Neoproterozoic peripheral-basin deposits in eastern Finnmark, N. Norway: stratigraphic revision and palaeotectonic implications

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Neoproterozoic (Upper Riphean-lowermost Vendian) deposits of an extensional peripheral basin in the Tanafjorden-Varangerfjorden Region of eastern Finnmark, northern Norway, have been analysed with respect to the basin development and signatures of tectonic controls on sedimentation. Correlation of the Veinesbotn Formation southwest of Varangerfjorden with the Riphean succession (the Vadsø and Tanafjorden groups) to the north indicates a much younger relative age of the former than previously assumed and hence implies the presence of a major fault zone hidden beneath Varangerfjorden. This Varangerfjorden Fault Zone (VFZ) had probably two phases of extensional fault activity. The first phase (middle Late Riphean) is inferred from the evidence of syntectonic sedimentation in the Vadsø Group and the lowermost formation of the Tanafjorden Group, which suggests a syn-rift phase and possible activity of a basin-margin normal fault. The remainder of the Tanafjorden Group, including the Veinesbotn Formation, indicates post-rift thermal-sag phase, when coastal onlap of the basin margin occurred due to a relative sea-level rise.
The second phase (terminal Riphean) is inferred from the revised stratigraphic correlation that implies a major reactivation of the VFZ. The fault involved was probably normal and dipping steeply to the south, opposite to the dip direction of the basin margin fault in the first phase. This suggests reactivation and *rotation* of the basin margin fault, or reactivation of a south-dipping intrabasinal fault. Fault-block rotation and footwall erosion were probably responsible for the major low-angle unconformity between the Riphean and Vendian successions. In addition, the topography created by the VFZ probably controlled the location and orientation of the Varangerfjorden palaeovalley that accommodated the oldest (earliest Vendian) part of the glacigenic deposits in the Vestertana Group. The tectono-stratigraphic model should further be evaluated on the basis of seismic profiles across the inner Varangerfjorden.

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Introduction

It has recently been suggested that the Neoproterozoic sedimentary succession within the NW-SE trending Timan-Varanger Belt (Fig. 1a) constitutes the southwestern margin of a long-lived, Middle to Late Riphean, oceanic basin which was subject to extentsion in Middle to Late Riphean time and was subsequently deformed during the Timanian (Baikalian) Orogeny (Olovyanishnikov et al. 2000, Roberts & Siedlecka 2002). In this model the West Timan Fault (WTF, Fig. 1a), in the Kanin-Timan region, represents the peripheral boundary between the sedimentary succession and the Archaean basement, while the Central Timan Fault (CTF) separates two different sedimentary domains referred to as the 'pericratonic' and 'basinal' zones.

The Sredni-Rybachi Fault Zone (SRFZ) along the Murmansk coast and the Trollfjorden-Komagelva Fault Zone (TKFZ) on Varanger Peninsula (Fig.1b) are thought to correspond to the CTF (Fig. 1a). The palaeomargin fault (WTF), in contrast, has not been recognized in the northwestern segment of the Timan-Varanger Belt. Instead, the contact between the basement and the sedimentary rocks in the Tanafjorden-Varangerfjorden Region (TVR, Fig. 1b) has been considered erosional and unfaulted (e.g. Banks et al. 1974, Åm 1975, Siedlecka & Roberts 1992, Siedlecka et al. 1995, 1998, Rice et al. 2001). An unconformable contact has also been documented in the southeastern part of Sredni Peninsula (Siedlecka et al. 1995). The early idea of Holtedahl (1918), postulating a major fault below Varangerfjorden found no support in those studies and was virtually abandoned.

In the present paper, the Upper Riphean-lowermost Vendian peripheral-basin deposits, in the TVR (Fig. 1b) and adjacent areas to the west (Fig. 2) is discussed in the light of the more recent tectonic and geochronological framework (Olovyanishnikov et al. 2000, Gorokhov et al. 2001a). The stratigraphic revision proposed here implies the presence of a major fault or fault zone below Varangerfjorden, hence supporting the early concept of Holtedahl (1918). The timing and kinematic of this lineament, here referred to as the Varangerfjorden Fault Zone (VFZ) (Fig. 1a, b) is discussed along with

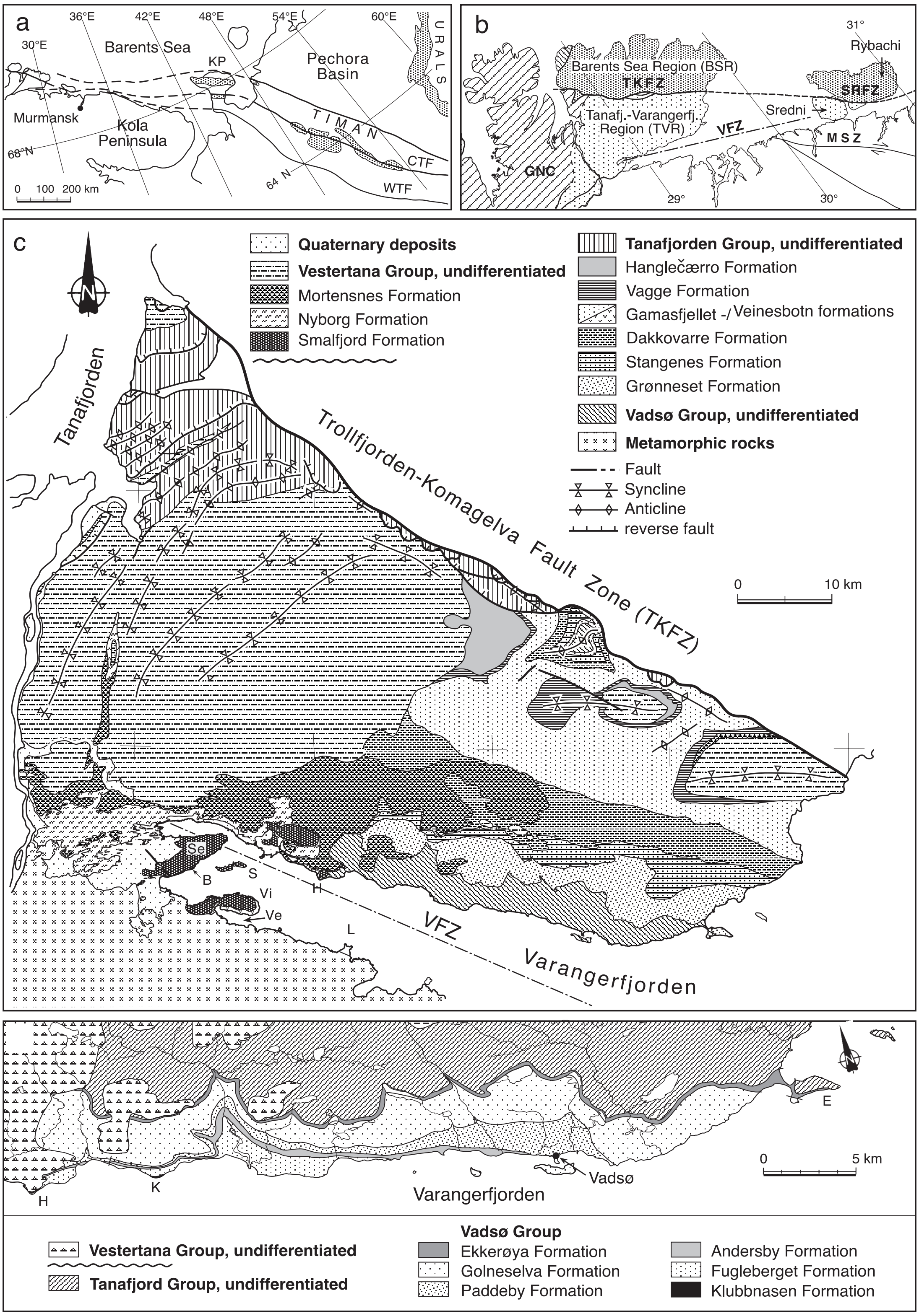

Fig. 1. (a) Outline map showing the Timan-Varanger Belt. KP-Kanin Peninsula; CTF-Central Timan Fault; WTF-West Timan Fault. Based on Olovyanishnikov et al. 2000. (b) Map showing the location of the Tanafjorden-Varangerfjorden and Barents Sea regions, the Gaissa Nappe Complex (GNC) and Sredni / Rybachi region. TKFZ - Trollfjorden Komagelva Fault Zone; SRFZ - Sredni-Rybachi Fault Zone; VFZ –the inferred Varangerfjorden Fault Zone; MSZ- Murmansk Shear Zone; Modified from Siedlecka et al. 1995. (c) Geological map of the TVR. B-Location of the Bigganjargga tillite; S-Skjåholmen; Se-Selesnjar'ga; H-Handelsneset; L-Lattanjar'ga; Ve-Veinesfjorden; Vi-Vieranjar'ga. After Siedlecki (1980), Røe (1987a) and Siedlecka (1991). (d) Geological map of the southernmost part of Varanger Peninsula and the Vadsø Group. H-Handelsneset; K-Klubbnasen and E-Ekkerøy. After Røe (1987a, b) and Siedlecka (1991).

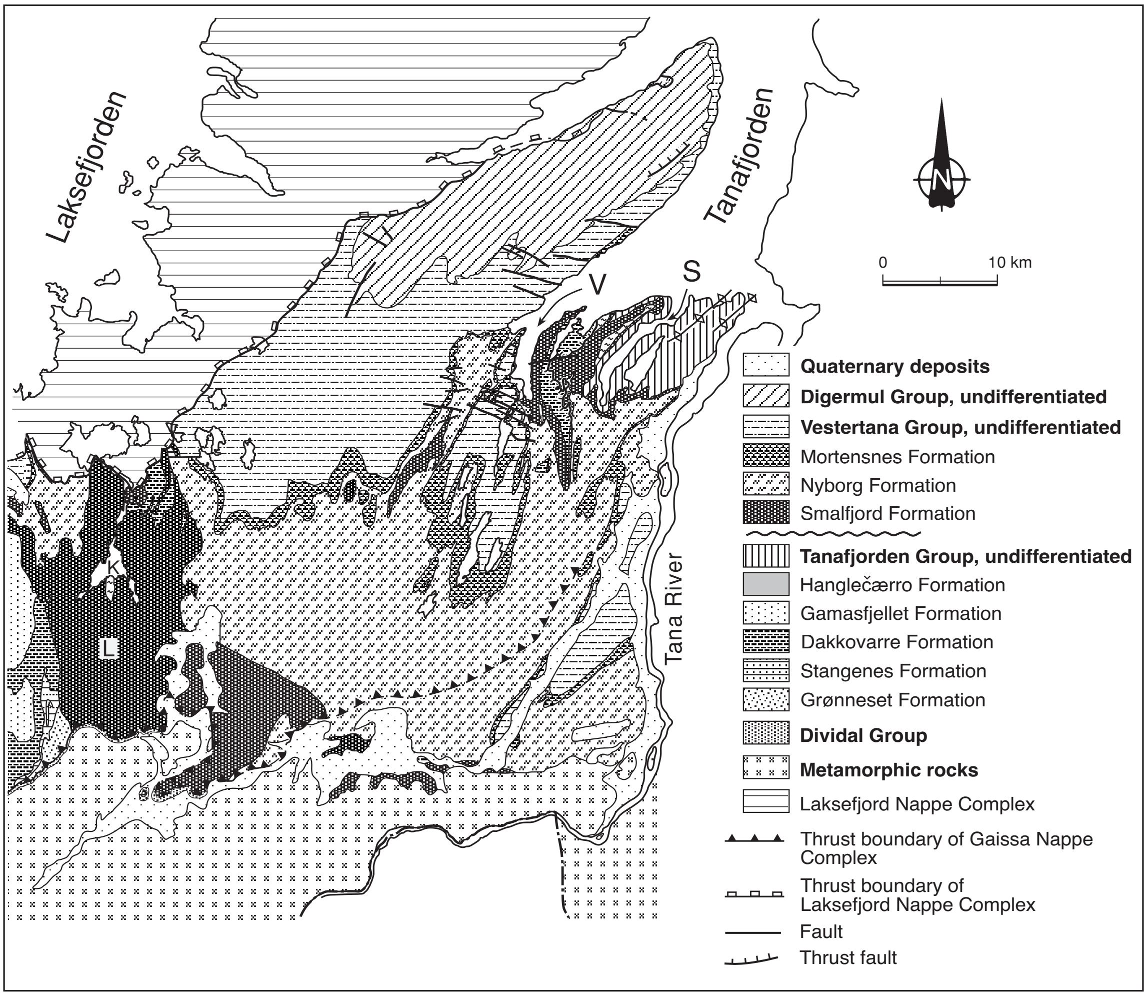

Fig. 2. Geological map of the Laksefjorden -Tanafjorden Region. K- Krokvannet; L- Laksefjordvidda; S-Smalfjorden and V-Vestertanafjorden. Modified from Roberts (1998).

the tectonic setting of the Neoproterozoic peripheral basin. The inferred VFZ is concealed by the modern fjord and Vendian and Quaternary deposits, hence the tectono-stratigraphic model is hypothetical, but considered to be a reasonable 'best-fit' integration of the available data. The model could readily be verified, or rejected, by seismic reflection profiles across the inner part of Varangerfjorden, if such data is acquired.

Geological setting

The NW-SE trending Trollfjorden-Komagelva Fault Zone (TKFZ) divides the Varanger Peninsula into two regions (Fig. 1b), characterized by Neoproterozoic sedimentary successions of greatly different thicknesses, differing structural style and different metamorphic grade (Rice et al. 1989, Siedlecka & Roberts 1992).

The TKFZ acted as a normal fault in Late Riphean time (Siedlecka 1975, 1985), and the subsequent history of brittle to ductile deformation along the central and southeastern parts of this fault zone can be summarized as follows (Karpuz et al. 1993, 1995): (1) an episode of SW-directed compression, recorded in the southeastern part of the Varanger Peninsula, thought to represent a vestige of the Vendian Timanian orogen; (2) a phase of strike-slip, or perhaps oblique-slip movements, both dextral and sinistral, of assumed Caledonian origin; and (3) an extensional to transtensional movement of assumed Mesozoic-Cenozoic age. The lateral movement along the fault zone was below the limit of palaeomagnetic resolution (Torsvik et al. 1995).

On the northeastern side of the TKFZ, the Upper Riphean Barents Sea Group is 8000 m thick, comprised of a lower turbiditic succession (c. 4000 m) passing upwards into a succession of fluvio-deltaic and shallow-marine deposits (e.g. Pickering 1981, 1982, Siedlecka 1978, 1985, Siedlecka & Edwards 1980, Siedlecka et al. 1989, Hjellbakk 1993, 1997, Røe 1995). An angular unconformity separates the Barents sea Group from the mainly shallow marine Løkvikfjellet Group (c. 5700 m), which is of latest (terminal) Riphean or Vendian age (Siedlecka & Levell 1978, Siedlecka & Roberts 1992) .

The Upper Riphean sedimentary succession on the southwestern side of the TKFZ in the TVR and adjacent areas is c. 2000 m thick and comprises the Vadsø and Tanafjorden Groups, which consist of fluvio-deltaic and shallow-marine deposits (e.g. Siedlecka & Siedlecki 1971, Banks et al. 1974, Røe 1975, Johnson et al. 1978). The Tanafjorden Group is unconformably overlain by the Vendian tillite-bearing formations (lower part of the Vestertana Group; Banks et al. 1971, Edwards 1984), which are absent on the other side of the TKFZ, in the Barents Sea Region. The upper post-tillitic part of the Vestertana Group is of mid-Vendian to earliest Cambrian age and consists of mainly shallow marine deposit (Banks et al. 1971, Banks 1973).

The Upper Riphean deposits on Varanger Peninsula have, until recently, been interpreted as having accumulated in a failed rift arm emanating from a triple junction in the Iapetus Ocean and linking with a pre-Uralian ocean (Siedlecka 1975, Drinkwater et al. 1996). More recent work in Russia, however, summarised in e.g. Olovyanishnikov et al. (2000) and Roberts & Siedlecka (2002) has suggested that the Timan-Varanger Belt represents the extensional (passive) southwestern margin of an oceanic basin, the central parts of which are buried beneath the Palaeozoic and younger deposits of the Pechora Basin (Fig. 1a). In this model, the TVR corresponds to the 'pericratonic' zone and the Barents Sea Region to the 'basinal' zone. In the Timan-Kanin region the rocks were deformed and the WFT and CTF structurally inverted during the Timanian orogeny (Olovyanishnikov et al. 2000) and similar kinematic behaviour was demonstrated for the TKFZ and the SRFZ (Karpuz et al. 1995, Roberts 1995).
The Lower Vendian deposits south of the TKFZ have been attributed to deposition during an extentional tectonic setting wheras a foreland basin scenario ahead of the emerging and encroaching Timanian Orogen, is envisaged for the post-tillittic, Middle Vendian to lowermost Cambrian succession (Roberts 1996, Gorokhov et al. 2001).

The present paper focuses on the Upper Riphean-lowermost Vendian peripheral-basin deposits in the TVR and adjacent areas to the west. A new correlation is suggested for the sandstone succession exposed along the southwestern coast of Varangerfjorden and the formations in the coastal section to the north which, in the author's opinion, has important palaeotectonic implications.

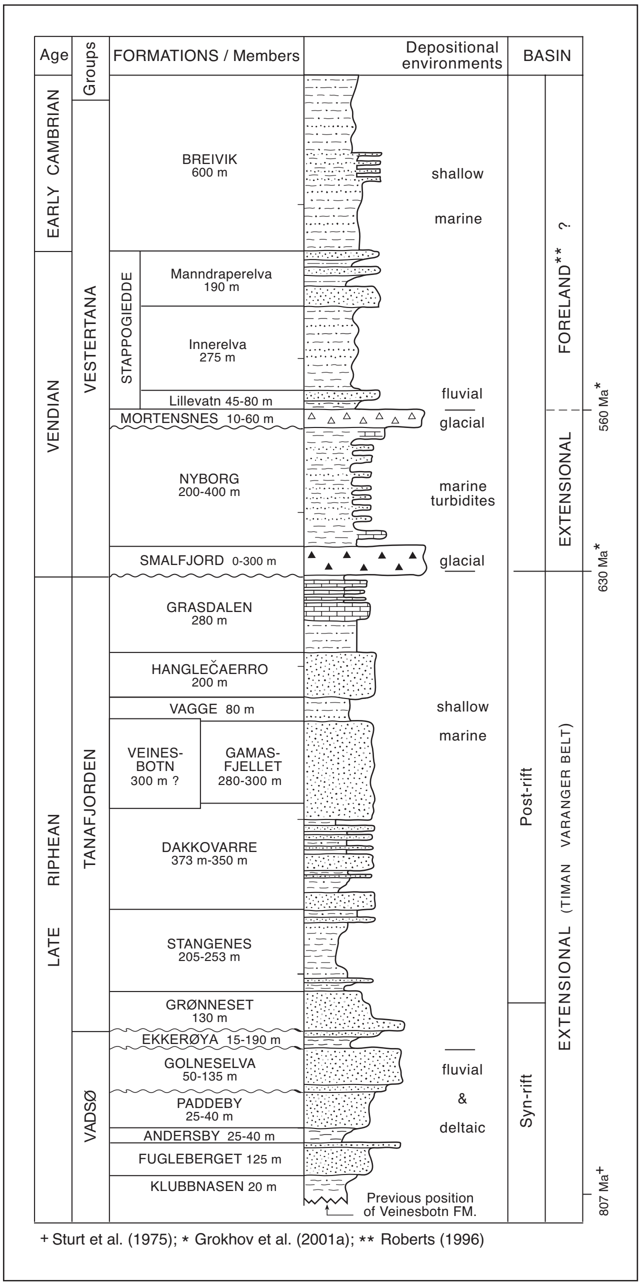

Fig. 3. Lithostratigraphy of the Vadsø and Tanafjorden Groups (Late Riphean) and Vestertana Group (Vendian-Early Cambrian) .

Tectonic structures

There is a marked east-west change in the structural style of deformation of the largely autochthonous and parautochthonous rocks in the TVR. Caledonian deformation predominates in the western part of the region (Fig. 1b, c), adjacent to the Gaissa Nappe Complex (Fig. 2), where the folds are asymmetrical and SE-vergent, with axes trending NE-SW and with a penetrative axial-plane cleavage (Roberts 1996, Sygnabere 1997). To the east, the deformation is limited to a gentle (5-12°) tilt towards the north and northeast, whereas open folds with axes trending E-W occur in the proximity of the TKFZ (Fig. 1c). This deformation evidently postdates the Mid-Upper Vendian Stappogiedde Formation of the Vestertana Group (Fig. 3), which is the youngest succession in the eastern part of the TVR. Near the southeastern termination of the onshore trace of the TKFZ (Fig.1c) small asymmetrical folds and thrusts indicate SW-directed compression, or possibly transpression, related to the Timanian orogeny (Karpuz et al. 1995, Roberts 1995, 1996, Sygnabere 1997).

The sedimentary succession in the eastern part of the TVR is cut by two mafic dykes, trending N-S and is of probable Late Devonian age (Beckingsale et al. 1975, Guise & Roberts 2002, Rice et al. 2003) and the coastal outcrops of Riphean-Vendian rocks commonly show fractures and small normal faults.

Stratigraphy

The Upper Riphean to lowermost Cambrian sedimentary succession, which constitutes the TVR and forms part of the Gaissa Nappe Complex to the west (Fig. 2), comprises three lithostratigraphic groups, separated by unconformities (Fig. 3): the Upper Riphean Vadsø Group and Tanafjorden Group, and the Vendian to lowermost Cambrian Vestertana Group. The hiatus between the Riphean and Vendian rocks represents a significant event, in space and time, involving tectonic tilting and erosion of the lithified Riphean deposits. In the TVR and the adjacent Vestertana district (Figs.1 and 2), the tilting was towards the north/northeast and accompanied by a progressive southward erosion of most of the Riphean succession. In the Laksefjordvidda area (Fig. 2), the tectonic tilting was towards the northwest and c.700 m of rocks were removed by erosion (Føyn & Siedlecki 1980).

Based on the Rb-Sr dating of illite subfractions from the Stangenes Formation of the Tanafjorden Group and the Nyborg and Stappogiedde formations of the Vestertana Group (Fig. 3) and on the assumption that the younger diagenetic illites were related to tectonic deformation events. Gorokhov et al. (2001a) inferred that the age of the Riphean/Vendian boundary is <630 Ma and that the glacigenic lower part of the Vestertana Group is 630-560 Ma in age. The diagenetic ages of 560 Ma and 440-390 Ma of the intertillitic Nyborg Formation and post-tillitic Stappogiedde Formation (Fig. 3), respectively, were linked by Gorokhov et al. (2001a) to the Vendian Timanian (Baikalian) orogeny and the Silurian Scandian (Caledonian) orogeny.

The characteristics of the three lithostratigraphic groups (Fig. 3) are summarized below. The description of the Vadsø Group and Tanafjorden Group is limited to their outcrops north of Varangerfjorden. The Veinesbotn Formation, which erosionally overlies the basement along the southern coast of inner Varangerfjorden, is described separately in a subsequent section. This formation, previously interpreted to be the oldest part of the Vadsø Group (Banks et al. 1974), is argued here to represent basin-margin onlap and to belong to the Tanafjorden Group.

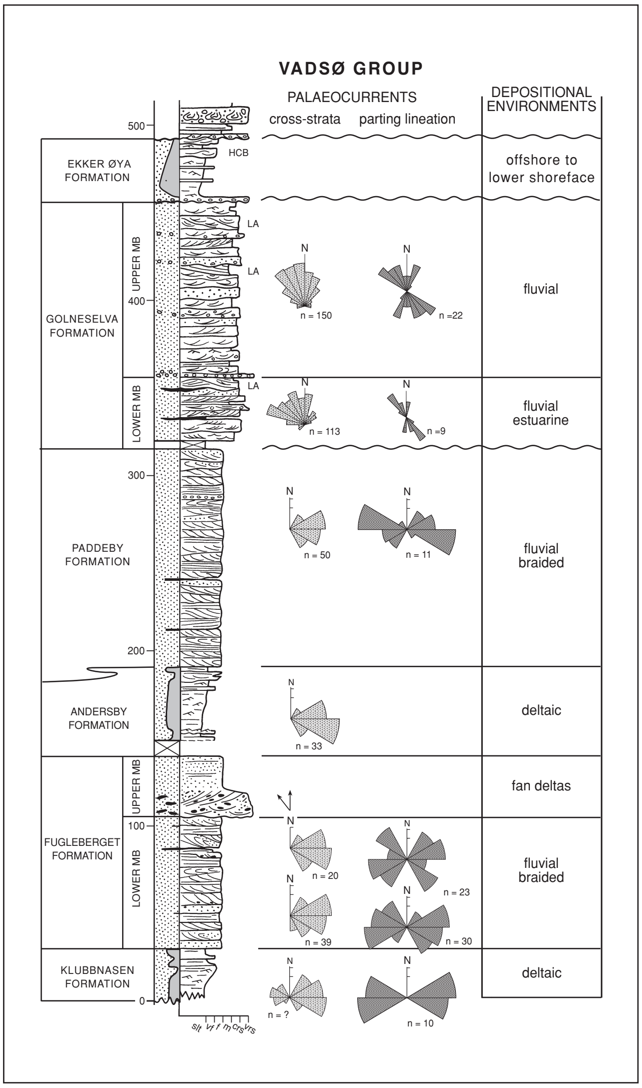

Fig. 4. Lithostratigraphy, palaeocurrents and depositional environments of the Vadsø Group. The dip and dip direction of planar cross-beds in the Fugleberget and Paddeby formations have been corrected for low-angle structural dip; the other palaeocurrent measurements are from bedding-plane exposures.

The Vadsø Group

The Vadsø Group is 290-660 m thick (Banks et al. 1974) and consists of three units bounded by unconfomities (Fig.4). The lower of these allostratigraphic units comprises two coarsening-upward successions of deltaic to fluvial deposits, namely the Klubbnasen Fm.-Fugleberget Fm. and the Andersby Fm.-Paddeby Fm. succession. Various parts of this allostratigraphic unit have been described in detail by Hobday (1974), Røe (1975, 1987c), Aasheim (1990) and Røe & Hermansen (1993). The deltaic systems of the Klubbnasen and Andersby formations were dominated by fluvial processes, with tidal influences in the former case. Palaeocurrent data suggests eastward progradation of the deltas, which is consistent with the palaeochannel directions in the overlying fluvial sandstones. The conglomeratic upper member of the Fugleberget Formation, in contrast, shows palaeotransport towards the north and northwest (Fig. 4). These coarse-grained deposits were previously interpreted as fluvial (Hobday 1974), but the presence of large-scale (>12 m thick), Gilbert-type conglomeratic foresets and/or massive sandstones above the fluvial channel-fills (Fig. 4) suggests a retrograding fan-delta system.

The Golneselva Formation, the middle allostratigraphic unit of the Vadsø Group (Fig. 4), consists mainly of medium- to coarse-grained fluvial sandstones, deposited by rivers flowing towards the northwest and north, with channels of widely varying dimensions and styles (Banks & Røe 1974). The lowermost part of this formation consists of wave-rippled sandstone and was initially interpreted to be of lacustrine origin (Banks & Røe 1974). However, the microfaunal content of siltstone layers (Vidal 1981) and the occurrence of tidal bundles in some of the cross-stratified sandstones above the wave-worked facies suggest estuarine depositional conditions for this lowermost part of the Golneselva Formation.

The upper allostratigraphic unit of the Vadsø Group is the Ekkerøya Formation (Fig. 4), a transgressive to regressive succession of shelfal to shoreline deposits (Røe 1975, Johnson 1978, Aasheim 1990). The abundance of hummocky cross-stratification suggests a storm-dominated, open-marine environment, which contrasts with the confined nature of the earlier deltaic systems. The Ekkerøya Formation is 15-40 m thick in the coastal outcrop sections (Røe 1970), but thickens to 190 m towards the north, where two regressive parasequences are recognized (Johnson 1978).

The base of the Vadsø Group is hidden beneath the fjord. The unconformity between the lower and the middle allostratigraphic unit represents a major change in the basin configuration and palaeogeography, attributed to tectonics (Røe 1975). Similarily, microfauna indicates a considerable hiatus between the Golneselva Formation and the Ekkerøya Formation (Vidal 1981), accompanied by a major palaeogeographic change (Røe 1975). The unconformity separating the Vadsø Group from the overlying Tanafjorden Group (Fig. 3) is of a regional extent (Rice & Townsend 1996), and the succession in Varangerfjorden suggests a corresponding fall of relative sea level (Røe 1975). The two oldest units of the Vadsø Group (Fig. 3) are not recognizable outside the TVR. According to Rice & Townsend (1996), the Ekkerøya Formation is a lithostratigrahic equivalent to the Brennelvfjord Member of the Porsangerfjorden Group in west Finnmark.

The Tanafjorden Group

The Tanafjorden Group is 1448-1665 m thick and consists of sandstones and siltstones, with a mixture of carbonate and muddy siliciclastic facies at the top (Fig. 3, Siedlecka & Siedlecki 1971). The thickness and gross lithology of this group are remarkably consistent along a NW-SE trend across the Varanger Peninsula. Along a NE-SW trend, the erosional effects of the base Vendian tilting are clearly recognizable by a progressive southward truncation of the Tanafjorden Group (Røe 1970). In the southwest, along the northern margin of Varangerfjorden, the Vestertana Group rests directly on the lower part of the Vadsø Group (Fig. 1c, d; Banks et al. 1974).

The Tanafjorden Group is mainly of shallow-marine origin (Johnson et al. 1978), and apparently lacks internal unconformities. The alternation of formations dominated by siltstones and sandstones (Fig.3) reflects shoreline shifts associated with transgressions and regressions. The uppermost carbonate-rich formation indicates a quiet-water environment periodically starved of clastic sediment supply.

The Gamasfjellet Formation, c. 300 m thick, is the youngest Riphean formation exposed in the coastal section north of Varangerfjorden (Fig. 1c). This formation is of particular interest here, because it will be further argued that this unit is probably a lateral equivalent of the Veinesbotn Formation defined south of the fjord. The Gamasfjellet Formation is a monotonous succession of mainly medium-grained sandstones with trough cross-stratification and sporadic current- and wave-ripple cross-lamination. Cosets of trough cross-strata have a sheet to wedge-shaped geometry and indicate palaeocurrents flowing towards the NNE and NE (Fig.5), whereas sporadic current ripples suggest transport towards the southwest. The rare wave ripples are multidirectional in orientation. A conspicuous feature of the Gamasfjellet Formation is its reddish- purple to maroon colouration, although the lowermost part of this succession in the Varanger section is white with red or purple patches. The formation is thought to have been deposited in a tide-dominated, shallow shelfal environment (Johnson et al. 1978).

All the formations of the Tanafjorden Group are involved in the southeastward-emplaced Gaissa Nappe Complex (Fig. 2) west of the Varanger Peninsula. Based on the Rb-Sr isotope data, Gorokhov et al. (2001b) have suggested that the Kildinskaya Group on the Sredni Peninsula is a time–equivalent of the Tanafjorden Group, rather

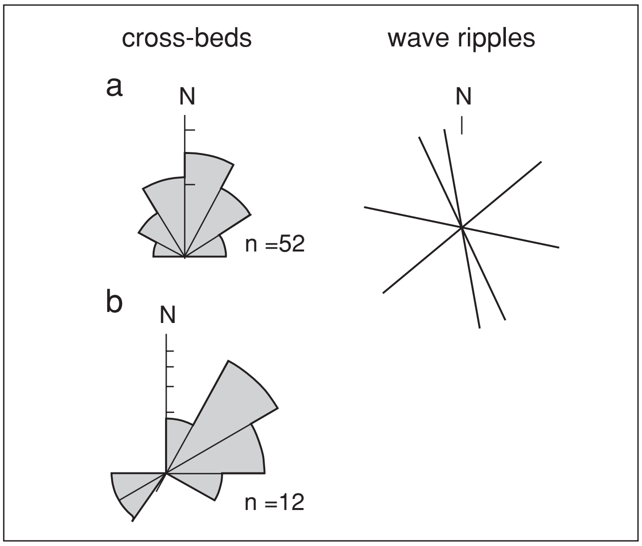

Fig. 5. Palaeocurrent directions and wave-ripplecrest trends from the lower part of the Gamasfjellet Formation in the Varangerfjorden area. (a) 0-10 m;(b) 10 to c. 130 m.

than of the Vadsø Group, as previously assumed by Samuelsen (1995, 1997) and Siedlecka et al. (1995).

The Vestertana Group

The Vestertana Group (Fig. 3), of Vendian to earliest Cambrian age (Reading 1965), consists of two tillite-bearing formations (Smallfjord and Mortensnes) separated by interglacial turbiditic deposits (Nyborg Formation) and overlain by deposits of high- to low-energy nearshore and shelf environments (Banks et al. 1971, Edwards 1975, 1984). The lower glacial and interglacial succession is most complete in the Vestertana district (Fig.2, Edwars 1984) and the Smalfjord and Nyborg formations are absent in the eastern part of the TVR (Røe 1970). The upper, postglacial succession is more extensively exposed on the Digermul Peninsula (Fig. 2, Reading 1965, Banks et al. 1971).

In the inner part of Varangerfjorden and in the Laksefjordvidda area (Fig. 2), glacial palaeovalleys have enhanced the angular discordance at the base of the Vestertana Group (Bjørlykke 1967, Føyn & Siedlecki 1980, Edwards 1984). The trend of the glacial palaeovalley in the Varangerfjorden area is parallel to the fjord, with glaciofluvial deposits indicating transport towards the northwest (Bjørlykke 1967), whereas the trend of the Krokvannet palaeovalley, in the Laksefjord-Vidda area, is NNW-SSE (Fig. 2). The main part of the valley fills, up to 300 m thick, is sligthly younger than deposits of the Smalfjord Formation in other areas (Edwards 1984). The Smalfjord and Mortensnes formations in the Vestertana district suggest glacial transport both from the south and north while the interglacial and early postglacial deposits were sourced from the south (Banks et al. 1971, Edwards 1984).

The Veinesbotn Formation

The type area of the Upper Riphean Veinesbotn Formation, c. 300 m thick and dominated by sandstones, is at the head of Veinesfjorden and along the southern coast of Vieranjar'ga (Fig. 1c; Banks et al. 1974). The deposits are also partly exposed on the island of Skjåholmen and a minor outcrop is present below the Bigganjargga tillite (Smalfjord Formation) on Selesnjar'ga (Fig. 1c). The formation rests on the Archaean basement with a probable erosional contact (e.g. Siedlecka et al. 1995) and is overlain with an angular unconformity by the Smalfjord Formation. The heterolithic deposits (Fig. 6) that overlie the sandstones in the Skjåholmen area are thought to be the uppermost part of the Veinesbotn Formation. Banks et al. (1974) did not describe this unit and suggested that it represented the lower part of the Klubbnasen Formation. Rice et al. (2001) have recently recognized a sedimentary succession that possibly underlies the Veinesbotn Formation as defined by Banks et al. (1974) at Lattanjar'ga, ca.10 km east of the type area (Fig. 1c).

The ensuing description of the Veinesbotn Formation is based on the outcrop sections at the head of Veinesfjorden, the southeasten part of Vieranjar'ga and the Skjåholmen area (Fig. 1c). The heterolithic uppermost part of the formation at this last locality will be discussed separately, because these deposits are crucial to an understanding of the stratigraphic position of the Veinesbotn Formation relative to the formations exposed to the north.

Facies associations in the type area

The Veinesbotn Formation consists mainly of medium- to coarse-grained, cross-stratified sandstones and subordinate siltstones. Conglomerates and pebbly sandstones occur only in the lower part. The formation is of reddish (mainly maroon) colour in the lowermost part and alternating white, buff and maroon in higher stratigraphic levels. Reddish colouration dominates the more than 60 m thick exposed succession of southeastern Vieranjar'ga. The type sections show vertically stacked facies associations of fluvial, delta-plain and shallow-marine offshore deposits. The fluvial and deltaic facies associations constitute the lower 27 m of the formation at the head of Veinesfjorden (see log in Fig. 6a), whereas a shallow-marine facies association is found at the other localities. The present author's field observations do not support the earlier suggestion by Hobday (1974) that a fluvial facies occur interbedded with shallow-marine sandstones in the lower half of the formation.

Fluvial facies association. – This basal facies assemblage is c. 9 m thick and consists of medium- to coarse-grai-

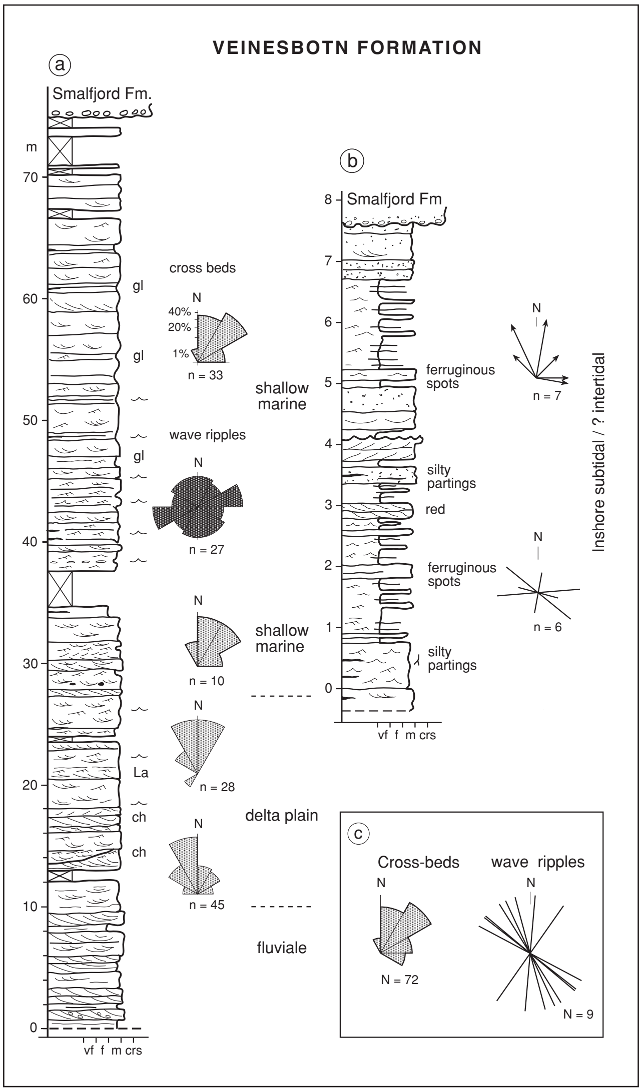

Fig. 6. Logged profiles of the Veinesbotn Formation. (a) The lower part, head of Veinesfjorden; (b) the uppermost heterolithic unit on Skjåholmen. (c) Palaeocurrents and wave-ripplecrest trends, southeast coast of Vieranjar'ga.

ned, feldspathic sandstones and subordinate pebbly sandstones and conglomerates. Gravel clasts, up to 5 cm in size, comprise vein quartz, granodiorite, gneisses and K-feldspar. Trough-shaped sets of cross-strata, mainly thicker than 50 cm, predominate and form cosets up to 200 cm in thickness. These are overlain by cosets of crude, medium-scale trough cross-strata and/or planar parallel strata. Notable features include a composite bar, 1.3 m high and more than 26 m long, with a convex-upward geometry and internal low-angle inclined, parallel stratification, capped by a coset of medium-scale trough cross-stratification. Concave-upward, channel-like scours paved with conglomerate and filled with pebbly sandstone are locally present. The latter shows flat or gently inclined stratification, accentuated by the alignment and local concentration of gravel clasts. Pebbles tend to occur also along the concave-upward bases of trough cross-sets in sandstones.

The lack of bedding-plane exposures renders the determination of palaeocurrent directions difficult, but the geometry of the larger trough cross-sets and the orientation of scour margins indicate a palaeoflow towards the north-northwest. A few large-scale cross-sets, with apparently planar geometry, indicate local palaeocurrents towards the northwest and northeast.

This facies association is thought to be of fluvial origin, on account of its textural and mineralogical immaturity, channel scours, unidirectional palaeocurrents and the absence of wave- or tide-produced features. The river channels were at least a few metres deep, as can be judged from cross-set thicknesses and the size of the composite mid-channel bar. The upward decrease in trough cross-set sizes and the appearance of upper-stage plane-parallel stratification indicate the decreasing capacity of an aggrading channel, but are not diagnostic of any particular channel pattern (Bridge 1984). However, the large bar composed of low-angle parallel stratification and showing a well-preserved convex-upward morphology may indicate braided river channels. Bearing in mind the retrogradational nature of the fluvial system of the Veinesbotn Formation, the lack of overbank mudstones in the succession is consistent with the notion of a braided fluvial system with unstable, rapidly shifting channels.

Delta-plain facies association. – This facies assemblage is c. 18 m thick (Fig. 6a), dominated by sandstones, and consists mainly of medium-scale trough cross-sets, up to 20 cm thick, organized into cosets and alternating with ripple cross-lamination and subordinate planar cross-sets. These bedsets, less than 1 m thick, are capped with thin, discontinuous layers of silty sandstone in the lower part of the succession, and with horizons of symmetrical and locally flat-topped wave ripples in the upper part. The wave ripples are generally small and, on bedding planes, show well-developed interference patterns.

The bedsets are either laterally continuous on an outcrop scale (<20 m) or pinch out, bounded by planar or concave-upward erosional surfaces. Some bedsets show internal evidence of lateral accretion. At least one asymmetrical palaeochannel appears to have been filled mainly by lateral accretion, although vertical accretion prevailed near the steeper, outer channel margin in the final stages. The bedding-plane exposures of cross-strata and the orientation of channel margins indicate palaeocurrent directions mainly towards the north-northwest (Fig. 6a) in the lower part of the delta-plain succession and towards the north in the upper part. The palaeoflow directions are similar to those in the underlying fluvial facies association, which – together with the lack of tide-produced structures – indicates an environment dominated by fluvial processes and increasingly subject to intermittent reworking by sea waves. This evidence suggests a delta-plain environment of a retreating deltaic system. The distributary channels were relatively small and sinuous, as is indicated by the evidence of lateral accretion, and the scarcity of siltstone interbeds suggests unstable channels subject to rapid migration and/or frequent avulsion. The upward change from fluvial to deltaic deposits, accompanied by a change in channel pattern and decrease in channel dimensions, is attributed to a reduced gradient of the fluvial system caused by gradual marine transgression.

Shallow-marine facies association. – This facies assemblage is a monotonous succession of trough cross-stratified sandstones, with subordinate current- and wave-ripple cross-lamination and sporadic interlaminae rich in glauconite. The trough cross-sets are mainly 20-30 cm thick, but up to 50 cm in places, and cosets form beds of sheet to wedge-shaped geometry. The cross-strata suggest prevalent palaeocurrents towards the northeast (Fig. 6), which contrasts with the NNW-directed palaeocurrents of the underlying fluvial and deltaic facies associations. Quantitative data on the direction of current-ripple migration was not obtainable, but many of these features seem to be oriented at a high angle or even opposite to the direction of 3-D dunes (trough cross-sets). Wave-ripple crests are multidirectional, but predominantly trending NE-SW (Fig. 6a), which is nearly perpendicular to the fluvio-deltaic palaeocurrents and probably represents the palaeoshoreline trend.

The sandstones are interpreted to have been deposited in a tide-dominated, wave-influenced shallow shelfal environment. Subtidal conditions are inferred from the predominance of shore-parallel palaeocurrents and absence of intertidal features in the studied outcrops. Shore-parallel tidal currents are common in modern tidal seas (Dalrymple 1992), and the unidirectional palaeocurrent trend in the present case is consistent with the general tendency for the circular pattern of the main tidal flow in such environments and the limited preservation potential of the subordinate tidal currents. The directions of inshore tidal currents, in contrast, tend to be shore-normal, reflecting the onshore/offshore flow, and with a better preservation of the onshore or offshore subordinate tidal current.

The uppermost heterolithic deposits in the Skjåholmen area

A unit of heterolithic deposits, 4 to 7 m thick, overlies the sandstone succession of the Veinesbotn Formation with a transitional contact in the Skjåholmen area (Fig. 1c). The coastal cliff outcrop on the southeastern side of Skjåholmen is excellent, with a lateral extent of a couple of hundred metres, and the succession has been logged in detail in the more accessible eastern part of the outcrop section (Fig. 6b). The lower part was logged to the west of a minor local fault, with a down-to-east throw of a few decimetres, and the upper part was measured directly east of the fault.

Sedimentary facies. – The heterolithic unit consists of thinly interbedded sandstones and dark-grey, muddy siltstones, alternating with thicker beds of cross-stratified sandstone (Fig. 6b). The cross-stratified sandstone is white but in places with maroon or purple patches. The thinly-bedded heterolithic facies forms packages 10 to 100 cm in thickness. Sandstone beds are up to 7 cm thick, but mainly less than 2 cm, and the siltstone commonly abounds with thin sand interlaminae, streaks and lenses (starved ripples). The sandstones are fine to coarse grained and apparently massive (structureless), but in places show current- or wave-ripple cross-lamination. Symmetrical or slightly asymmetrical wave-ripple forms are common on the upper surfaces of the thin sandstone beds, and small, triradiate or polygonal mud cracks are present.

The cross-stratified sandstone facies forms isolated beds or bedsets, 20 to 80 cm thick. The sandstones are medium to coarse grained, mainly light-grey in colour, with purple patches and rusty-brown spots. The sets of cross-strata are planar or trough-shaped, less than 20 cm thick. Thin beds of coarse-grained, wave-ripple cross-laminated sandstone are locally capping the bedsets of medium-grained, cross-stratified sandstone, and some of the cross-sets are covered with thin, discontinuous siltstone drapes. The bedsets of this sandstone facies have uneven thicknesses, markedly thinning or thickening laterally over distance of a few tens of metres.

Wave-ripple crests in either of these facies have a polymodal orientation, but seem to be trending preferentially NW-SE. The sets of current-ripple cross-laminae and dune cross-strata suggest current directions ranging between northwest and east.

Depositional environment. – The thinly-bedded heterolithic facies suggests a wave-influenced tidal environment with highly fluctuating current energy. The thicker-bedded, cross-stratified sandstones are probably small tidal bars. The occurrence of mud cracks may indicate desiccation and thus intertidal conditions. The highly fluctuating current energy, as well as the variable palaeocurrent directions, support the notion of an inshore tidal environment, different from the subtidal, shelfal depositional setting of the underlying sandstone succession.

Stratigraphic position. – The heterolithic unit has a transitional lower contact (Fig. 6 b) and is considered to be the uppermost part of the Veinesbotn Formation, contrary to the earlier suggestion that these deposits might be the lowermost part of the Klubbnasen Formation (Fig. 3, Banks et al. 1974). It should be emphasized that the sandstones in the Klubbnasen Formation are fine to very fine grained, considerably finer than in the present case, and that the thin, ripple cross-laminated sandstone beds in the lower part of the Klubbnasen Formation are fluvially induced as the offshore directed palaeocurrents suggest (Fig. 4). One might argue, hypothetically, that the tidal heterolithic unit represents a transgressive system subsequently buried by the regressive deltaic deposits of the Klubbnasen Formation. This possibility, however, can reasonably be precluded on account of the strikingly finer grain sizes of the latter formation.

Heavy mineral assemblage

Siedlecka and Lyubtsov (1997) have analysed the ultrastable and stable heavy minerals suits from the sedimentary successions on each side of the TKFZ. The sample from the Veinesbotn Formation show a dominance of zircon (48 wt.%), with tourmaline and rutile accounting for 30% and 23% respectively. The relative proportion of these heavy minerals deviates from both that encountered from the fluvial, Fugleberget and Golneselva Formations of the Vadsø Group and the upper part of the shallow marin Tanafjorden Group, including the Gamasfjellet Formation. The fluvial formations of the Vadsø Group have a higher zircon/tourmaline ratio (3.8-30) than that in the Veinesbotn Formation (1.6). Tourmaline is the main heavy mineral in the marine sandstones of the Tanafjorden Group, where the zircon/tourmaline ratio is 0.4 –0.8. The Veinesbotn Formation is also the only formation containing a significant amount of rutile.

The difference in the heavy mineral composition of the Veinesbotn Formation and the other formations of the TVR has little bearing on the following discussion concerning the stratigraphic position of this former formation. The data set is very limited, because only one sample from each formation was analysed and their geographic and stratigraphic positions are unspecified. For example, it is unclear whether the sample from the Veinesbotn Formation was collected from its fluvial-deltaic part or the overlying shelfal deposits. In addition, the composition of a heavy mineral suit depends not only on the source rock, but can change significantly with sediment transport, amount of reworking and the energy of the waves or currents relative to the density, shape and size of the grains (Stapor 1973).

Revised stratigraphic correlations

Banks et al. (1974) suggested that the Veinesbotn Formation was the lowermost unit of the Vadsø Group (cf. Fig. 3), on account of its inferred erosional basal contact with the Archaean basement, its geographical distribution and the assumption that the heterolithic deposits overlying the formation's sandstones in the Skjåholmen area represented the lower part of the Klubbnasen Formation. As pointed out in the previous section, this last assumption is incorrect, because the heterolithic deposits at Skjåholmen have a transitional lower contact and apparently belong to the same depositional system as the underlying tidal sandstones of the Veinesbotn Formation. In short, there is no obvious stratigraphic link between the heterolithic succession at Skjåholmen and the Vadsø Group on the northern side of Varangerfjorden.

The fact that the Veinesbotn Formation directly overlies the basement does not necessarily mean that these deposits are the oldest part of the Vadsø Group, as previously assumed (Banks et al. 1974, Siedlecka 1975, Siedlecka et al. 1995, 1998, Rice et al. 2001). It is suggested here that this relationship simply reflects the basin-margin coastal onlap in response to a relative sea-level rise subsequent to the deposition of the fluvio-deltaic systems of the Vadsø Group. This interpretation is favoured here for the following two reasons. First, there is a marked difference in lithofacies and palaeocurrent pattern between the Veinesbotn Formation and the oldest formations north of Varangerfjorden. The main part of the Veinesbotn Formation was deposited in an open-marine, high-energy shelfal to nearshore environment, whereas the regressive, deltaic-fluvial sucessions of the oldest unit in the Vadsø Group (Fig. 4) were deposited in a restricted, roughly E-W trending marine basin, with an abundant fluvial supply. The deposits of the Veinesbotn Formation were derived from the south, whereas the palaeocurrent directions in the lower part of the Vadsø Group suggest prevalent sediment supply from the west or northwest.

Second, the main, marine part of the Veinesbotn Formation is similar to the sandstone formations of the Tanafjorden Group in terms of the textural and mineralogical maturity and the tide-dominated, open-marine depositional setting (Johnson 1977a, b, Johnson et al. 1978, Røe, unpublished data). In particular, there is a remarkable similarity between the marine sandstones of the Veinesbotn Formation and the deposits of the Gamasfjellet Formation. They both represent a shallow tidal environment, and the attributes shared include the characteristic reddish colouration, lacking in the other sandstone formations in the Varangerfjorden area; the predominance of trough cross-stratification with subordinate ripple cross-lamination, and the predominance of unidirectional, northeastward palaeocurrent directions. The colouration, which is caused by hematite pigment, suggests that that the two formations are not only similar in terms of their depositional and palaeogeographic setting, but shared the same diagenetic environment, where F^{+2} underwent oxidation to Fe^{+3}.

The above evidence suggests that the main part of the Veinesbotn Formation is most probably a lateral equivalent of the Gamasfjellet Formation of the Tanafjorden Group, with the implication that the Vadsø Group has no equivalent unit on the inner, southern side of Varangerfjorden. The upward transition from the mainly fluvio-deltaic Vadsø Group to the shallow-marine Tanafjorden Group, together with the greater regional extent of the latter deposits, is consistent with the notion of basin expansion and overall coastal onlap (Fig. 7a). The unconformable position of the Veinesbotn Formation on the basement in the inner, southern side of Varangerfjorden indicates a non-depositional basin margin to the south, inundated by the sea at a relatively late stage, probably at the time when the middle part of the Tanafjorden Group succession was deposited.

The suggested revised stratigraphic correlation and the conclusion that the sedimentary rocks in the Lattanjarga area are older than the Veinesbotn Formation (Rice et al. 2001) suggest that the Lattanjarga succession may be a part of the Dakkovarre Formation (Fig. 3). The heterolithic upper part of the Veinesbotn Formation may correspond to the lowermost siltstone deposits of Vagge Formation, although no comparative sedimentological analysis has been attempted to verify this suggestion.

The Varangerfjorden Fault Zone (VFZ)

Based on the revised stratigraphic relationships, a WNW-ESE fault is inferred to separate the rock succession on the northern side of Varangerfjorden from the rock succession of the fjord and on its southern side. This major inferred palaeotectonic lineament, running north of the fjord axis (between Skjåholmen and Handelsneset, Fig. 1c) and referred here to as the Varangerfjorden Fault Zone (VFZ), corresponds to the earlier hypothetical structure suggested by Holtedal (1918, p. 264). Holtedahl`s original suggestion of a fault below the modern Varangerfjorden was based mainly on the rapid rise of the Archaean basement and its rugged topography to the south of the fjord, contrasting with the low-angle structural attitude of the sedimentary rock succession to the north. The local occurrences of tillite in basement depressions to the west and southwest of Varangerfjorden suggested to him that the present-day topography, was at least partly, inherited from the Precambrian and that the fault was older than the tillite-bearing sedimentary formations. The revised stratigraphy strongly supports Holtedahl's suggestion.

The VFZ is thought to have been a tectonic lineament with two phases of fault activity (Fig. 7). While the youngest phase (terminal Riphean) is deduced from the revised stratigraphic correlation which implies a major tectonic displacement between Handelsneset and Skjåholmen, the oldest phase is inferred from signatures of syn-tectonic sedimentation within the lower part of the Late Riphean succession, and will be discussed first prior to the important terminal Riphean tectonic event.

The middle Late Riphean fault activity and basin development

On account of the interpretation that the Veinesbotn Formation belong to the Tanafjorden Group in an onlap configuration with respect to the Archaean basement, it is appropriate to consider the possibility that a basin-margin fault (VFZ) was active during sedimentation of the lower part of the Riphean succession.

Signatures of syn-tectonic sedimentation

The areal distribution of the main part of the Vadsø Group is limited to the coastal areas of Varangerfjorden (i.e., parallel or subparallel to the regional strike of the peripheral basin), which generally precludes a 3-D analysis of the depositional architecture of the group's component formations and the corresponding palaeogeomorphological changes. In such a case, the signatures of syndepositional tectonic activity are difficult to recognize (see Frostick & Steel 1993). However, the striking reversal of fluvial palaeocurrent directions across the unconformity separating the Paddeby and Golneselva formations (Fig. 4) suggests a major change in the basin's geomorphological and palaeogeographic configuration. The basin axis, previously inclined towards the east-southeast, apparently became tilted towards the northwest, which can be attributed to active tectonics (Røe 1975). Syndepositional tectonic activity is also indicated by the northward thickening of the Ekkerøya Formation (Johnson 1978).

An ongoing study of soft-sediment deformation features in the Vadsø Group suggests that the liquefaction leading to the formation of large to very large-scale convolution structures was triggered by seismic activity. It is well recognized that the cyclic stress generated by earthquakes with a magnitude of >5 (Richter scale) is capable of liquifying sand at or near the surface (Youd & Perkins 1978, Seed 1979).
In the Vadsø Group (Fig. 4), convolutions occur in some of the sandy intervals of the three argillaceous formations, in some horizons in the Fugleberget and Paddeby formations, and abundantly in the Golneselva Formation (Hobday 1974, Banks & Røe 1974, Røe unpublished data). The evidence that the liquefaction was caused by earthquakes, rather than depositional processes such as storms or flood surges, includes the following aspects of the convolutions: (1) their large scale (0.3-2 m amplitude) in all the formations, irres-

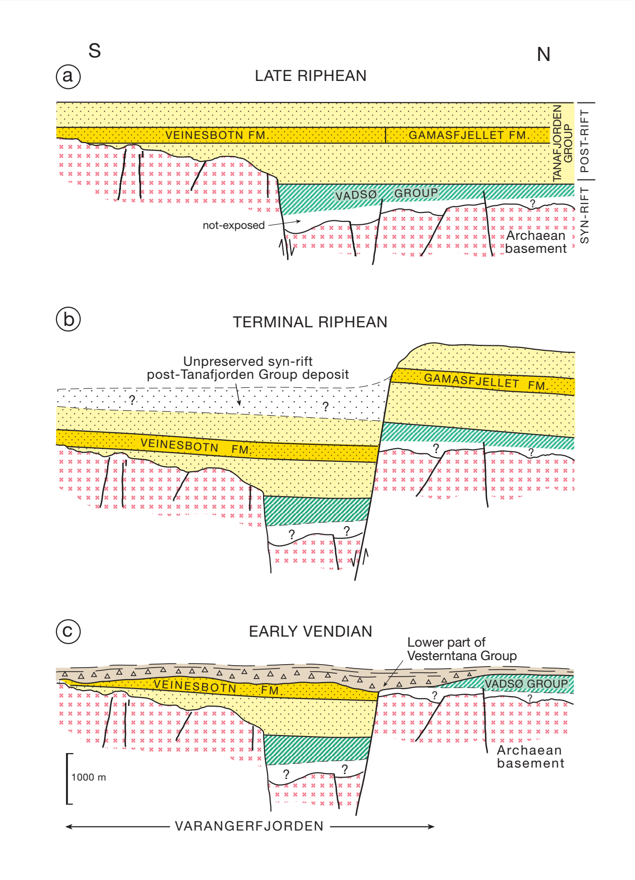

Fig. 7. Hypothetical section across Varangerfjorden and the concealed VFZ. Note the correlation of the Veinesbotn Formation with the Gamasfjellet Formation. (a) The first, middle Late Riphean syn-rift phase (Vadsø Group and lowermost Tanafjorden Group) followed by post-rift deposition onlapping the basin margin. (b) The second, terminal Riphean synrift phase. See text (p. 271) for alternative fault position. (c) Base Vendian erosion followed by deposition of the oldest glacigenic sediments of Vestertana Group in the Varangerfjorden palaeovalley. Differential isostatic subsidence across the faults is not accounted for in this figure.

pective of sedimentary facies; (2) their large lateral extent (Golneselva and Ekkerøya formations); and (3) the occurrence of associated sandstone dykes (Andersby Formation), indicating that the liquefaction occurred several metres below the sediment surface. One or more of these criteria have commonly been invoked as indicating a tectonic origin of similar deformation structures (e.g., Johnson 1977, Leeder 1987, Ord et al. 1988, Rosetti 1999).

In the Tanaforden Group, convolute stratification predominates in the middle part of the Grønneset Formation. A detailed study by Johnson (1977) concluded that the soft-sediment deformation there was of tectonic origin, on account of the considerable lateral extent and abundance of the convolutions. Notably, no analogous features occur in the overlying sandy formations, despite the similarity of facies and sediment texture. The lack of unconformities and the uniform thicknesses of the successive formations in this thick (c.1600 m) shallow-marine succession are consistent with the notion of sedimentation in a tectonically quiet setting.

Basin development

The evidence for synsedimentary tectonism in the Vadsø Group and in the Grønneset Formation, and the non-tectonic setting for the remainder of the Tanafjorden Group suggests, in the framework of an extensional basin, an upward transition from a rift-controlled basin to one dominated by passive subsidence (Fig. 7a). Palaeocurrents in the fluvial and deltaic formations of the Vadsø Group are consistent with sediment dispersal in rift basins having both a longitudinal and a transverse component (Fig. 4).The fine-grained fluvial and deltaic succession in the lower allostratigraphic unit probably corresponds to the longitudinal system, while the coarse fan-deltaic member of the Fugleberget Formation represents the transverse system.

The change in the tilt of the basin floor across the Paddeby/Golneselva unconformity suggests, that in the context of a rift-basin, probable fault-block rotations occurred perhaps involving scissor-like movement on a basin-margin fault or, alternatively, a reversal of rift assymmetry with time (e.g. Lambaise & Bosworth 1995). The large variety of channel styles and scales within the Golneselva Formation (Banks & Røe 1974) may be attributed to an interfingering of longitudinal and transverse alluvial systems, with an upward increase in the transverse system as the upward change in palaeocurrents from NW to NNW suggests.

The soft-sediment deformation structures in the Grønneset Formation represent the last record of tectonic activity in the basin. Acommodation for the overlying, conformable, shallow-marine succession was largely provided by thermal subsidence in addition to isostatic and eustatic effects. The regional distribution of the Ekkerøya Formation (Rice et al. 1996) suggests that the initial basin expansion preceded the last tectonic events and may thus have a eustatic origin.

The rift model for the lower part of the Riphean succession may suggest that this part of the basin-fill is bounded, at least partly in space and time, towards the Archaean basement by a major, synsedimentary fault beneath Varangerfjorden (Fig. 7a). Such a north-dipping normal fault would correspond to the Western Timan Fault in the Timan-Kanin Region (WFT Fig.1a). Notably, the WNW-ESE trend of Varangerfjorden, markedly atypical for the fjords in east Finnmark, is parallel and subparallel to the structurally controlled trends of the Murmansk coast and the northeastern Kola coast on the Russian side (Fig.1a).

The terminal Riphean fault activity

Timing

The second phase of fault activity along the VFZ is believed to have occurred after the deposition of the Tanafjorden Group, which lacks clear evidence of syndepositional tectonic activity. The tillite-bearing Smalfjord Formation overlies the Veinesbotn Formation on the southern side of the VFZ, but covers the lower part of the Vadsø Group on the northern side (Figs. 1c, d and 7c), which suggests that the main faulting occurred prior to the deposition of the Smalfjord Formation in the Varangerfjorden glacial palaeovalley. Notably, these valley-fill deposits of the Smalfjord Formation, are slightly older than the basal part of the Vestertana Group in most other areas (Edwards 1984).

Olovyanishnikov et al. (2000) have linked the 630 Ma age of diagenetic illite in the Stangenes Formation (Fig. 3) with the phase of tectonic deformation that caused the low-angle northward tilting of the Riphean sedimentary succession in the TVR. It may be reasonable to assume that the fault activity was associated with the tilting and that the 630 Ma (base Vendian) age corresponds to the final tectonic event of the second phase of faultactivity. Consequently, a terminal Riphean age is suggested for this phase of fault activity.

Fault kinematics

The position of the Smalfjord Formation on the Veinesbotn Formation south of the VFZ and on the lower part of the Fugleberget Formation to the north suggests that the second phase (terminal Riphean) of fault activity along the inferred VFZ may have involved a southward-dipping normal fault, a reverse fault with southward slip, or a dextral strike-slip fault with or without a normal component of displacement. All these fault varieties have been recognised along the TKFZ. However, terminal Riphean fault activity has not been reported from this latter fault zone and hence it cannot be directly compared with the VFZ. If the faulting resulted in northward tilting of the Riphean sedimentary succession, the VFZ must have had a considerable vertical displacement and thus could not have had pure strike-slip kinematics.

A southward-dipping normal fault is more likely than a reverse fault because the inferred VFZ is apparently much older than the Timanian compression on Varanger Penninsula provisionally dated to circa 560 (±28) Ma (Gorokhov et al. 2001). In addition, the evidence of pre-Caledonian compression is limited to the eastern part of the Varanger Peninsula (Karpuz et al. 1995, Roberts 1996) and associated with a possible structural inversion of the TKFZ (Olovyanishnikov et al. 2000). If the VFZ was characterised by reverse faults, the evidence of this regime, in the form of small-scale folds and contractional faults in the less competent parts of the Late Riphean sedimentary succession, should be expected to occur along the entire coastal section.

Accordingly, the second phase (terminal Riphean) of faultactivity along VFZ is also thought to have been formed in an extensional tectonic regime and characterised by normal fault kinematics (Fig.7b). Provided that no concurrent or subsequent strike-slip movement occurred, the cumulative vertical displacement on the VFZ between Skjåholmen and Handelsneset (Fig. 1c) would amount to an amplitude of c.1300 to1500 m. The southward dip of the fault, opposite to the dip of the first phase (middle Late Riphean) normal, basin-margin fault, suggests reactivation of an intrabasinal fault (Fig. 7b) or reactivation and *rotation* of a high-angle basin- margin fault. The latter possibility is, in the authors opinion, not unlikely in particular because of the large timespan the hiathus between the Tanafjorden Group (Late Riphean) and Vestertana Group (Vendian-Early Cambrian) probably represents.

Although the formation of Vendian valleys was promoted by the sea-level fall associated with the onset of continental glaciation, it is likely that the topography created by the VFZ determined the location and orientation of the glacial valley in the Varangerfjorden area. The trend of this palaeovalley, characterised by a relatively steep (10°) northern flank and northwestward sediment transport, differs from the predominantly northward and southward glacial transport recorded at higher stratigraphic levels (Edwards 1984). The age of the NNW-SSE trending Krokvannet palaeovalley within the Gaissa Nappe Complex (Fig.2) resemble that of the Varangerfjorden palaeovalley, which may suggest a similar underlying structural control.

Concluding remarks

The proposed tectono-stratigraphic model for the Upper Riphean and lowermost Vendian peripheral-basin deposits in the TVR implies the presence of a major, WNW-ESE trending fault zone hidden beneath Varangerfjorden, here referred to as the Varangerfjorden Fault Zone (VFZ). The inferred VFZ had probably two phases of extensional tectonic activity (Fig.7). The first phase (middle Late Riphean) is suggested by the signatures of syntectonic sedimentation in the mainly fluvio-deltaic deposits of the Vadsø Group and lowermost, shallow-marine formation of the Tanafjorden Group. In the context of an extensional basin, this suggests syn-rift sedimentation probably along a basin-margin, north-dipping normal fault. The remainder of the Tanafjorden Group is attributed to the post-rift thermal-sag stage with a coastal onlap of the faulted margin (Fig. 7a).

The second phase (terminal Riphean), is inferred from the revised stratigraphic correlation, which suggests that the main, shallow-marine part of Veinesbotn Formation, exposed along the southwestern coast of Varangerfjorden, corresponds to the Gamasfjellet Formation of the Tanafjorden Group to the north (Fig. 7a, b). This relationship suggests a major, probably south-dipping normal fault and reactivation of the VFZ. The opposite fault dip direction, relative to that of the older (first phase) basin-margin fault, suggests reactivation of an south-dipping intrabasinal fault or possibly reactivation and rotation of the basin-margin fault itself. Fault-block *rotation* and erosion of the footwall were probably responsible for the major low-angle semi-regional unconformity at the base of the Vestertana Group. In addition, the topography created by the VFZ probably controlled the location and orientation of the earliest Vendian, Varangerfjorden palaeovalley, which accommodated the oldest glacigenic deposits of the Vestertana Group.

In the regional framework suggested by Olovyanihnikov et al. (2000) the Late Riphean palaeomargin fault (VFZ) would correspond to the WTF in the Timan-Kanin region (Fig. 1a). The evidence of syn-rift sedimentation in the lower part of the Riphean succession in the TVR does not support the opinion of Olovyanihnikov et al. (2000) that the sedimentation in the inner 'pericratonic' domain of the Timan-Varanger Belt, including the TVR, occurred subsequently to the faulting. Evidence forwarded by these authors that the Middle-Late Riphean extensional basin was younger towards the northwest may, however, suggest that the syn-rift to post-rift transition occurred later in the northwestern part of the Timan-Varanger Belt and that the syn-rift sedimentation in the TVR could have been coeval with sedimentation along the more mature, tectonically inactive, basin-margin to the southeast, in the Kanin-Timan areas. The presence of thick, Upper Riphean carbonate ramp buildups along the outer margin of the platform in these latter areas (Olovyanihnikov et al. 2000) is consistent with such a diachronous model, although the exact age relationships between these deposits and the syn- and post-rift, mainly terrigenous, successions in the TVR cannot be determined.
The CTF and to a lesser extent the WTF (Fig. 1a) experienced structural inversion during the Late Vendian, Timanian orogeny (Olovyanihnikov et. al. 2000). In contrast, the inferred VFZ was probably subject to a second phase (terminal Riphean) extensional faulting and evidence of pre-Caledonian compressional deformation is absent in the coastal sections of inner Varangerfjorden. This major extensional phase, involving fault-block rotation and erosion of large parts of the Riphean succession, was probably not confined to the VFZ, but might have involved the TKFZ as well. This tectonic event would, however, be difficult to recognise along the latter lineament because of the possible structural impact of the subsequent Timan inversion. Nevertheless, if the angular unconformity between the Barents Sea Group and the Løkvikfjellet Group in the BSR is coeval with the unconformity between the Tanafjorden Group and Vestertana Group in the TVR, it can reasonably be assumed that the tilting of the sub-unconformity successions in both regions was caused by the same process of regional tectonic development.

The inferred VFZ is concealed by the modern fjord as well as Vendian and Quarternary deposits. In this paper, a 'best-fit' intergration of the available data, including results of recent geochronological studies, has been attempted. The tectono-stratigraphic model can readily be tested by means of seismic reflection profiles across the inner part of Varangerfjorden, in addition to a detailed comparative petrographic and biostratigraphic analysis of the correlated formations. It is the present author`s intention to stimulate such research.

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References

Banks, N.L. 1973: Innerelv Member: Late Precambrian marine shelf deposits, East Finnmark. *Norges geologiske undersøkelse 288,* 7-25.

Banks, N. L., Edwards, M. B., Geddes, W. P., Hobday D.A. & Reading, H.G. 1971: Late Precambrian and Cambro-Ordovician sedimentation in East Finnmark. *Norges geologiske undersøkelse 269,* 197-236.

Banks, N.L. & Røe, S.-L. 1974: Sedimentology of the Late Precambrian Golneselv Formation, Varangerfjorden, Finnmark. *Norges geologiske undersøkelse 303*, 17-38.

Banks, N.L, Hobday, D.K. , Reading, H.G. & Taylor, P.N. 1974: Stratigraphy of the Late Precambrian `Older Sandstone Seriers` of Varangerfjord Area, Finnmark. *Norges geologiske undersøkelse 303*, 1-15.

Beckinsale, R.D., Reading , H.G. & Rex, D.C. 1975: Potassium-argon ages for basic dykes from East Finnmark: stratigraphic and structural implications. *Scottish Journal of Geology 12*, 51-65.

Bjørlykke, K.O. 1967: The Eokambrian "Reuch moraine"at Bigganjargga and the geology around Varangerfjord, northern Norway. *Norges geologiske undersøkelse 251*, 18-44.

Bridge, J.S. 1985: Paleochannel patterns inferred from alluvial deposits: A critical evaluation. *Journal of Sedimentary Petrology 55*, 579-589.

Coleman, J.M. & Gagliano S.M. 1965: Sedimentary structures : Mississippi river deltaic plain. *In* Middleton G.V. (ed.) Primary sedimentary structures and their hydrodynamic interpretation. *Soc. Econ. Paleont. Mineral. Spec. Publ. 12*, 133-148.

Dalrymple R.W. 1992: Tidal depositional systems. *In* Walker R.G. & James N.P.(eds.) *Facies Models, response to sea level change, 195-219.*

Drinkwater, N.J., Pickering, K.T. & Siedlecka, A. 1996: Deep water faultcontrolled sedimentation, Arctic Norway and Russia: response to late Proterozoic rifting and the opening of the Iaptus Ocean. *Journal of the Geological society of London.153,* 427-436.

Edwards, M.B. 1975: Glacial retreat sedimentation in the Smalfjord Formation, Late Precambrian, N. Norway. *Sedimentology 22,* 75-94.

Edwards, M.B. 1984: Sedimentology of the upper Proterozoic glacial record, Vestertana Group, Finnmark North Norway. *Norges geologiske undersøkelse 394,* 1-76.

Frostic, L.E. & Steel, R.J. 1993: Tectonic signatures in sedimentary basin fills: an overview. In Frostic & Steel (eds.): *Tectonic controls and signatures in sedimentary successions. Special Publication International Association of Sedimentologists 20,* 1-9.

Føyn, S. & Siedlecki, S. 1980: Glacial stadials and interstadials of the Late Precambrian Smalfjord Tillite on Laksefjordvidda, Finnmark, North Norway. *Norges geologiske undersøkelse 358,* 31-45.

Gorokhov, I.M., Siedlecka, A, Roberts, D, Melnikov, N.N.& Turchenko, T.L. 2001a: Rb-Sr dating of diagenetic illite in Neoproterozoic shales, Varanger Peninsula, northern Norway. *Geological Magazine 138*, 541-562.

Gorokhov, I.M., Melnikov, N.N., Negrutsa, V.Z., Turchenko, T.L. & Kutavin, E.P. 2001b: Multistage illite evolution in Upper Proterozoic shales of Sredni Peninsula, the Murmansk coast of the Barents Sea. *Lithology and Mineral Resources 37*,162-169.

Guise, P.G & Roberts, D. 2002: Devonian ages from AR/AR dating of plagioclase in dolerite dykes, eastern Varanger Peninsula, North Norway. *Norges geologiske undersøkelse 440,* 27-37.

Hjellbakk, A. 1993: A flash-flood dominated braid delta in the Upper Proterozoic Næringselva Member, northern Norway. *Norsk Geologisk Tidsskrift 73,* 63-80.

Hjellbakk, A. 1997: Facies and fluvial architecture of a high-energy braided river: the Upper Proterozoic Seglodden Member, Varanger Peninsula, northern Norway. *Sedimentary Geology 114,* 131-161.

Hobday, D.K. 1974: Interaction between fluvial and marine processes in the lower part of the Late Precambrian Vadsø group, Finnmark. *Norges geologiske undersøkelse 303,* 39-56.

Holtedahl, O. 1918: Bidrag til Finmarkens Geologi. *Norges Geologiske Undersøkelse 84*, 314p.

Johnson, H.D. 1977: Sedimentation and waterescape structures in some Late Precambrian shallow marine sandstones from Finnmark, North Norway. *Sedimentology 24,* 389-411.

Johnson, H.D. 1978: Facies distribution and lithostratigraphic correlation in the Late Precambrian Ekkerøy Formation, east Finnmark, Norway. *Norsk Geologisk Tidsskrift 58,* 175-190.

Johnson, H.D., Levell, B.K. & Siedleki, S. 1978: Late Precambrian sedimemtary rocks in East Finnmark, north Norway and their relationship to the Trollfjord-Komagelv fault. *Journal of the Geological Society of London 135*, 517-533.

Karpuz, M.R., Roberts, D., Olesen, O., Gabrielsen, R.H. & Herrevold, T. 1993: Application of multiple data sets to structural studies on Varanger Peninsula, Northern Norway. *International Journal of Remote sensing 14,* 976-1003.

Karpuz, M.R., Roberts, D., Herrevold, T., Gabrielsen R.H. & Olesen, O. 1995: Structural and geophysical characteristics of the Trollfjorden-Komagelva Fault Zone,Varanger Peninsula, northern Norway (extended abstract). *In* Roberts, D. & Norgulen, Ø. (eds.) Geology of the eastern Finnmark-western Kola Peninsula Region. *NGU Special Publication 7,* 151-152.

Lambaise, J.J. and Bosworth, W. 1995: Structural controls on sedimentation in continental rifts. *In* (Lambaise ed.) *Hydrocarbon Habitat in Rift Basins, Geological Society Special Publication 80,* 117-144.

Leeder, M. 1987: Sediment deformation structures and the palaetectonic analysis of sedimentary basins, with case-study from the Carboniferous of northern England: *In* Jones, M.E. & Preston, R.M.F (eds): Deformation of Sediments amd Sedimentary Rocks. *Geological Society Special Publication, 29,* 137-146.

Olovyanishnikov V.G., Roberts D. & Siedlecka, A. 2000: Tectonics and sedimentation of the Meso- to Neoproterozoic Timean-Varanger Belt along the Northeastern Margin of Baltica. *Polarforschung 68*, 267-274.

Ord D.M., Clemmey, H. & Leeder, M.R. 1988: Interaction between faulting and sedimentation during Dinatian extention of the Solway basin, SW Scotland. *Journal of the Geological Society London 145*, 249-259.

Pickering, K.T. 1981: The Kongsfjord Formation - a Late Precambrian submarine fan in north-east Finnmark, North Norway. *Norges geologiske undersøkelse 367*, 77-104.

Pickering, K.T. 1982: A Precambrian upper basin slope and prodelta in northeast Finnmark, North Norway-a possible ancient upper continental slop. *Journal Sedimentary Petrology 52,* 171-186.

Reading, H.G. 1965: Eocambrian and Lower Palaeozoic geology of the Digermul Peninsula, Tanafjord Finnmark. *Norges geologiske undersøkelse 234*, 167-191.

Rice, A.H.N., Bevins, R.E., Robinson, D. & Roberts, D. 1989: Evolution of low-grade metamorphic zones in the Caledonides of Finnmark, N.Norway. *In* Gayer, R.A. (e.d.), *The Caledonide Geology of Scandinavia,* Graham & Trotman, London, 177-191.

Rice, A. H. N. & Townsend, C. 1996: Correlation of the late Precambrian Ekkerøya Formation (Vadsø Group; E. Finnmark) and the Brennelvfjord Interbedded Member (Porangerfjord Group; W. Finnmark), N. Norwegian Caledonides. *Norsk Geologisk Tidskrift 76,* 55-61.

Rice, A.H.N., Hofmann, Ch. & Pettersen A. 2001: A new sedimentary succession from the southern margin of the Neoproterozoic Gaissa basin, South Varangerfjord, North Norway. *Norsk Geologisk Tidskrift 81,* 41-48.

Rice, A.H.N, Ntaflos, T, Gayer, R.A. & Beckingsale, R.D. 2003: Metadolorite geochronology and dolerite geochemistry from E. Finnmark, N. Scandinavian. *Geological Magazine*, In press.

Roberts, D. 1995: Principal features of the structural geology of the Rybachi and Sredni Peninsulas, Northwest Russia, and some comparisions with Varanger Peninsula, North Norway. *NGU Special Publication 7,* 247-258.

Roberts, D. 1996: Caledonian and Baikalian tectonic structures on Varangerpeninsula, Finnmark, Norway, and coastal areas of Kola Peninsula, NW Russia. *Norges geologiske undersøkelse 431*, 59-61.

Roberts, D. 1998: Bergrunnskart Honningsvåg-Geologisk kart over Norge, M 1:250 000. Norges geologiske undersøkelse.

Roberts, D. & Siedlecka, A. 2002: Timanian orogenic deformation along the northeastern margin of Baltica, Nortwest Russia and Northeast Norway, and Avalonian-Cadomian connections. *Tectonophysics 352*, 169-184.

Rosetti D.F. 1999: Soft-sediment deformation structures in late Albian to cenomian deposits , Sao Luis Basin, northern Brazil: evidence for paleoseismicity. *Sedimentology 46*, 1065-1081.

Røe, S-L. 1970: Correlation between the Late Precambrian Older Sandstone Series of the Tanafjord and Varangerfjord areas: preliminary report. *Norges geologiske undersøkelse 266,* 230-245.

Røe, S-L. 1975: Stratification, sedimentary processes and depositional environments of part of the Late Precambrian Vadsø Group, Varangerfjord area, Finnmark. Unpublished Cand. Real. thesis, University of Bergen. 187pp.

Røe, S-L. 1987a: Ekkerøy bergrunnskart 2435 2, 1:50 000, foreløpig utgave, Norges geologiske undersøkelse.

Røe, S-L. 1987b: Vadsø bergrunnskart 2435 3, 1:50 00, foreløpig utgave, Norges geologiske undersøkelse.

Røe, S-L.1987c: Cross-strata and bedforms of probable dune to upper -stage plane bed origin from a Late Precambrian fluviale sandstone, northern Norway. *Sedimentology 34*, 89-101.

Røe, S-L. 1995: Stacked fluviodeltaic cycles in the Upper Proterozoic Godkeila Member, Varanger Peninsula, northern Norway. *Norsk Geologisk Tidskrift 75*, 229-242.

Røe, S-L. & Hermansen, M. 1993: Processes and products of large, Late Precambrian sandy rivers in Northern Norway. *In* Marzo, M. & Puigdefabregas, C. (eds.): *Special Publication International Association of Sedimentologists 17*, 151-166.

Samuelsson, J. 1995: Biostrathigraphy of the Kildin Island and the Sredni and Rybachi Peninsulas, Kola, northwestern Russia-preliminary results (extended abstract). *NGU Special Publication 7,* 327-329.

Samuelsson, J. 1997: Biostratigraphy and palaebiology of Early Neoproterozoic strata of the Kola Peninsula, Northwest Russia. *Norsk Geologisk Tidsskrift 77,* 1-28.

Seed, H.B. 1979. Soil liquefaction and cyclic mobility evaluation for level ground during earthquakes, *Journal Geotechnical Engineering Division Proceeding. A.S.C.E. 105, GT2,* 201-255.

Siedlecka, A. 1975: Late Precambrian stratigraphy and structure of the northeastern margin of the Fennoscandian Shield (East Finnmark-Timean Region). *Norges geologiske undersøkelse 316*, 313-348.

Siedlecka, A. 1978: Late Precambrian tidal-flat deposits and algal stromatolites in the Båtsfjord Formation, East Finnmark, North Norway. *Sedimentary Geology 21*, 177-310.

Siedlecka , A. 1985: Development of the Upper Proterozoic sedimentary basins on the Varanger Peninsula, East Finnmark, North Norway. *Geological Survey Finland 331*, 175-185.

Siedlecka, A. 1991: Nesseby bergrunnskart 2335 2, 1:50 000, foreløpig utgave. Norges geologiske undersøkelse.

Siedlecka, A. & Edwards , M. B. 1980: Lithostratigraphy and sedimentation of the Riphean Båsnæringen Formation, Varanger Peninsula, north Norway. *Norges geologiske undersøkelse 355*, 27-47.

Siedlecka, A. & Lyubtsov, V. V. 1997: Heavy mineral assemblages of the Neoproterozoic successions of Varanger Peninsula, Northern Norway. *Norges geologiske undersøkelse 433*, 26-27.

Siedlecka, A., Pickering, K.T. & Edwards M.B. 1989: Upper Proterozoic passive margin, deltaic complex, Finnmark, N. Norway. *In* Whateley, M.K.G. & Pickering, K.T. (eds.): Deltas: Sites and Traps for fossil Fuels. *Geolgical Society Special Publication 41,* 205-219.

Siedlecka, A., Lyubtsov V.V. & Negrutsa, V.Z. 1995: Correlation between Upper Proterozoic successions in the Tanafjorden-Varangerfjorden Region of Varanger Peninsula, northern Norway, and on Sredni Peninsula and Kildin Island in the northern coastal area of Kola Peninsula in Russia. *NGU Special Publication 7*, 217-232.

Siedlecka, A. & Roberts, D. 1992: The bedrock geology of Varanger Peninsula, Finnmark, North Norway: an excursion guide. *NGU Special Publication 5,* 1-45.

Siedlecka, A. & Roberts, D. 1995: Neoproterozoic sedimentation and subsequent tectonic deformation in the northern coastal areas of Norway and Russia. (Extended abstract). *NGU Special Publication 7,* 331-332.

Siedlecka, A., Roberts, D. & Olsen, L. 1998: Geologi på Varangerhalvøya: En oversikt med ekskursjonsforslag. Gråsteinen 3. *Norges geologiske undersøkelse* 122 pp.

Siedlecka, A & Siedlecki, S. 1971: Late Precambrian sedimentary rocks of the Tanafjord-Varangerfjord region of Varanger Peninsula, Northern Norway. *Norges Geologiske Undersøkelse 209*, 246-294.

Siedlecki S. 1980: Geologisk kart over Norge, bergrunnskart VADSØ-M. 1:250 000. Norges geologiske undersøkelse.

Siedlecki, A. and Levell, B.K. 1978: Lithostratigrapy of the Late Precambrian Løkvikfjellet Group on Varanger Peninsula, East Finnmark, North Norway. *Norges Geologiske Undersøkelse 343*, 73-85.

Stapor Jr., F.W. 1973: Heavy mineral concentrating processes and density/shape/size equilibria in the marine and coastal dune sands of the Appalachicola, Florida, region. *Journal of Sedimentary Petrology 43*, 396-407.

Sturt, B.A., Pringler, I.R. & Roberts, D. 1975: Caledonian nappe sequence of Finnmark, northern Norway, and the timing of the orogenic deformation and metamorphism. *Geological Society American Bulletin 86*, 710-718.

Sygnabere T.O. 1997: Strukturgeologisk kartlegging av den kaledonske fronten i de østlige delene av Tanafjord-Varangerfjord regionen , Varangerhalvøya (Finnmark), og dens betydning for utviklingen av Trollfjorden -Komagelva forkastningssone. Unpublished Cand. Scient.Thesis, University of Bergen, 127 pp.

Torsvik, T. H., Roberts, D. & Siedlecka A. 1995: Palaeomagnetic data from sedimentary rocks and dolorite dykes, Kildin island, Rybachi, Sredni and Varanger peninsulas, NW Russia and NE Norway: a review. *NGU Special Publication 7*, 315-326.

Townsend C. 1987: Thrust transport direction and thrust sheet restoration in the Caledonides of Finnmark. *Journal of Structural Geology 9,* 345-352.

Vidal,G.1981: Micropaleontology and biostratigraphy of the Upper Proterozoic and Lower Cambrian sequence in East Finnmark, Northern Norway. *Norges geologiske undersøkelse 362*, 53p.

Vidal, G & Siedlecka, A. 1983: Planktonic, acid-resistant microfossils from the Upper Proterozoic strata of the Barents Sea Region of Varanger Peninsula, East Finnmark, Northern Norway. *Norges geologiske undersøkelse 382*, 145-79.

Youd, T.L. & Perkins, D. M. 1978: Mapping liquefaction-induced ground failure potential. *Jour. Geotechnical Engineering Division Proceeding A.S.C.E. 104*, GT4, 433-46.

Aasheim, R. 1990: Sedimentologisk analyse og facies korrelasjoner i Ekkerøya Formasjonen, Varangerhalvøya. Unpublished Cand.Sient. thesis. University of Bergen. 115 pp.+ figs.

Åm, K. 1975: Areomagnetic basement complex mapping north of lattitude 62 north, Norway. *Norges geologiske undersøkelse 316*, 351-374.