorden, south of Trollfjorden.

Day 5: Friday, August 5th. Digermulen Peninsula.

The programme scheduled for this day is **totally dependent** on the weather conditions, particularly the direction and strength of the wind which in this area changes fast and is unpredictable. The localities are described below according to the scheduled priority. The main objective of the programme is to examine the Stappogiedde and Breivika Formations of the upper Vestertana Group (Figs. 5,9,10). Descriptions of localities given below are fairly detailed as compared with those from other areas. The reason for this is that the details, in particular with respect to the Manndrapselva Member and the Breivika Formations, are not available in publications. They are based either on unpublished observations (by Siedlecka) or on the Ph.D.thesis of Banks (1971).


GEOLOGICAL MAP OF THE SOUTHEASTERN COAST OF THE DIGERMULEN PENINSULA (based on Reading 1965, examination of aerial photographs and field observations made by Siedlecka in 1989)
LEGEND
1 Quaternary gravel and sand
DIGERMULEN GROUP
Duolbasgaissa Formation
2 Massive-bedded quartzite
3 Thin-bedded quartzite
VESTERTANA GROUP
Breivika Formation
Upper member
4 Grey-green siltstone
Lower member
5 Grey-green mudstone and quartzitic sandstone
Stappogiedde Formation
Manndrapereiva Member
6 Red quartzitic sandstone, greywacke and mudstone
Innereiva Member
7 Blue-green and brownish-red mudstone
Lillevatn Member
8 Grey quartzitic sandstone and mudstone
Mortensnes Formation
9 Tillite
Nyborg Formation
10 Red mudstone and sandstone
Smalfjord Formation
1i Tillite
TANAFJORDEN GROUP
Hanglecerro Formation
12 Blackish-grey quartzite
Fault
Reverse Fault
Bedding, deep indicated
Cleavage, deep indicated
Joints
Fold axes
5.1-5.3 Localities and sections (see text)
Digermulen
Njuokkunjargaisa
JÅKKAN
NJARGA
Vuorrevag
čuk ka
Igaisa
Breidvika
Gäv'dulučuk ka
Bardeluovtgaisa
mouth of the Bardeluovtjåkka River
Låd'njes-
gaisa
5.1
mounth of the Manndrapselva River
5.2
5.3
Arasuolo
Gupsa
Stappugied'di
Fig. 9

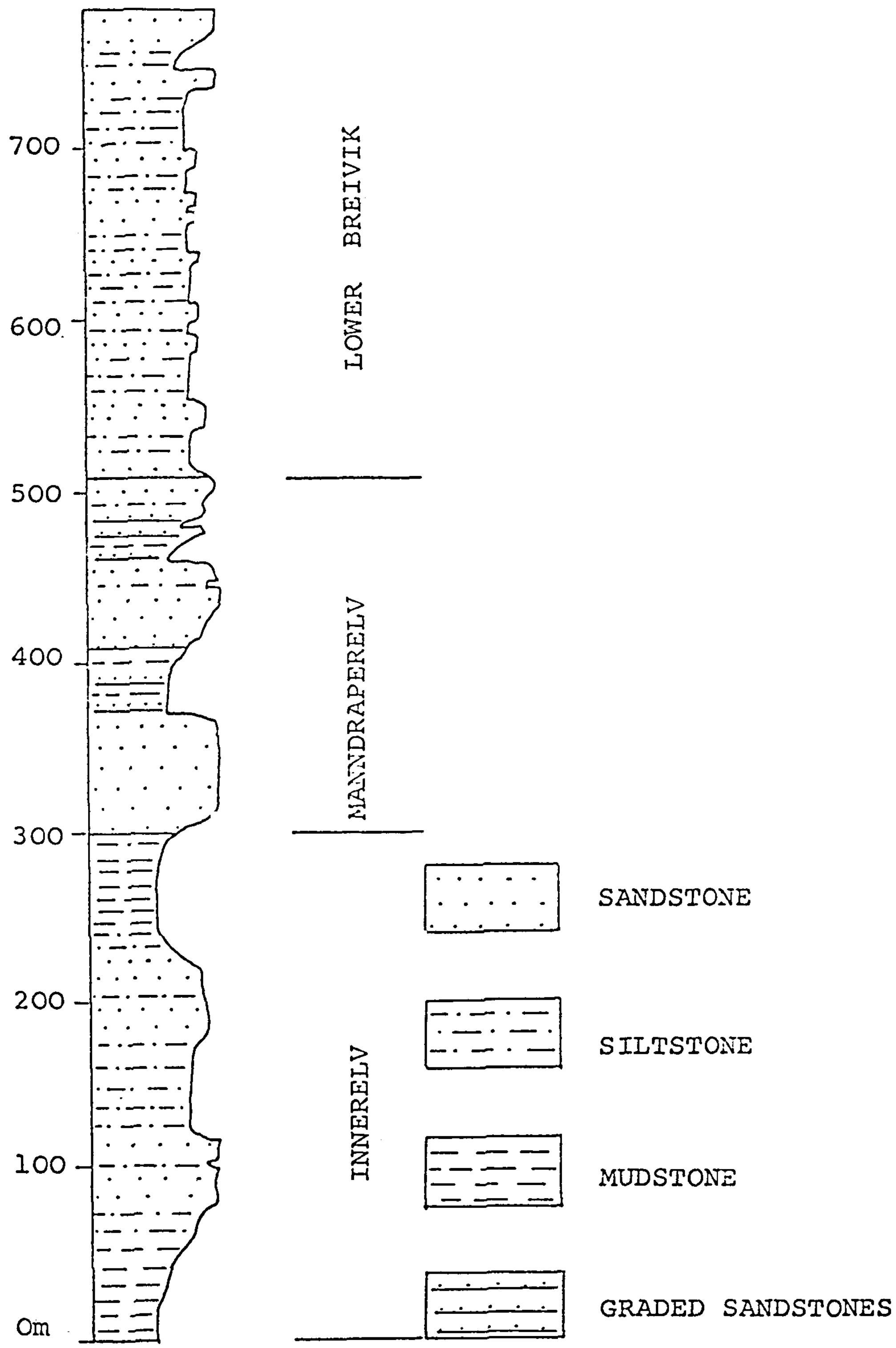


Fig. 10. Simplified section through the Innerelva, Manndraperelva, and Lower Breivika Members on the Digermulen Peninsula, Tanafjorden.

(from Banks 1971)

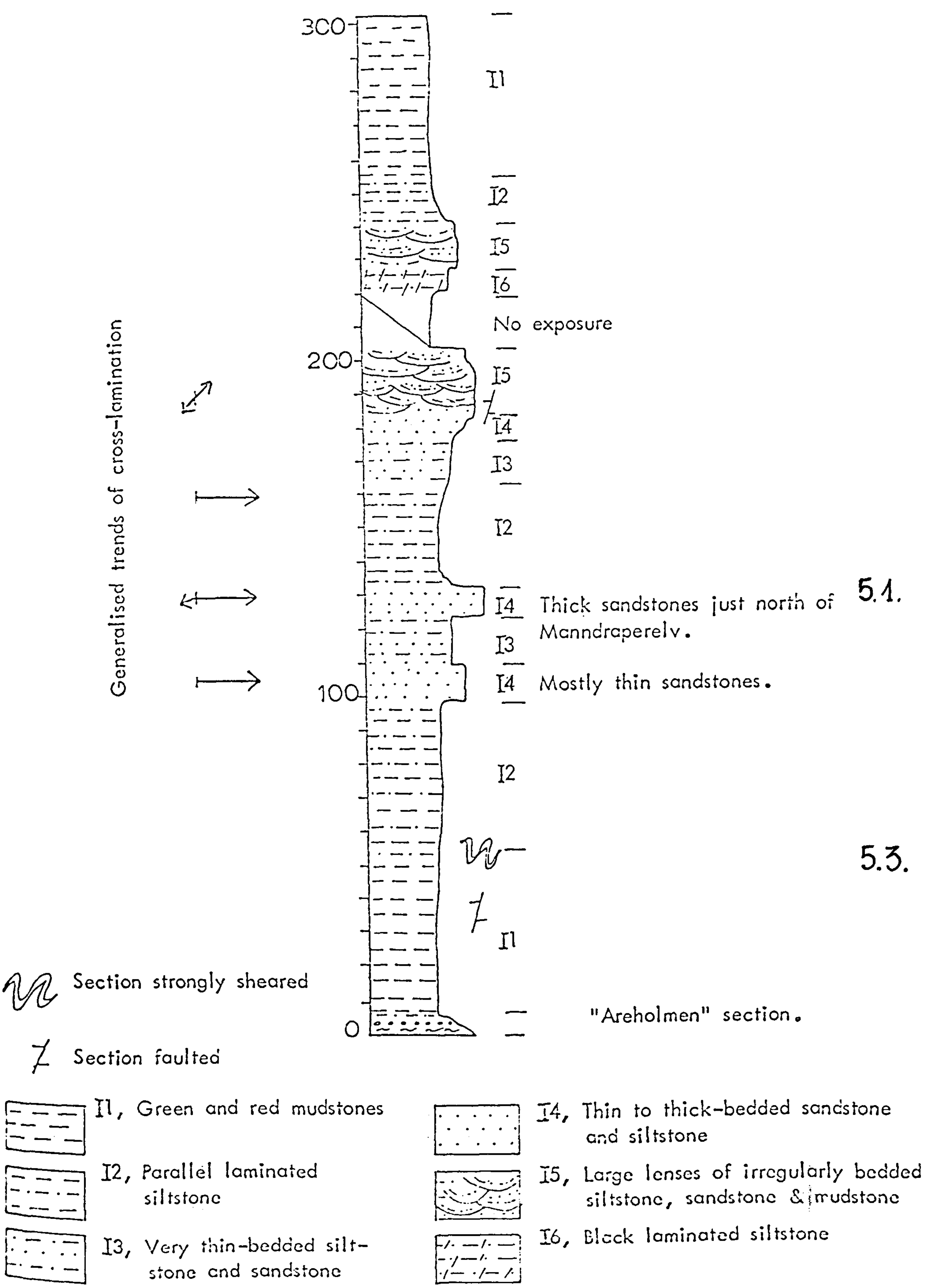


Fig. 11. Main section of Innerelva Member, Digermulen Peninsula, near Manndraperelva.

(from Banks 1971)

5.1. This is the fossiliferous locality described in Farmer et al.(1992). A c. 7 m thick bed of thick-bedded, lenticular, grey sandstone belonging to the **Innerelva Member** is exposed just above sea level immediately north of the mouth of the Manndrapselva River (Map-sheet Langfjorden 2236 2, 428 310, locality 2 on Fig.09). The sandstone, which marks the top of the 2nd coarsening upwards sequence of Banks (1971, 1973), is characterised by parallel lamination (lower part of the 7 m interval) and by an extensive deformation caused by slumping and loading (upper part of the 7 m interval). The sandstone thins to about 2 m over a distance of approximately 100 m. An **Ediacara fauna** was found in a siltstone just above the top of the sandstone interval. Most of the specimens were found on one bedding plane c.35 cm above the top of the sandstone interval.

This fossiliferous bed occurs c.135 m above the lower boundary of the Innerelva Member (Fig.11, cf.Farmer et al.1992).

5.2. Section along the Manndrapselva River (Figs.9,11). The section described by Banks (1971) as the Manndrapselv Section was measured mainly along the coast and <u>not</u> along the river. The coastal section, however, is difficult to walk and therefore we suggest a traverse along the river section which gives a good general impression of facies development and boundaries between the stratigraphic units.

About 170 m of the **Innerelva Member** is exposed in the river section, stratigraphically above the locality 5.1. This interval embraces the 2nd coarsening upwards sequence (130 - 205 m) and the upper sequence with a reverse motif (Banks 1973). Parallel-laminated siltstones, mudstones and sandstones are arranged in five distinctive facies reflecting increasing energy related to depth and proximity to the coastline (Banks 1971, 1973). Facies 1 does not occur in this section; it may be seen in the next locality. A blue-green coloration predominates (facies 1 and 6 are the exceptions) and sedimentary structures are fairly well preserved in spite of the presence of a tightly spaced cleavage. The **Mandraperelva Member** consists of three informal subunits: Lower Sandstone, First Coarsening Upward Sequence and Second Coarsening Upward Sequence with a total thickness of about 200 m (Banks 1971, Figs 12,14). An easily recognised field criterion of this member is its predominantly red coloration. The boundary between the Innerelva and Manndraperelva Members has been drawn beneath thin-bedded red sandstones and above siltstones and mudstones. This contact is sharp but gradational (Banks 1971, p.40). The Lower Sandstone is c. 70 m thick and there is no single section where the unit may be conveniently studied.

The First Coarsening Upwards Sequence consists in its lower part of graded green-grey sandstone and interbedded mudstone, while the upper part is composed of red and white sandstone (Fig.13). The boundary against the Lower Sandstone was located by Banks (1971) at the colour change from red to green, coinciding with a change to finer grained sediment. The First Coarsening Upwards Sequence has been interpreted as regressive from relatively deep-water turbidites into shallow-water (?)marine sandstones (Reading 1965, Banks 1971). The Second Coarsening Upwards Sequence exhibits similarities to the First Sequence and has been subdivided into 8 subunits (Fig.14). On the whole the Second Sequence represents a slope to shelf deposit. The energy level on the shelf appears to have been lower than in the First Sequence. After discussing the possible factors of cyclicity in the Manndraperelva Member, Banks (1971) concluded that tectonic subsidence was more important than any eustatic changes and that the sediment supply could have been cyclic due to changes in sediment transport. A summary of Banks' (1971) interpretation is shown in Fig.12. The Manndraperelva Member may be interpreted as a highstand systems tract with the three submembers representing (from the bottom) one aggradational and two progradational parasequences.

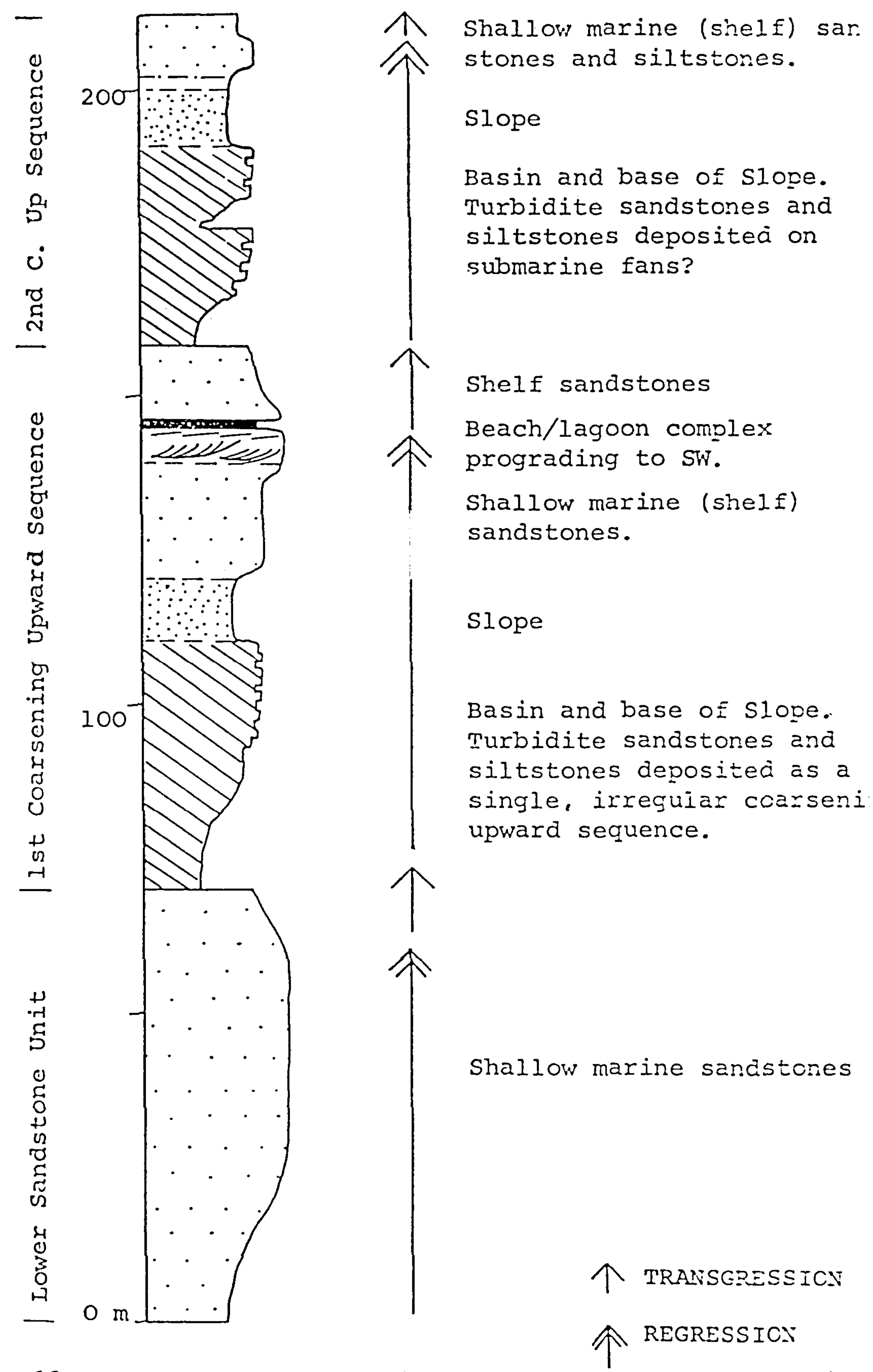


Fig. 12. Summary of the environmental interpretation of the Manndraperelva Member as seen in the Manndraperelva section, Digermulen Peninsula. (from Banks, 1971)

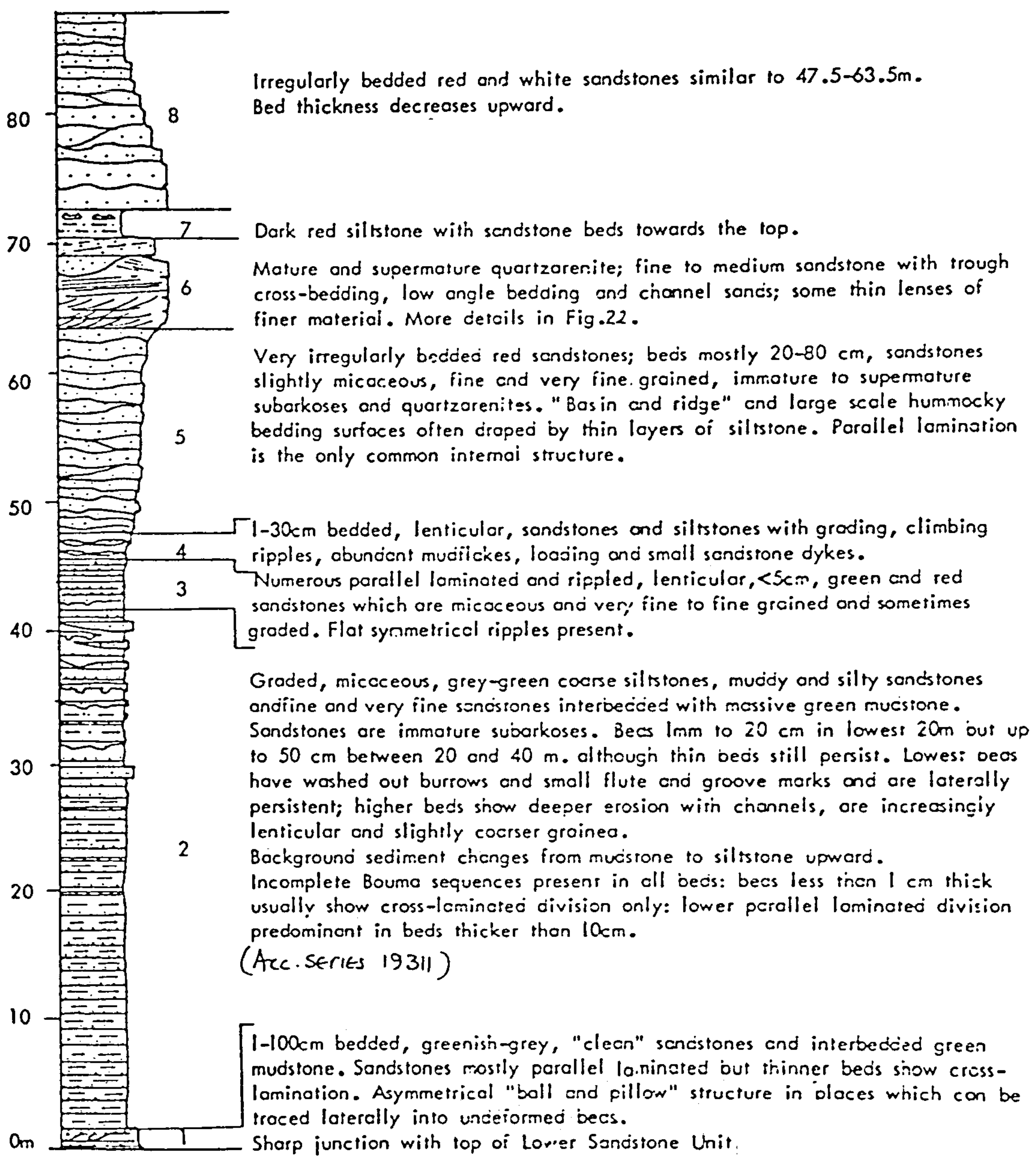


Fig. 15. First Coarsening Upwards Sequence, Manndraperelva Member, Manndraperelva section.
(from Banks, 1971)

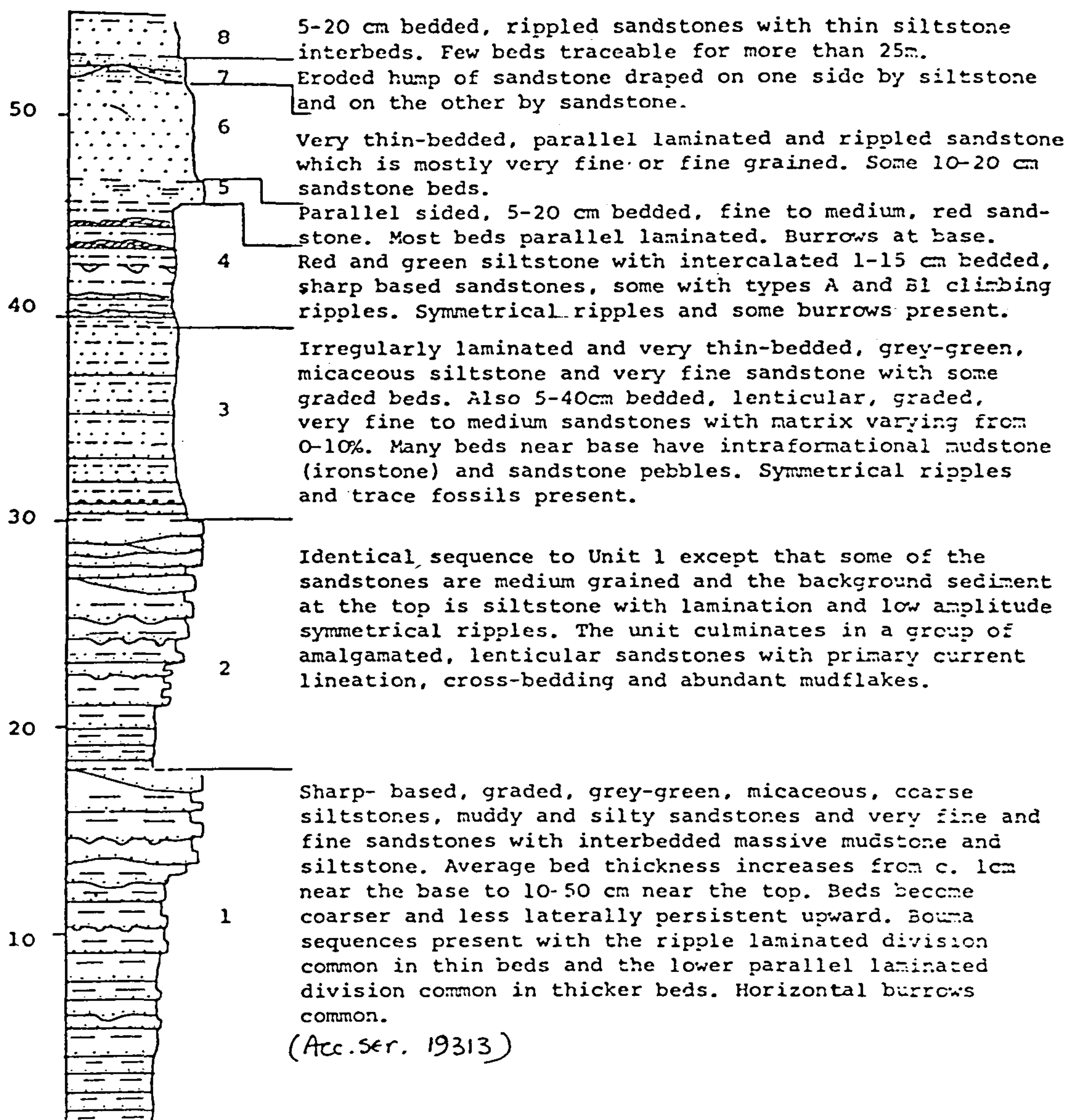


Fig. 14. Second Coarsening Upwards Sequence, Manndraperelva Member, Manndraperelva section. (from Banks, 1971).

The **lower Breivika member,** < 264 m thick, consists of a complex alternation of sandstones and shales deposited on a shelf in some tens of metres water depth. Both storms and tidal currents were considered responsible for the deposition of the sandstone beds (Banks 1971). The lower boundary of the formation was located above red and white sandstone (Manndraperelva Member) and beneath interbedded sandstone and siltstone. Trace fossils are abundant in the lower Breivika Formation: Phycodes (already in the lowest 3 m of the section), Rusophycus (first 70 m above the base) and Cochlichnus were described by Banks (1970). Farmer et al. (1992) mentioned in addition Gyrolithes, Sabellidites and Vendotaenia. It was proposed that the Precambrian - Cambrian boundary should be placed either at the base of or within this member (Farmer et al.1992, Vidal & Moczydlowska in press).

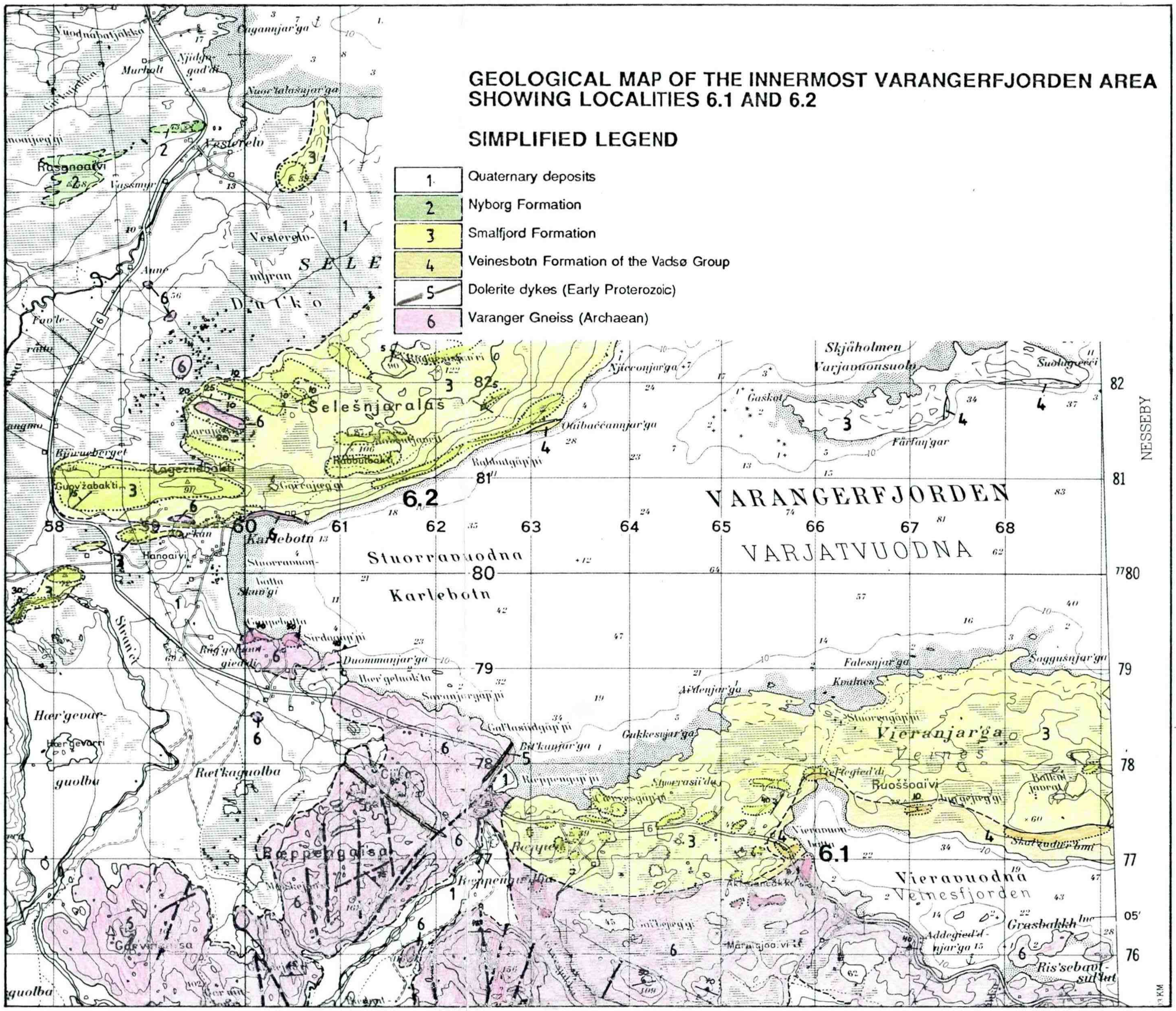
The **upper Breivika member** consists of greenish-grey siltstone and fine-grained sandstone and is c. 350 m thick. The base is placed at a non-erosive sharp contact above a white burrowed sandstone. Parallel and cross lamination, asymmetrical ripples and graded-bedding are present. The beds contain common Teichichnus associated with vertical spiral burrows, Phycodes palmatum, and Gyrolithes-like forms (Banks 1970). The beds were deposited on a somewhat deeper shelf with reduced sediment supply compared to the lower Breivika member.

5.3. (Optional). Coastal section between the mouth of the Manndrapselva River and Arasulluok'ta: lowermost c. 60 m of the **Innerelva Member** mudstones and contact with the **Lillevatnet Member** (Figs.9,11). Bedding strikes subparallel to the coast, and the beds are heavily cleaved and dissected by a system of E - W oriented joints and minor faults dipping steeply towards the north. The mudstones are horizontally laminated and their coloration is blue-green in the stratigraphically higher part of the section changing to brownish-red in its lower half. In places there are yellowish-brown, carbonate-bearing laminae as well as elongated carbonate concretions paralleling cleavage and late joints.

Possible fossils (tube- to funnel-shaped objects) were found in 1989 by Moczydlowska (unpublished) in a strongly cleaved mudstone about half way in the section, just beneath the no. 55 painted on the rock and marking a salmon fishing permit. The contact between the Innerelva and the Lillevatnet members is exposed immediately northeast of the mouth of Arasulluok'ta (Fig 9). There is a rapid downward transition from the brownish-red mudstone to interbedded grey siltstone, mudstone and sandstone. The grey-coloured beds are thin- to medium-bedded, lenticular, trough cross-bedded or graded; very coarse- to fine-grained. The mudstone is strongly cleaved and contains pyrite concretions. The lithostratigraphic boundary between the two discussed members was placed by Banks (1971) at the base of the first bed of brownish-red mudstone.The transitional zone has been interpreted as transgressive and fluvial to intertidal (Reading & Walker 1966, Banks et al. 1970, Banks 1970). Edwards (1984) confirmed the transgressive character of the uppermost Lillevatn Member and interpreted the sands as a delta destructive coastline interfingering with shelf muds. (A parasequence boundary followed by an aggradational to progradational parasequence ?).

Day 6: Saturday, August 6th. Vieranjarga and Bigganjarga, southern side of Varangerfjorden.

The objective of this day is to examine sections of the **Smalfjord Formation** on the southern side of the Varangerfjorden Palaeovalley, and the relationship between this formation and its substratum.



GEOLOGICAL MAP OF THE INNERMOST VARANGERFJORDEN AREA SHOWING LOCALITIES 6.1 AND 6.2
SIMPLIFIED LEGEND
1 Quaternary deposits
2 Nyborg Formation
3 Smalfjord Formation
4 Veinesbotn Formation of the Vadsø Group
5 Dolerite dykes (Early Proterozoic)
6 Varanger Gneiss (Archaean)
VARANGERFJORDEN
VARJATVUODNA
6.1
6.2
Karlebotn
Seleśnjarga
Vieranjarga
Veinesfjorden
NESSEBY

Fig. 15

6.1. Dark-grey diamictite is exposed in a road-cut on the northern side of the E6 highway and in minor outcrops nearby (Fig.15). The matrix of the diamictite is sandy and muddy. Rock fragments, mostly 1 - 5 cm in size, are of crystalline rocks and of sandstone and shale. The diamictite has been interpreted by Edwards as a lodgement tillite (his facies D1). Towards the northeast, along a dirt road, lenses of stratified conglomerate and sandstone may be observed. These rocks were interpreted as supraglacial drift by Edwards (1984, p.7, his fig.5).

Sandstones of the **Veinesbotn Formation** (lowermost formation of the Vadsø Group) are exposed on the grass-covered slopes east of the tillite. The boundary between the Smalfjord and Veinesbotn formations may be mapped along the southern side of Vieranjar'ga; however, the precise contact between these two formations is seldom exposed. Sandstones of the Veinesbotn Formation are well exposed in road cuts c.300 m to the east. Some 25 m towards the east, across a depression, Archaean gneisses are exposed (see description in Siedlecka & Roberts 1992, their locality 1).

Coastal exposures on the northern side of Vieranjar'ga at Kvalnes may be reached by walking (c.40 minutes) along a path. In fair weather conditions and at low tide, exposures of the lodgement tillite, supraglacial diamictite and several sandstone facies, including braided stream and submarine fan accumulations, may be exposed in the intertidal zone ((see Edwards 1984, pp.7-8 and his fig.5).

6.2. A c.40 minute walk from Karlebotn along the southern coast of Selesnjar'ga to Oaibaccannjar'ga (Bigganjar'ga) (Figs 5,15). Archaean gneiss is exposed at Karlebotn on the sea-shore and immediately above the dirt road. Above the gneiss, on a grass-covered slope, there are grey sandstones belonging either to the Veinesbotn Formation or to the Smalfjord Formation.

At Oaibaccannjar'ga, just at sea level, diamictite rests on a striated pavement. This is the famous **Bigganjar'ga Tillite,** the 'glacial striae and boulder-clay' locality described by Reusch (1891) and often called **'Reusch's moraine'.** This locality is briefly described in Siedlecka & Roberts (1992, their locality 2 and fig.8 on page 16).

The moraine itself is only a few metres thick, it is grey coloured, massive and contains fragments primarily of crystalline rocks. The striated sandstones of the substratum belong to the (upper) Veinesbotn Formation. The tillite is overlain by some 80 m of mainly massive sandstone, in places conglomeratic, which is discontinuously exposed in the slope above the tillite; and finally, in the uppermost part of the section (Cillit - Selesnjaralas), by trough cross-bedded sandstone and conglomerate. This section thus starts with a melt-out tillite followed by gravity flow sandy sediment and terminates with braided stream sand and gravel (Edwards 1984, p.8 - 9 and his fig.7).

Day 7: Sunday, August 7th. Vestertana.
The main objective of the programme is to examine the facies development of the Smalfjord Formation in the Vestertana area and compare it with that in the Varangerfjorden area. All but one of the exposures described below are located on the main road (Fig.5). The road transects the Gaissa Nappe Complex and the rocks here are distinctly more strongly cleaved than in the more easterly areas. Of the ten stops scheduled below only a few may be chosen depending on interest and time.

7.1. **Mortensnes** and **Nyborg Formations** are exposed on the northern side of the road in small road-cuts (427 1175). The tillite is grey, massive, strongly cleaved and contains fragments of crystalline rocks. There is a large sandstone clast in the tillite at road level. The Mortensnes Tillite may also be observed in a nearby abandoned quarry in the woods, northeast of the road. The contact between the tillite and the Nyborg

Formation is not exposed; it is considered to be tectonic here with the exposed rocks forming part of an eastward-facing open to tight fold. The Nyborg Formation is represented here by interbedded grey sandstone and red shale with graded-bedding and ripple-cross stratification (B/C facies of Edwards 1984).

7.2. Road-cut at the northern corner of Smalfjordvannet lake (4035 142). Banded grey diamictite of the **Smalfjord Formation** (member B ? of Edwards 1984).

7.3. Exposures of **Smalfjord** diamictite resting unconformably upon the **Dakkovarre Formation** of the Tanafjorden Group (c.286 190). The precise unconformity surface is not exposed. The tillite is grey, banded in the lower part, and massive higher up. It contains fragments of (Grasdalen) dolomite and of crystalline rocks. South of this locality, over a distance of about 1 km, there are extensive outcrops of sandstones and shales of the Nyborg Formation. Towards the northwest along the road, there are exposures of ferruginous sandstones of the Dakkovarre Formation but the precise unconformity surface is not exposed. Towards the northeast there is a spectacular view of the Smalfjord tillite dipping towards the northwest and resting unconformably on the Vagge and Gamasfjellet Formations of the Tanafjorden Group. Stangenestind (725 m a.s.l. - the highest point on Varanger Peninsula) is visible in the far distance.

7.4. Exposure of 'dolomitic tillite' of the **Smalfjord Formation** (387 203). The tillite contains dolomite fragments and its matrix (which is essentially composed of very fine-grained dolomite clasts) exhibits a bright orange colour. Pale-grey quartzitic sandstone of the **Dakkovarre Formation** occurs in the eastern part of the road-cut. The actual contact (unconformity) is not seen, there being a c. 2 m stratigraphic gap in the exposure.

7.5. Coastal exposure at Auskarnes on the southeastern side of Tarmfjorden, a c.10 minute walk from the main road (c.383 210). An inverted sequence of the **Smalfjord** and **Nyborg Formations** resting unconformably on the **Gamasfjellet Formation** may be observed at this locality. The latter forms the obvious white-capped hill.

Grey, strongly sheared **Smalfjord tillite** is followed by pale dolomites typical of the base of the Nyborg Formation and by red and green shales and sandstones of the Nyborg Formation. The Smalfjord - Nyborg unconformity is exposed in the same coastal section, c.1.5 km to the northeast.

7.6. A scenic stop at Indre Torhop to show the view towards the Digermulen Peninsula and the island of Aresuolo.

7.7. The laminated facies of the **Smalfjord tillite** is exposed in extensive road-cuts. Dropstones, including large boulders of crystalline rocks, are excellently exposed. This facies, typical of the upper parts of the tillite-to-mudstone sequences, was described by Edwards (1984) and interpreted as a glacimarine deposit.

7.8. Road-cuts in the sandstones and shales of the **Nyborg Formation** at the head of Vestertana.

7.9. Southwest of Vestertana, excellent exposure of the unconformable contact between the **Nyborg** and the **Mortensnes Formations** in road-cuts on the western side of the road. The tillite is mostly massive, but in places banding may be observed. The unconformity and sandy beds of the underlying Nyborg Formation are exposed immediately west of the tillite.

7.10 Road-cuts between two small lakes (291 149) show the same contact as at locality 7.9, this time in the western limb of this same anticlinal structure. Tillite is massive, but a banding is visible in its lower part.

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