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Revised stratigraphy and correlation of the Neoproterozoic successions of Varanger Peninsula, East Finnmark, northern Norway, and the Rybachi-Sredni peninsulas and Kildin Island in Northwest Russia

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Abstract

This contribution is principally a conspectus of research in diverse aspects of lithostratigraphy, sedimentology, micropalaeontology and geochronology carried out on Varanger Peninsula and neighbouring areas of Northwest Russia during the last half century. A programme of 1:50,000 scale bedrock mapping on Varanger was initiated in the 1960s and served as an invaluable basis for much of the research work that followed. Early discovery of the Trollfjorden-Komagelva Fault Zone assisted hugely in recognising Neoproterozoic platformal and basinal domains in the peninsula, and later collaboration with Russian geoscientists led to recognition of comparable depositional regimes on the Sredni and Rybachi peninsulas along the northern periphery of the Kola Peninsula. This review presents what is essentially a state-of-the-art summary of our current knowledge of the geology of these Arctic regions flanking the Barents Sea, complemented by a comprehensive literature list.

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Introduction and summary of research

The Neoproterozoic successions of Varanger Peninsula are unique in northern Scandinavia and have been investigated for more than a century. In the early stages of field investigation, the age of the strata in the Varangerfjorden and Tanafjorden areas had been broadly established based on (1) the interpretation of diamictites present in these areas as tillites, and (2) the discovery of Early Palaeozoic fossils in conformably overlying successions on Digermulen Peninsula (Fig. 1) west of Tanafjorden (Reusch 1891, Holtedahl 1918, Føyn 1937, Henningsmoen 1961, Reading 1965, Nikolaisen & Henningsmoen 1985). Subsequent discoveries of *Platysolenites antiquissimus* (Føyn 1967, Hamar 1967, Føyn & Glaesner 1979), microfossils (Vidal 1981, Vidal & Siedlecka 1983, Crimes & McIlroy 1999, Högström et al. 2013), Ediacaran biota (Farmer et al.1992) and columnar stromatolites (Bertrand-Sarfati & Siedlecka 1980) have since confirmed this interpretation.

The age of lithostratigraphic successions in the northern coastal areas of Varanger Peninsula, first observed and described briefly by Holtedahl (1918), has also been assumed to be largely Neoproterozoic, this being later confirmed by microfossils (Vidal & Siedlecka 1983) and the isotopic ages of cross-cutting metadolerite dykes (Rice et al. 2004). A systematic programme of geological mapping on Varanger Peninsula by the Geological Survey of Norway (NGU) commenced in 1967. In that year, Anna Siedlecka and Stanislav Siedlecki (both of whom had fieldwork experience from Svalbard) were assigned to the project and led an expedition crossing the peninsula from Komagelva to Trollfjorden/Tanafjorden. This fieldwork resulted in (1) the discovery of a major fault traversing the peninsula from Trollfjorden in the northwest to Komagelva in the southeast -(Siedlecka & Siedlecki 1967, 1971), known in subsequent literature as the Trollfjorden-Komagelva Fault Zone (TKFZ) (Siedlecka & Roberts 1992), separating the Barents Sea Region (BSR) to the northeast from the Tanafjorden-Varangerfjorden Region (TVR) (Fig. 2); and (2) the establishment of a formal lithostratigraphy for the successions occurring on both sides of this complex NW-SE-trending fault (Reading 1965, Siedlecka & Siedlecki 1971, 1972, Banks et al. 1971, 1974, Siedlecki 1980) (Fig.3).

The TKFZ is now known to constitute part of a major crustal lineament that extends southeastwards for >1800 km into the Timan Range (Timans) of Northwest Russia (Siedlecka 1975, Getsen 1991, Karpuz et al. 1993, Roberts et al. 1997, Olovyanishnikov et al. 2000), with a movement history ranging from likely Neoarchaean to Cenozoic time. A connection between Varanger geology and that of the Timans was an idea first proposed over a century ago by Ramsay (1899) and Tschernyschev (1901) and presented in a sketch map of *'The Timanian mountain chain'* by Reusch (1900) (Fig. 4). The hypothesis was largely neglected for several decades but revived by Schatsky (1958) and discussed by Siedlecka (1975), and subsequently confirmed in the 1990s during Russian-Norwegian collaborative fieldwork (see below).

On Varanger Peninsula, differences in Caledonian metamorphic grade and intensity of folding across the structure (Bevins et al. 1986, Rice et al. 1989a, b), and work along and adjacent to the fault zone (Karpuz et al. 1993, Herrevold et al. 2009), have led to its interpretation as a dextral strike-slip fault with this particular component of displacement (exceeding 207 km; Rice et al. 1989a, Roberts & Siedlecka 2012, Rice 2014) dating to Early Ordovician time (Rice & Frank 2003). Because of this complexity, the stratigraphic relationship between the

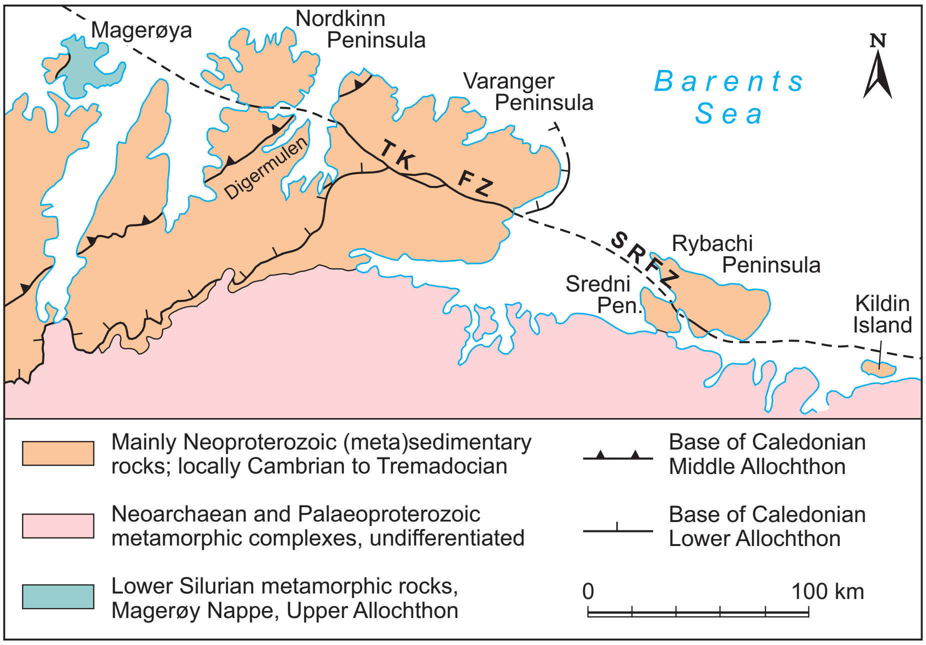

Fig. 1. Location map showing the Rybachi, Sredni, Varanger, Digermulen and Nordkinn peninsulas and Kildin Island. TKFZ – Trollfjorden-Komagelva Fault Zone, SRFZ – Sredni-Rybachi Fault Zone.

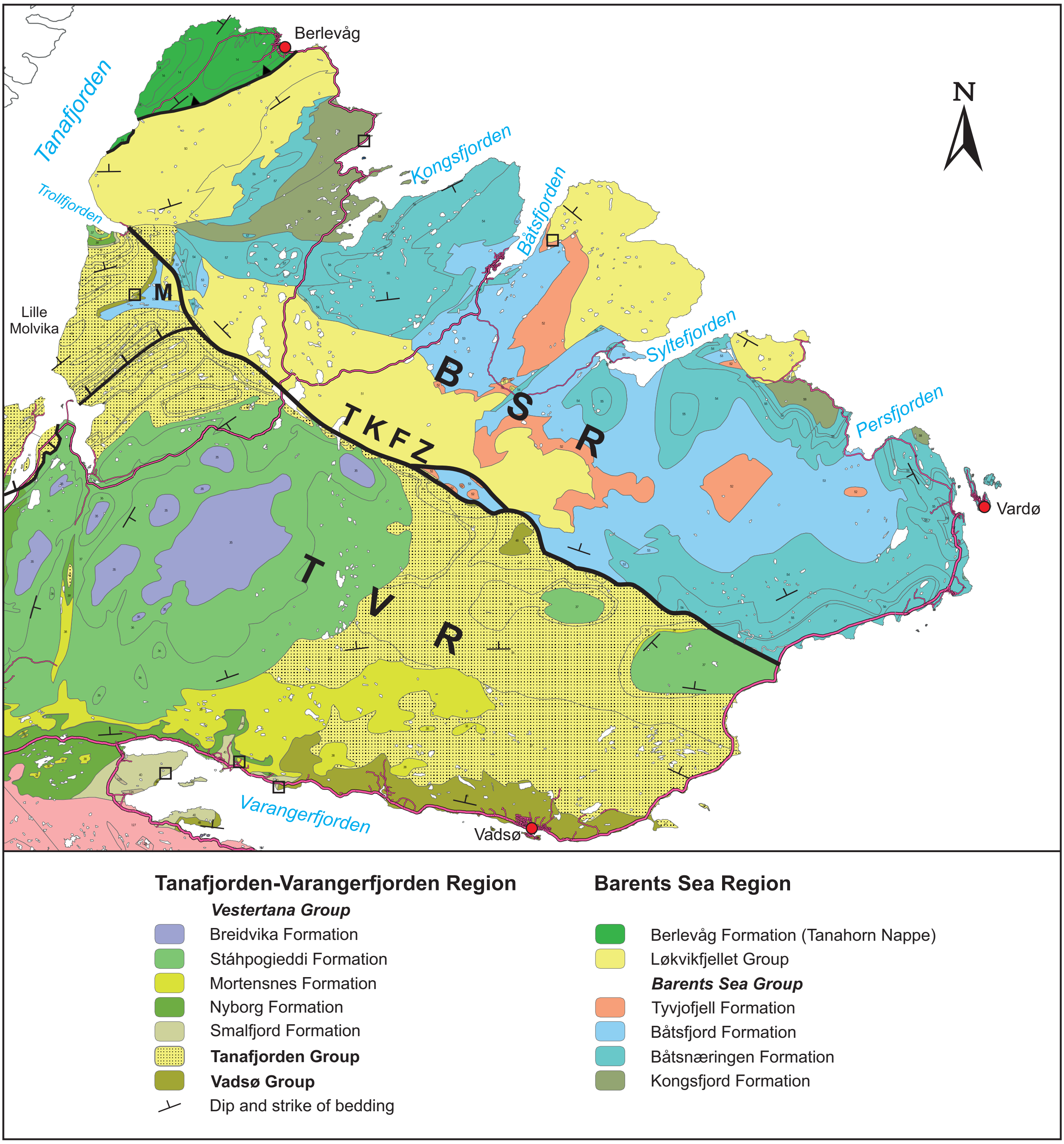

Fig. 2. Simplified geological map of the Varanger Peninsula. BSR – Barents Sea Region; TVR – Tanafjorden-Varengerfjorden Region. TKFZ – Trollfjorden-Komagelva Fault Zone. M – Mánjunnás area. The localities of the field photographs are shown by a small open-square symbol. Photos in Fig. 5 are from three localities in westernmost Varangerfjorden. The two photos in Fig. 6 are from one locality in western Kongsfjorden. Fig.7 is from one locality in Båtsfjorden. The four photos in Fig. 8 are from one locality close to Mánjunnás. The map is modified from one shown in Roberts & Siedlecka (2012).

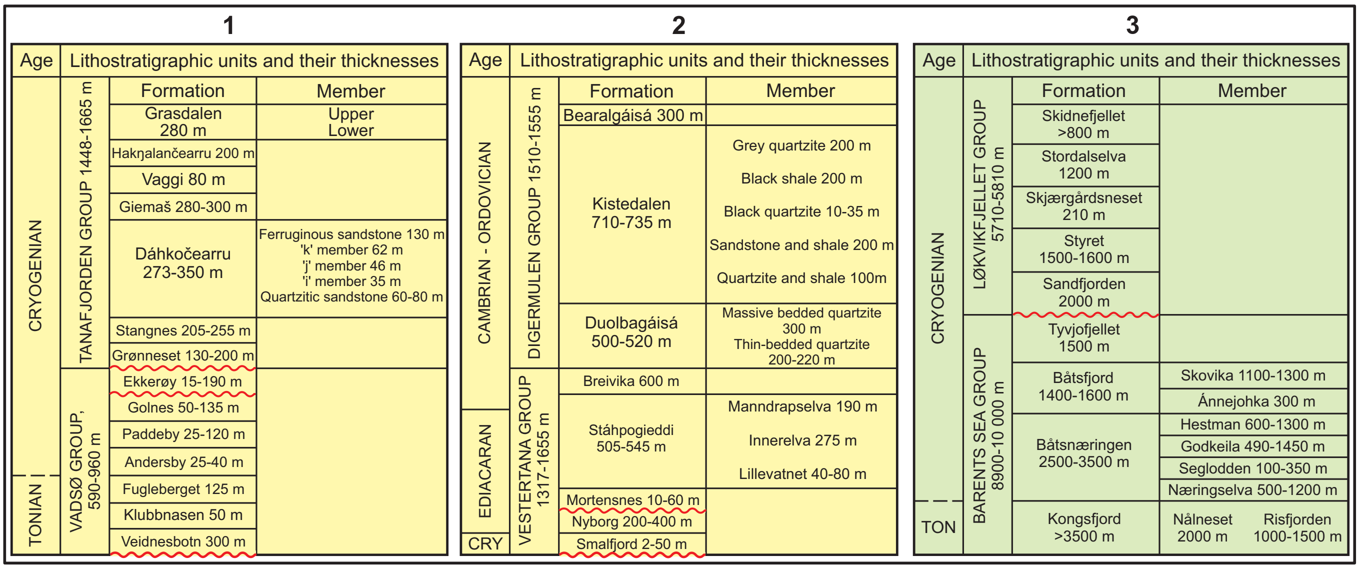

Fig. 3. Lithostratigraphical successions of the Varanger Peninsula. Columns 1 and 2 are from the Tanafjorden-Varangerfjorden Region with the youngest groups, formations and members in column 2. Column 3 depicts the Tonian-Cryogenian stratigraphy in the Lower Allochthon of the Barents Sea Region. Major unconformities are shown by a wavy red line. Stromatolites occur in the Grasdalen and Båtsfjord formations. Diamictites are in the Smalfjord and Mortensnes formations of the Vestertana Group.

successions in the BSR and the TVR had initially been uncertain and speculative, but this was subsequently resolved (Rice 1994) (see later).

Continuation of the TKFZ southeastwards, between the Rybachi and Sredni peninsulas and north of Kildin Island (Fig. 1) was confirmed during a collaborative research programme between NGU and the Russian Academy of Sciences (RAS) in the early 1990s. In those areas, lithostratigraphic successions on both sides of the fault zone (there termed the Sredni-Rybachi Fault Zone: SRFZ) were examined jointly by NGU and RAS geologists. Our Russian colleagues also participated in field excursions on Varanger Peninsula. While lithostratigraphic correlation between the formations on Rybachi Peninsula and the Kongsfjord Formation and parts of the Båtsnæringen Formation of the BSR was fairly straightforward, a direct correlation of the stratigraphic column between that on Sredni and the section of the TVR was more difficult. Although there is an overall similarity of the TVR and Sredni successions, there are no diamictites present on the Sredni Peninsula (Siedlecka et al. 1995a). The succession on Kildin Island also differs quite considerably from that on Sredni and comprises both siliciclastic and carbonate strata with columnar stromatolites (Lyubtsov et al. 1989, Raaben et al. 1995).

For many years, research on Varanger Peninsula was focused on the TVR and its glaciogenic deposits (Fig. 5), and little attention paid to the thick, basin-margin, turbiditic, submarine-fan to deltaic successions of the BSR and their counterparts just to the southeast in Russia. The 3.2 km-thick Kongsfjord Formation (Siedlecka 1972) comprises mostly medium- to thick-bedded greywackes with intercalated thin semi-pelitic units, in many places with flute and groove casts on bottom surfaces of greywacke beds (Fig. 6). The entire formation has been referred to as the Kongsfjord Submarine Fan (Pickering 1981, Siedlecka et al. 1995b). Until quite recently, the chronostratigraphic terminology used for the Neoproterozoic of Varanger Peninsula and neighbouring areas has been based on the Russian system (e.g., Riphean, Vendian), but in more recent literature and legends to map compilations this has been replaced by the new, internationally accepted nomenclature (ICS 2020; Tonian, Cryogenian, Ediacaran).

The main purpose of this paper is to review and discuss the development of lithostratigraphical and sedimentary research and the main criteria upon which the ages and correlations along strike and across the TKFZ and SRFZ were based as the work progressed through several decades; and thereby to pinpoint those proposals which are somewhat contentious and those which are well documented and thus readily acceptable. To this end, the contribution should therefore provide an invaluable literature source and basis for future generations of geoscientists working in the region. Structural and metamorphic geology has also figured prominently in several research projects, but this is not a topic of the present contribution. Although we do mention the ages of certain folds and cleavages in some paragraphs, we here refer the reader to some of the more important publications on this subject, e.g., Roberts (1972, 1995, 1996), Bevins et al. (1986), Townsend et al. (1986), Townsend (1987), Rice et al. (1989a, 1989b), Karpuz et al. (1993), Rice & Frank (2003), Herrevold et al. (2009) and Rice (2014).

Correlation across the TKFZ-SRFZ

Varanger Peninsula

Lithostratigraphy

The extensive mapping and sedimentological studies of the 1960s and 70s led to the establishment of a formal lithostratigraphy for the region (Banks et al. 1971, 1974, Siedlecka & Siedlecki 1971, 1972) (updated in Fig. 3). The first attempt at lithostratigraphic correlation across the TKFZ, although now outdated in many respects, was essentially based on field observations in the northwestern part of Varanger Peninsula, in the Lille Molvika area, eastern Tanafjorden, where successions of the TVR were apparently resting with a sedimentary contact on formations of the BSR (Siedlecka & Siedlecki 1972). Subsequent fieldwork in the BSR had revealed that there is a low-angle unconformity also between the Barents Sea Group and the overlying Løkvikfjellet Group (Fig. 7) Siedlecki & Levell 1978). A similar low-angle unconformity between the Tanafjorden Group and the Vestertana Group in the TVR had been known since the time of Holtedahl's (1918) investigations and consequently the initial lithostratigraphic correlation of the early 1970s was based on the assumption that these unconformities represented one and the same tectonic event. This, combined with the 'Eocambrian' age of the tillites and new information provided by biostratigraphic studies (Vidal 1981, Vidal & Siedlecka 1983), provided a basis for suggesting a Vendian age for the Vestertana Group and the uppermost part of the Barents Sea Group, and a Riphean age for the lower part of the Barents Sea Group and for the Tanafjorden and Vadsø groups (Siedlecka & Roberts 1992). In consequence, the Løkvikfjellet Group was then inferred to be Vendian (Ediacaran) and younger (Vidal & Siedlecka 1983, Siedlecka & Lyubtsov 1997); and a mostly Cambrian age has even been suggested by Rice et al. (2012). This proposal, as we now know, cannot be correct (Roberts & Siedlecka 2012, Zhang et al. 2015), as will be discussed later.

Ekkerøy Formation: a 'missing link'

The area between Lille Molvika and the Trollfjorden (Gulgofjorden) valley was re-examined by Johnson et al. (1978) who concluded that the contact between the successions of the BSR and TVR, previously described as sedimentary (Siedlecka & Siedlecki 1972), is tectonic, representing a thrust fault within the Gaissa Nappe Complex. This interpretation was followed in compiling the 1:250,000 map-sheet Vadsø (Siedlecki 1980). However, in 1991, the present authors visited the area together

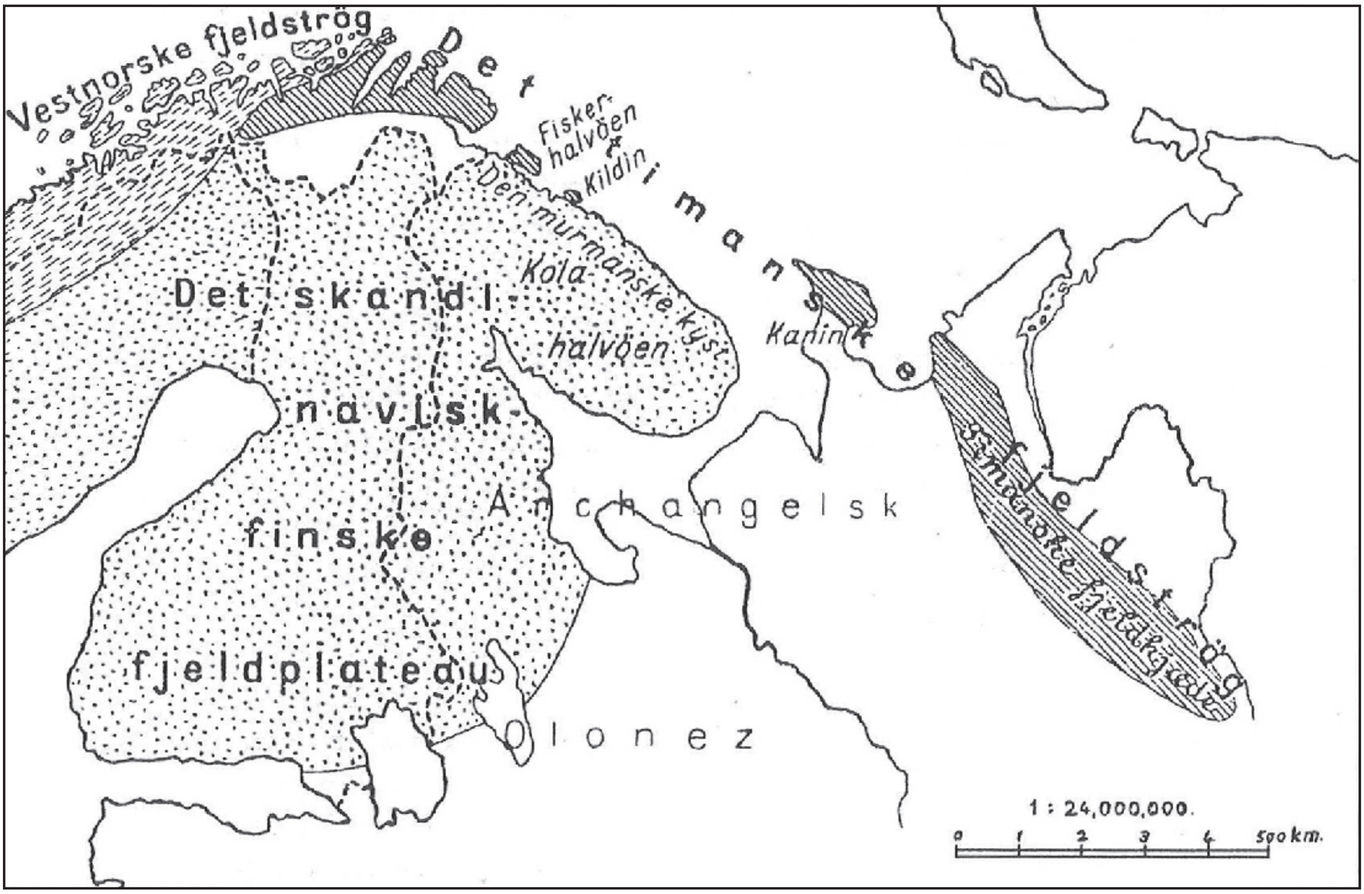

Fig. 4. Original map reproduced from Reusch (1900) showing the postulated extent of the Timanian Mountain Range (det timanske fjeldströg) based on the interpretations of Ramsay (1899) and Tschernyschev (1901). The northern part of the Caledonides was then called the West Norwegian Mountain Range (vestnorske fjeldströg); and the Fennoscandian Shield termed 'Det skandinavisk-finske fjeldplateau'.

with Russian (RAS) geologists and we were all convinced that the contact is clearly primary, most likely an angular unconformity and with pockets of sedimentary breccia and conglomerate in places along the contact (Fig. 8). Later, Rice (1994) confirmed this observation and documented in detail the erosional nature of the contact between the Båtsfjord Formation (and possibly parts of the Tyvjofjellet Formation) and the overlying Ekkerøy Formation of the Vadsø Group. This important documentation of the 'missing link' between the TVR and the BSR contributed considerably to a better understanding of the relationship between the successions across the TKFZ, and correlations which followed were duly modified (e.g., Siedlecka & Roberts 1995, Siedlecka & Lyubtsov, 1997, Rice et al. 2004, 2012, Halverson et al. 2005, Herrevold et al. 2009). The discovery also laid doubt on the previously proposed location of the Riphean-Vendian boundary, based on poorly preserved microfossils, within the lower part (Ánnejohka Member) of the Båtsfjord Formation (Vidal & Siedlecka 1983).

The Ekkerøy Formation (Banks et al. 1974), the uppermost unit in the Vadsø Group, is separated by unconformities both from the remainder of the Vadsø Group below and from the overlying Grønneset Formation at the base of the Tanafjorden Group. This formation extends throughout the peninsula and thickens from just over 15 m in the southeast in the type locality on the island Store Ekkerøya to 130 m at Trollfjorden. Its maximum recorded thickness is 190 m at Skipskjølen in the northernmost part of the TVR close to the TKFZ. The formation has been studied in detail by Johnson (1978) who defined it as a marine-dominated deltaic sequence. He concluded that the considerable increase in thickness towards the northwest is a result of both variation in depositional thickness and the presence of a south-dipping unconformity at the base of the Grønneset Formation. The unconformity beneath the Ekkerøy Formation marks a significant hiatus (Røe 1975), as also indicated by microfossil assemblages (Vidal 1981).

At this point it should be mentioned that, based on a suggested correlation between the Ekkerøy Formation and a lithostratigraphic unit (Brennelvfjord Member) near Lakselv,

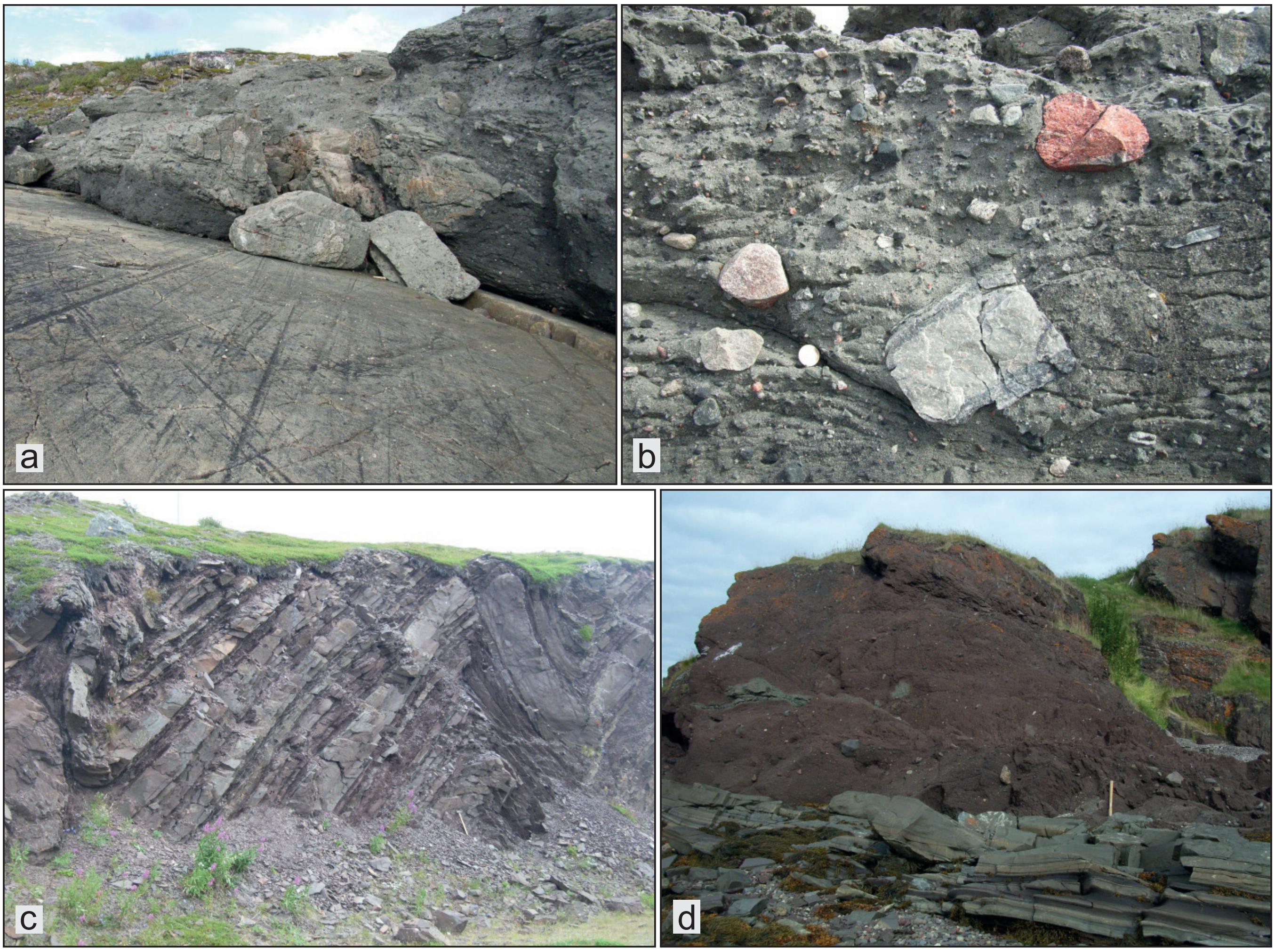

Fig. 5. (a) Diamictite (tillite) of the Smalfjord Formation, also known as "Reusch's moraine", lying upon glacially striated sandstone of the Veidnesbotn Formation at the headland Oiabáccanjarga, western Varangerfjorden. (b) A close-up of the diamictite at the same locality showing the variable clast composition, size and angularity. (c) Roadside exposure of Nyborg Formation sandstones and shales deformed by Caledonian folds, c. 2 km west of Mortensnes, Varangerfjorden. (d) Diamictite of the Mortensnes Formation lying upon sandstones of the Nyborg Formation, at the headland Handelsneset (Mortensnes), Varangerfjorden. The localities are shown in Figure 2.

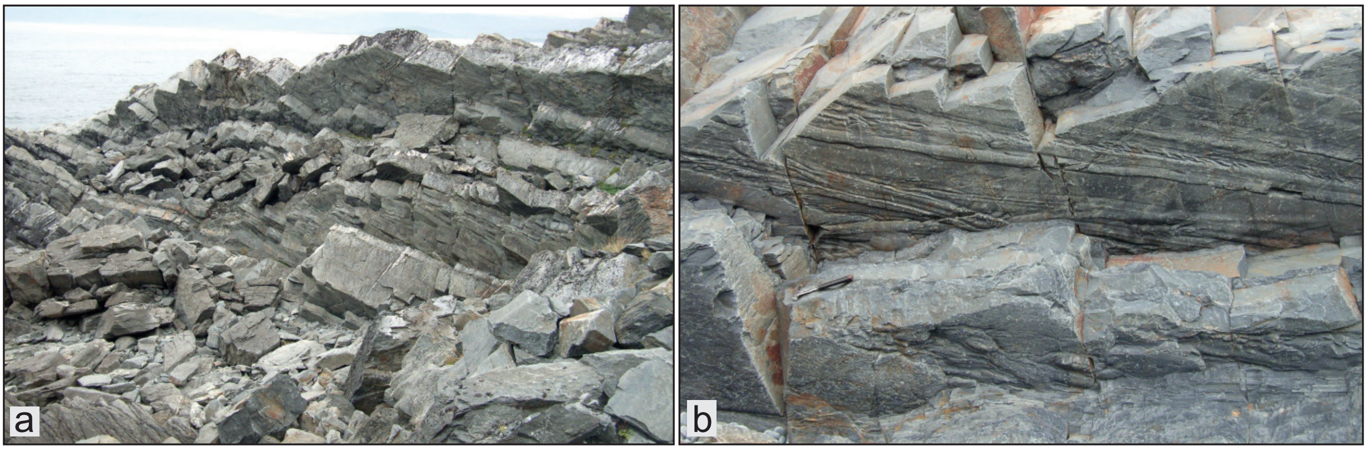

Fig. 6. (a) Kongsfjord Formation; characteristic thick-bedded greywacke with intercalations of siltstone and mudstone, locality in Risfjorden, western Kongsfjorden. (b) Groove casts, frondescent marks and other sole structures on the bottom surfaces of two beds of greywacke. Kongsfjord Formation, c. 5 km north of the fishing settlement Kongsfjord. The locality is shown in Figure 2.

Porsangerfjord, Rice & Townsend (1996) proposed that the Ekkerøy Formation be renamed, informally, as the Ekkerøya (Ekkerøy) group. These authors described in some detail their reasons for suggesting a change in the lithostratigraphic terminology, while at the same time (op cit p. 69) noting that "a direct correlation of the two units is not strictly valid". In view of the speculative nature of this suggested correlation we prefer to retain the name Ekkerøy Formation, which is a clearly definable, thin, mappable unit over most of Varanger Peninsula as shown on several 1:50,000 bedrock map-sheets (e.g., Siedlecka & Roberts 2009, Siedlecka et al. 2020).

The Lille Molvika formation, Mánjunnás area

In the early period of mapping and establishing a lithostratigraphy for the successions underlying Varanger Peninsula, a sedimentary unit, temporarily and informally named the *Lille Molvika formation,* was recorded in the tectonically complicated area southwest of the westernmost part of the TKFZ close to Tanafjorden, and a brief description given by Siedlecka & Siedlecki (1972, p. 356). In this description, the uppermost part of the Båtsnæringen Formation (c. 1300 m) and lower parts of the Båtsfjord Formation (c. 1200 m) were identified, these being succeeded upwards by 200 m of siliciclastic rocks tentatively believed to be equivalents of the Tyvjofjellet Formation at the top of the Barents Sea Group. The actual contact was nowhere exposed, however, and its nature could therefore not be described. This 200 m-thick siliciclastic unit is overlain by the Grønneset Formation of the Tanafjorden Group. However, it was pointed out that similar lithologies had previously been observed at other localities in the TVR (Føyn 1937, Siedlecka & Siedlecki 1971) where their substratum was not exposed. This unit -- the Lille Molvik formation -- was later correctly identified as the Ekkerøy Formation (Johnson 1978); but unfortunately, the basal contact with the rocks of the Barents Sea Group was then reinterpreted as tectonic (Johnson et al. 1978, see above, Siedlecki 1980). Subsequently, A.H.N. Rice (written communication, 2007, copied from his field notebook) re-examined the rocks of the Ekkerøy Formation and focused on the lower and upper contacts with the adjacent rocks. It was clear from his description that the contacts are *erosional,* the lower one with up to 25 cm of relief and with channels cut into higher units of the Båtsfjord Formation; and with channel infill breccias composed of both angular intrabasinal clasts of red sandstone and subrounded extrabasinal clasts of vein quartz. This breccia is overlain by a 15 cm-thick ferruginous breccia. Rice (1994) had already earlier clearly stated that this breccia marks the base of the Ekkerøy Formation, thus agreeing with the interpretation reached by us and Russian colleagues in 1991. As a result of all the new field investigations during the 1990s, the rocks directly beneath the erosional base of the Ekkerøy Formation were subsequently ascribed to the Skovika Member of the Båtsfjord Formation on the 1:50,000 map-sheet Trollfjorden (Siedlecka et al. 2009). Clearly, the sedimentary rocks of the Barents Sea Group had been lithified and tilted at some point in Cryogenian time before uplift and erosion heralded the major transgression which gave rise to deposition of the Ekkerøy Formation.

While working on the sedimentology and development of the Annejohka Member (lower Båtsfjord Formation) and looking for stromatolites present in other sections of the BSR, Siedlecka (1978) reported that in the Mánjunnás area (Fig. 2) (then called by her the 'Posthøyden' area, a name used on older topographic maps to show the 'postman's route' from Tana to Trollfjorden) the member is only c. 100 thick, consists of dark shales with a few dolomitic beds and does not contain stromatolites. Its contact to the overlying siliciclastic rocks was not exposed in the examined section and this relationship was therefore unclear. The 'Mánjunnás area' (M in Fig.2), as named by Rice (1994), is located southwest of the TKFZ and exposes the only known occurrence of rocks of the Barents Sea Group within the TVR. These BSG rocks are thus located within the Gaissa Nappe Complex. It is appropriate to mention here that the locality Mánjunnás actually lies outside Rice's 'Mánjunnás area', which is thus a misnomer. However, we retain the name here for the purpose of convenience since there are no other geographical names on official maps in the actual area.

Biostratigraphic evidence in the TVR

Diverse organic-walled microfossils and the foraminifer *Platysolenites antiquissimus,* together with a variety of trace fossils, present in the successions of the TVR (Føyn 1967, Hamar 1967, Banks 1970, Vidal 1981, Crimes & McIlroy 1999, Högström et al. 2013) have provided quite reliable biostratigraphic evidence for the age of several formations and members in this part of Varanger Peninsula. Along with the well-documented Cambrian to Tremadocian body fossils in the conformably overlying successions on the nearby Digermulen Peninsula (Henningsmoen 1961, Reading 1965, Føyn 1967, Nikolaisen & Henningsmoen 1985), and the presence of diamictites in the lower half of the Vestertana Group, the Neoproterozoic age of the rocks of this region had thus been confirmed. Some uncertainty remained, however, over the precise ages of the oldest formations in the Vadsø Group.

Biostratigraphy based on microfossils, the discoidal Ediacara biota and an abundant ichnofauna have thus helped to refine the chronostratigraphic scheme for this region (Banks 1970, 1973, Vidal 1981, Farmer et al. 1992, Vidal & Moczydlowska 1995, Crimes & McIlroy 1999, Högström et al. 2013, Jensen et al. 2018). Vidal (1981, p. 81) presented an interregional correlation for Scandinavia and Russia, assigning the Vadsø Group to the Upper Riphean (Tonian to Late Cryogenian) and the remainder of the overlying succession up to the base of the Cambrian within the Breidvika Formation, to the Vendian period. More recently, Högström et al. (2013) have suggested that the base of the Cambrian should be lowered to the uppermost part of the Stáhpogieddi Formation (Fig. 3).

In addition to the diverse macro- and microfauna mentioned above, columnar algal stromatolites occur in the Grasdalen Formation in the westernmost TVR in the Gaissa Nappe. Although not indicating any definitive age, it has been suggested that these particular stromatolites are most likely to be late Cryogenian (Bertrand-Sarfati & Siedlecka 1980). This age assignment would appear reasonable considering that the Grasdalen Formation lies just beneath the Ediacaran diamictites of the Smalfjord Formation (Fig. 3).

Biostratigraphic evidence in the BSR

In the BSR, on the contrary, the biostratigraphic evidence is scarce and therefore of little use for a reliable consideration and refinement of the age of the succession. Hitherto, the only useful evidence was provided by poorly preserved microfossils from the Ánnejohka Member of the Båtsfjord Formation (Vidal & Siedlecka 1983), some of which may be a result of redeposition. In this paper (*op. cit.*, pp. 70-71), the authors concluded that the Upper Riphean-Vendian boundary is quite likely to be located within the lower Båtsfjord Formation, basing their conclusion on the presence of assemblages of certain diagnostic taxa. An uncritical acceptance of this conclusion has thus led researchers into regarding the Løkvikfjellet Group as most likely of Vendian (Ediacaran) (Vidal & Siedlecka 1983, Siedlecka & Lyubtsov 1997) or even Cambrian age (Rice et al. 2012). The suggested location of this important Cryogenian-Ediacaran boundary, however, contradicts the field relationships described above and is therefore in need of reassessment. This problem has already been pointed out by Roberts & Siedlecka (2012) and a late Tonian to Cryogenian age for the Løkvikfjellet Group,

Fig. 7. The angular unconformity between the Båtsfjord Formation of the Barents Sea Group and the overlying Sandfjord Formation of the Løkvikfjellet Group; cliff locality in southeastern Båtsfjorden, looking c. northeast. The locality is shown in Figure 2.

based on detrital zircon analytical data (p.10), now seems much more likely. Stromatolites also occur in the Annejohka Member of the Båtsfjord Formation in several areas of the BSR but are of the non-columnar domal type. Descriptions of the Ánnejohka stromatolites are given in Siedlecka (1978, 1982).

Isotopic ages in the TVR

The precise depositional ages of most of the formations in the TVR are unknown, largely because no dateable volcanogenic lithologies, such as tuffs, have yet been found. An early radiometric study utilising the Rb-Sr whole-rock method gave an isochron age of 807 ± 19 Ma (Pringle 1973, corrected in Sturt et al. 1975) for shales of the Klubbnasen Formation. In the same study, a weighted mean isochron age of 668 ± 23 Ma was reported for the Nyborg Formation. Subsequently, Gorokhov et al. (2001) documented an age of diagenesis for the Nyborg of c. 560 ± 28 Ma based on Rb-Sr dating of illite subfractions. These same authors interpreted the glaciogenic events on Varanger Peninsula to be bracketed between c. 630 and c. 560 Ma. Another study on the Nyborg Formation, using the $^{40}Ar/^{39}Ar$ method on illite, produced a diagenetically related 'disturbance' age of c. 635 Ma (Dallmeyer & Reuter 1989). Here, it is appropriate to mention that the Smalfjord and Mortensnes glaciogenic events have been postulated to equate with the Marinoan (c. 636 Ma) and Gaskiers (c. 580 Ma) glaciations on other continents (Rice et al. 2012, Pu et al. 2016) but as yet there are no precise age constraints on the diamictites from Varanger Peninsula. However, a recent U-Pb dating on baddeleyite from a dolerite in the Ottfjället Dyke Swarm of the Middle Allochthon in Härjedalen, west-central Sweden, yielded a robust age of 596.3 ± 1.5 Ma (Kumpulainen et al. 2021). The dolerite intrudes a succession containing two separate diamictites which have been correlated with two diamictites in the Moelv area of southeastern Norway and also with the Smalfjord and Mortensnes diamictites of Varanger Peninsula (Kumpulainen 2011, Nystuen & Lamminen 2011). The implication of this correlation and dolerite dating is that the Mortensnes Formation cannot equate with the Gaskiers but is a part of a pre-596 Ma two-stage Varangerian glaciation broadly equivalent to the worldwide Marinoan event.

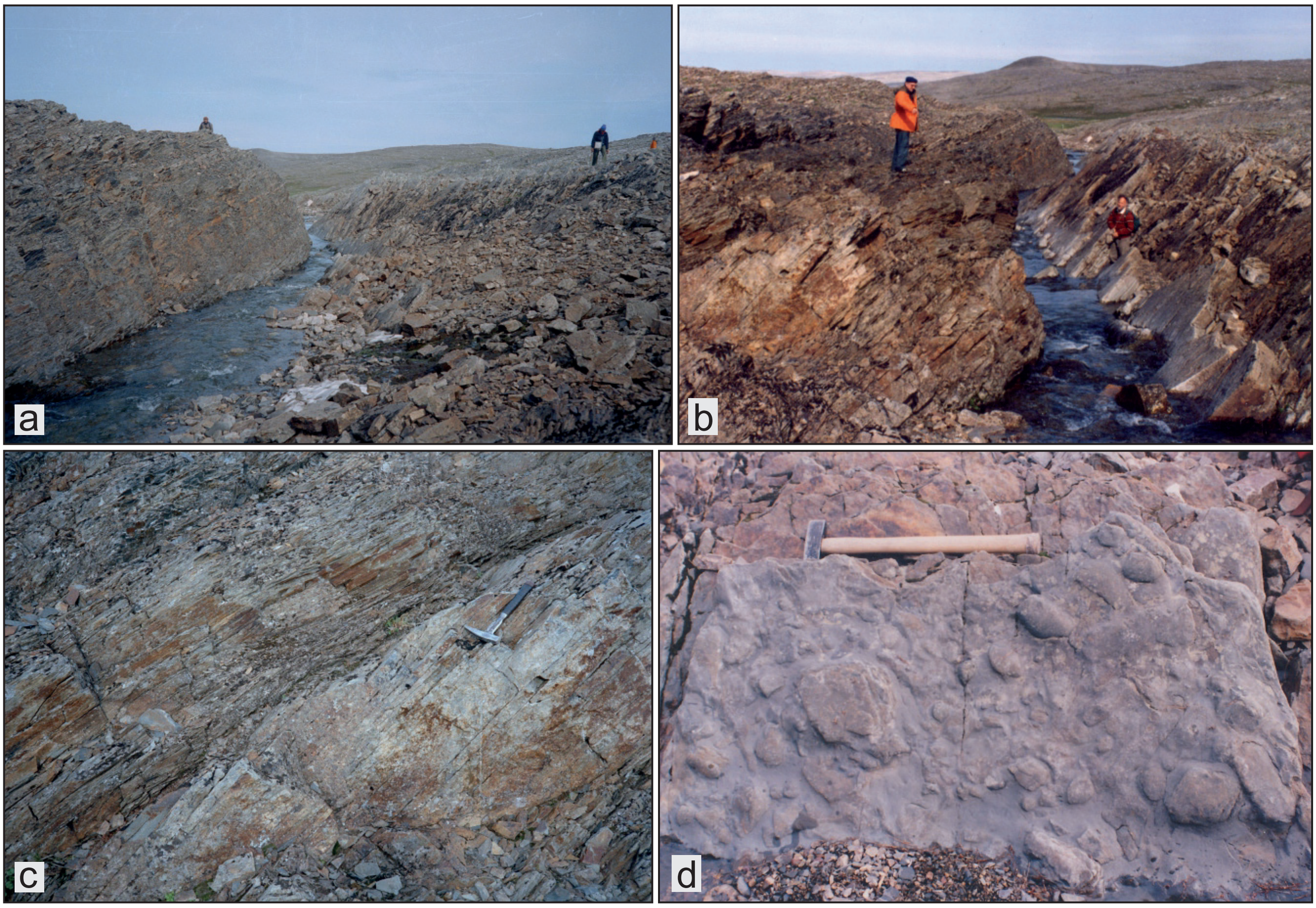

Fig. 8. The important locality in the Mánjunnás area, marked by a small open-square symbol in Figure 2. (a) General view, looking northeast, showing the stream Ávgajohka separating steeper-dipping strata of the Skovika Member of the Båtsfjord Formation to the right from rocks of the Ekkerøy Formation to the left. (b) Here, the stream has eroded into the thin-bedded Skovika sandstones, leaving the actual unconformity in the left-hand part of the photo. The late Valery Lyubtsov (in orange jacket) is standing on the gentler-dipping Ekkerøy Formation. (c) Close-up of part of the unconformable contact between the Skovika Member and the Ekkerøy Formation. Here, the apparent angular difference between the bedding in the two units is about 20°, but the true angle is close to 35°. (d) Conglomerate at the base of the Ekkerøy Formation, Ávgajohka, Mánjunnás area.

Isotopic studies involving detrital minerals from rocks in the TVR have generally yielded either diagenesis ages or wide-ranging ages of deposition from U-Pb zircon analyses for many formations (Gorokhov et al. 2001, Kirkland et al. 2008, Nicoll et al. 2009, Orlov et al. 2011, Roberts & Siedlecka 2012, Zhang et al. 2015). Deposition of formations of the Vadsø Group is considered to range from Tonian to Early Cryogenian, and the Tanafjord Group to be Cryogenian in its entirety (see details in Zhang et al. 2015). The Vestertana Group ranges from very latest Cryogenian (for the tillite of the Smalfjord Formation) through Ediacaran to Early Cambrian, with body fossils confirming the Cambrian age assignment, as noted earlier.

Dolerite dykes occur in the coastal areas between Store Ekkerøya and Komagnes. An initial K-Ar study gave ages of around 350-360 Ma for two of the dykes (Beckinsale et al. 1975). Subsequent, more precise $^{40}Ar/^{39}Ar$ dating of plagioclase from these same mafic dykes yielded crystallisation ages of 375 and 378 Ma (Guise & Roberts 2002).

Isotopic ages in the BSR

As with rocks in the TVR, precise radiometric ages for formations in the Barents Sea Region are lacking. An unpublished Rb-Sr whole-rock isochron age of 810 ± 60 Ma for mudstones in the Kongsfjord Formation has been cited by Siedlecka & Edwards (1980, A.Råheim pers. comm. 1977). A detrital zircon study by Zhang et al. (2015) on this same formation gave a probable Late Tonian to Early Cryogenian age. Orlov et al. (2011) showed a probability plot for detrital zircons from the overlying Båtsnæringen Formation and assigned an approximate age of 740 Ma to the formation but no analytical data or discussion were presented. Two formations in the unconformably overlying Løkvikfjellet Group (Sandfjorden and Styret formations) both gave broad, detrital-zircon, Cryogenian ages, in the range 850-630 Ma (Zhang et al. 2015).

The Kongsfjord Formation has also featured in an attempt to date the slaty cleavage in folded mudstones near Finnvika, Hamningberg, whereby Taylor & Pickering (1981) obtained a Rb-Sr isochron age of 520 ± 47 Ma, which they considered to relate to Caledonian folding. However, judging by the NNW-SSE trend of this fold-related cleavage it is more likely to be Timanian (cf. Roberts 1996, Herrevold et al. 2009). In this same general area, younger Caledonian folds and associated axial-planar cleavage trend NE-SW (Siedlecka & Roberts 2020, Gabrielsen et al., in prep.).

Mafic dykes are common throughout the BSR. Isotopic dating has recognised two age groups, (1) Late Devonian, c. 370 Ma dolerites (Beckinsale et al. 1975, Guise & Roberts 2002), and (2) Ediacaran, c. 577 Ma metadolerites (Beckinsale et al. 1975, Rice et al. 2004). One of the metadolerites cuts the unconformity at the base of the Løkviksfjellet Group.

Chemostratigraphy

Investigations involving the $\delta^{13}C$ values of dolostones in the Vestertana and Tanafjorden groups and comparing the data from Finnmark with the well-established $\delta^{13}C$ curve for the Neoproterozoic era, have provided useful indirect estimates of the ages of the formations and members (Halverson et al. 2005, Rice et al. 2011, 2012). A dolostone at the base of the Nyborg Formation has negative $\delta^{13}C$ values and other features suggesting that this is a Marinoan-type cap dolostone and, by correlation, having an age of c. 635 Ma (Rice et al. 2012). Thin dolostones at the very top of the Nyborg have even lower $\delta^{13}C$ values which compare well with the known Shuram-Wonoka negative anomaly at c. 590 Ma (Condon & Bowring 2011). These particular dolostones lie directly below the Mortensnes Formation which has been accorded an age of c. 584-582 Ma by a speculated correlation with the Gaskiers glaciation (Halverson et al. 2005, Rice et al. 2011). However, high-precision U-Pb geochronology has more recently recorded a robust age of 580-579 Ma for the Gaskiers diamictite at the type locality in Newfoundland (Pu et al. 2016). Also, as noted earlier, the Mortensnes diamictite is now considered to be older than 596 Ma (Kumpulainen et al. 2021).

In the BSR, carbon-isotope data are also recorded from the dolostones of the Annejohka Member of the Båtsfjord Formation. The isotope profile shows negative $\delta^{13}C$ values and it has been speculated that this particular profile may be correlated with that of the c. 800 Ma Bitter Springs Formation of central Australia (Halverson et al. 2005, Rice et al. 2012). Should this suggestion be accepted, then this would indicate that most of the Barents Sea Group is likely to be of Tonian age.

Rybachi and Sredni peninsulas and Kildin Island

In Russian literature, the traditional Russian period or system names Riphean and Vendian for divisions of the Meso- and Neoproterozoic have persisted up to the present day. There has even been a serious proposal forwarded for retaining the name Vendian in the International Chronostratigraphic Chart (Grazhdankin & Maslov 2015). The Riphean alone has either three or four subdivisions with poor age constraints. In some of our latest publications involving lithostratigraphy of areas in Russia we have, however, introduced the internationally accepted chronostratigraphic nomenclature, either directly, with Russian terms in parentheses, or vice versa. We follow this procedure in the text that follows.

Lithostratigraphy of Sredni Peninsula

The Tonian to Cryogenian (Upper Riphean in Russian literature) lithostratigraphcal succession of the Sredni Peninsula, and southernmost part of Rybachi Peninsula south of the SRFZ, shown in Fig. 9, rests nonconformably upon a Neoarchaean granite of the Murmansk Terrane. This primary contact was exposed by excavation in a locality in the southeasternmost part of

Fig. 9. Geological map of the Rybachi and Sredni peninsulas. This is a colour version of a black & white map first shown in the Russian publication of Negrutsa (1971) and modified slightly in Roberts (1995). The Skarbeevskaya Formation in the northwest is delimited by a moderately steep, SW-dipping reverse-fault, indicated by the traditional tags on the upthrust side. The small open-square symbol in the Motovskaya Formation indicates the locality for the two photos in Figure 11.

the peninsula (Siedlecka et al. 1995a). The complete succession, totalling c. 1900 m in thickness and representing a platformal domain akin to the TVR, is divided into two groups (Kildinskaya and Volokovaya) of mainly siliciclastic sedimentary rocks, though with laminated dolomites in the highest formation of the Kildinskaya Group. Four depositional sequences separated by angular unconformities are recognised in the succession (Negrutsa 1971). The separate sequences are considered to reflect lowstand, transgressive and highstand situations, mostly dominated by progradational developments, but the highest (the entire Volokovaya Group) exhibits an overall retrogradational trend. Details are given in Siedlecka et al. (1995a).

Although only 60 km apart along strike, the Tonian to Cryogenian successions of the TVR and of Sredni Peninsula show considerable differences in their development at formation level such that a straightforward lithostratigraphical correlation is fraught with difficulty. Nevertheless, collaboration and field discussions between Norwegian and Russian geologists in the 1990s resulted in agreement that the Vadsø Group of the TVR is likely to be broadly equivalent to the Kildinskaya Group, whereas the Volokovaya Group seems to correspond to the lower Tanafjorden Group (Siedlecka et al. 1995a).

Lithostratigraphy of Kildin Island

The Kildinskaya Group is also represented on Kildin Island where it is 1300 m thick and is divided into seven formations of mainly terrigenous siliciclastic rocks and interpreted in terms of transgressive-regressive episodes (Lyubtsov et al. 1989). Dolostones bearing several forms of columnar stromatolites in bioherms (Fig. 10) occur in the second and fourth lowest formations (Lyubtsov 1975, Raaben et al. 1995, Samuelsson 1997), but such carbonate rocks are not present at this level on Sredni. Direct detailed correlation with the succession on the Sredni Peninsula, as suggested by Russian workers, is therefore speculative.

Lithostratigraphy of Rybachi Peninsula

The 4000 m-thick continuous succession on Rybachi Peninsula, north of the SRFZ, is considered to be of Tonian-Cryogenian age. It comprises two groups, the lower Einovskaya and overlying Bargoutnaya, each divided into three formations (Fig. 9) consisting of grey turbiditic sandstones, conglomerates and cleaved shales or mudstones (Negrutsa 1971, Siedlecka et al. 1995b). In addition, there is a separate unit of similar lithologies in the northwest of the peninsula, the Skarbeevskaya

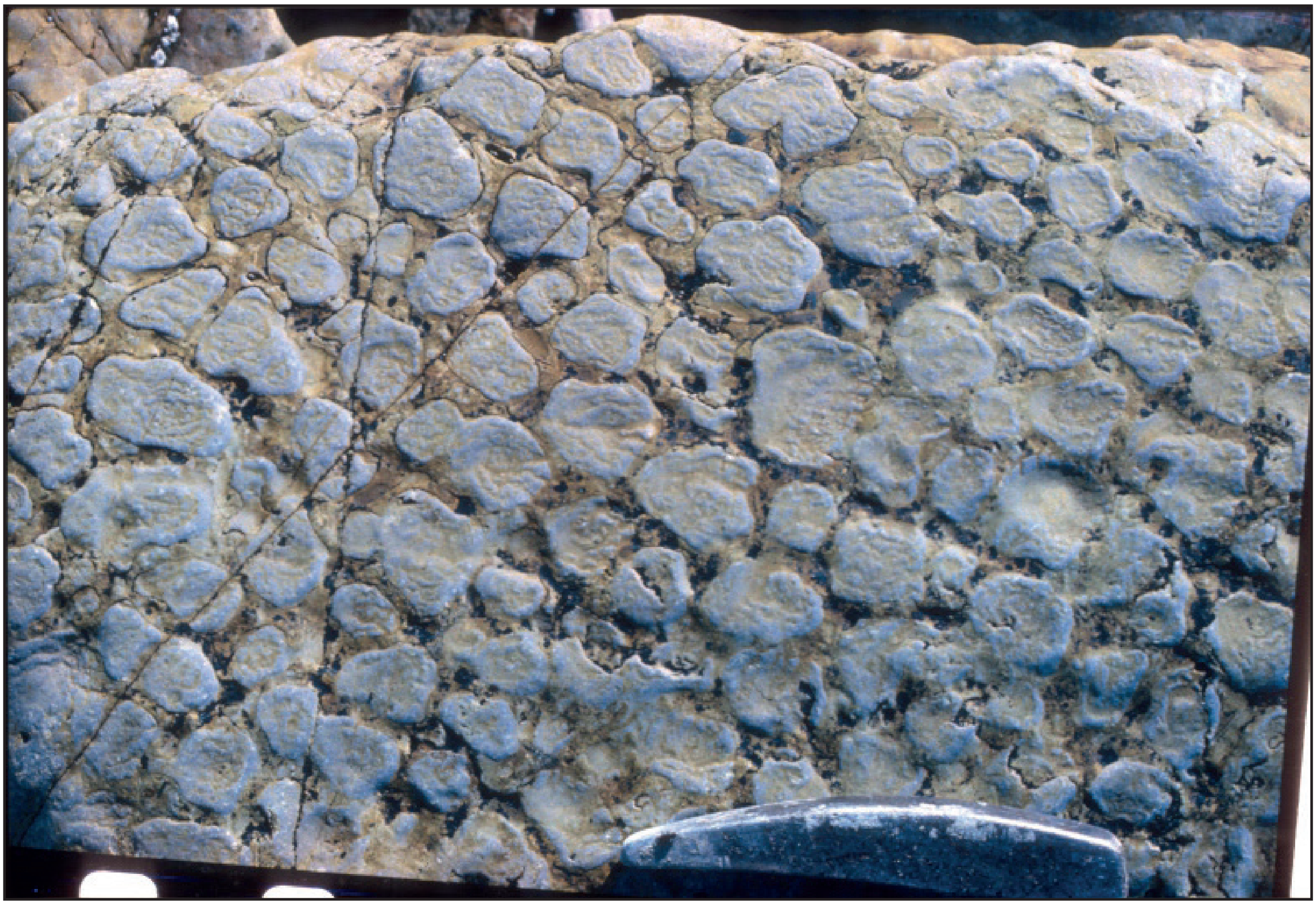

Fig. 10. Weathered top surface of a bioherm consisting of branched columnar stromatolites, from the Korovinskaya Formation of the Kildinskaya Group, Kildin Island. The photographed surface is roughly orthogonal to the long axes of the stromatolites and from the central part of the bioherm. The stromatolites here comprise the genus Gymnosolen (Krylov & Lyubtsov 1976, Raaben et al. 1995). Hammer-head at the bottom of the photo for scale.

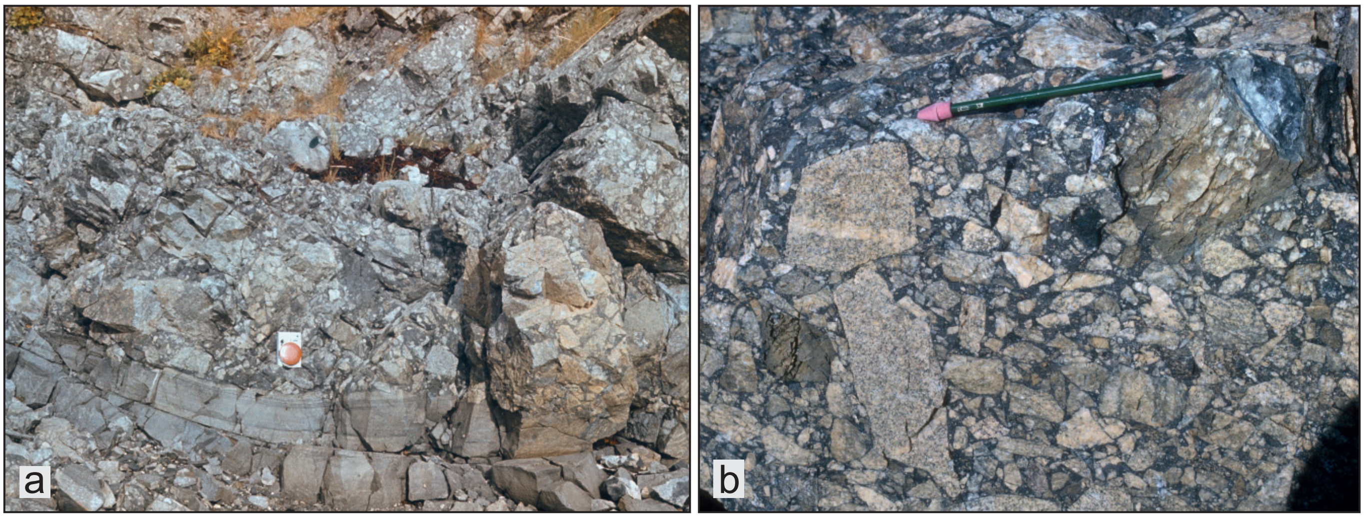

Fig. 11. The Motovskaya Formation olistostrome, near the base of the formation; locality on the foreshore at the innermost northern arm of the Motovsky Gulf (marked with a small open-square symbol in Fig. 9). (b) The same olistostrome at the same general locality but a few metres higher up in the unit. The angularity of the blocks and clasts is striking. Most of the blocks and smaller fragments are of granites, granodiorites and various gneisses of basement origin, but there are slabs of sandstone near the bottom of Figure 9a.

Formation, with a reverse-fault contact against all other formations (Fig. 9).

The complete sedimentary succession on Rybachi, part of the basinal domain as with the Barents Sea Group, is interpreted as a submarine proximal turbidite system consisting mainly of high-density turbidites. At the very base of the Einovskaya Group, the Motovskaya Formation consists of an olistostrome-breccia with both angular and rounded extrabasinal blocks (Fig. 11) and boulders up to several metres across, and with one granite block over 100 m in diameter (Siedlecka et al. 1995b). Deposition of the olistostrome, following a pulse of footwall fragmentation, evidently occurred down the submarine escarpment of an active, fault-controlled margin of the developing basin in which the turbidite system accumulated. The 'Rybachi Turbidite System' as a whole exhibits a major retrogradational development and terminates with upper-slope deposits. The age and regional geological location of the turbidite system on Rybachi suggest that it is a correlative of the Kongsfjord Submarine Fan-slope system of the Barents Sea Region of Varanger Peninsula (Siedlecka et al. 1995b).

Unlike the Sredni and Kildin successions, which show mainly compactional deformation in diagenesis-grade conditions, the formations on Rybachi were metamorphosed in anchizone conditions (Rice & Roberts 1995) and deformed into NW-SE-trending, open to tight folds overturned to the southwest, with a penetrative axial-plane slaty cleavage (Roberts 1995, Roberts & Karpuz 1995). This SW-directed compressional deformation is coeval with basin inversion during Ediacaran, Timanian orogenesis, which also included thrust reactivation of the original normal fault now represented by the SRFZ. A small component of sinistral oblique-slip movement has also been recorded along the SRFZ at this time. Similarly oriented folds and cleavage are widespread in the eastern part of the BSR on Varanger Peninsula, in places overprinted by Caledonian structures (Roberts 1996, Herrevold et al. 2009, Gabrielsen et al. in prep.).

Biostratigraphic evidence

Microfossils and columnar stromatolites on Kildin Island and in parts of the Sredni Peninsula have been described (in Russian) by Lyubtsov (1975) and Lyubtsov et al. (1989). A more detailed study of acritarchs, prasinophytes and cyanobacterial filaments was presented by Samuelsson (1997), and the columnar stromatolites on Kildin have been redescribed by Raaben et al. (1995); and based on the presence of typical form-genera are considered to be of latest Riphean (Cryogenian) age.

Well-preserved acritarchs from the Kildinskaya Group on both Sredni and Kildin have the highest taxonomic diversity and provide a well-constrained Late Riphean age. The Volokovaya Group is assigned a probable latest Riphean (Cryogenian) age (Samuelsson 1995, 1997). Unfortunately, very few taxa were recorded from the turbiditic formations on Rybachi Peninsula. Those recovered from the Skarbeevskaya Formation are weakly indicative of a terminal Riphean (Late Cryogenian) age (Samuelsson 1997).

Isotopic ages

There are relatively few isotopic ages reported and those available have quite low precision. K-Ar ages on glauconite from the three lowermost formations in the Kildinskaya Group on Sredni are mostly in the range 1050-670 Ma. A Pb-Pb study on phosphorite clasts in a conglomerate at the base of the Volokovaya Group gave an age of 830 ± 68 Ma (Negrutsa 1971). These clasts are probably derived from phosphorites in the Kildinskaya Group (Siedlecka 1995).

In an initial U-Pb study of detrital zircons from the Sredni Peninsula, sandstones from both the Zemlepakhtinskaya and the Kuyakanskaya formations yielded mostly Palaeoproterozoic and Mesoproterozoic zircon ages with just a few Archaean grains (Mikhailenko et al. 2016). The mean weighted ages of the three youngest zircon grains are late Stenian, circa 1086-1041 Ma. On Rybachi, detrital zircons from just one formation, the Lonskaya, have been analysed. Most grains are Neoarchaean to Palaeoproterozoic, 2.7 – 1.8 Ga. The youngest single zircon grain so far encountered has an age of c. 1350 Ma (Mikhailenko et al. 2016). The sources of the sandstones in all three formations are considered by these authors to be diverse crystalline complexes to the south on the Fennoscandian Shield.

In a Rb-Sr study of multistage illite generation in shales on Sredni Peninsula, Gorokhov et al. (1995, 2002) reported a maximum age of 570 Ma for the very fine (<0.1 μm) illite subfraction that is inferred to have developed in association with basin inversion and thrusting along the SRFZ. Subfractions of c. 0.2 μm mean size formed at about 620-610 Ma during burial and early diagenesis. Coarser illite subfractions, interpreted as detrital, gave ages of 834-807 Ma.

Discussion

After the pioneering investigations of Reusch (1891), Holtedahl (1918) and Føyn (1937), and the stratigraphical contributions by researchers and students from the University of Oxford on the Digermulen Peninsula, the systematic programme of geological mapping on Varanger Peninsula initiated by the Geological Survey of Norway in 1967 had, as its main objective, the production of 1:50,000 bedrock geological maps. To achieve this aim, careful mapping, examination of contacts between lithological units and sedimentological studies gradually led to the establishment of a formal lithostratigraphy (updated in Fig. 3). The very first and perhaps the most important result at this stage of the work was the discovery of the TKFZ, a major geofracture separating the southwestern from the northeastern half of the peninsula. At this early stage of investigations, the stratigraphic relationship between the sedimentary successions underlying the two separate areas remained unknown. What we did know then was Reusch's (1891) interpretation of conglomerates in innermost Varangerfjorden as tillites; and Holtedahl's (1918) discovery of a major hiatus and low-angle unconformity below one of the tillites. The stratigraphical work of Reading (1965) on the nearby Digermulen Peninsula (Fig.1) where discoveries of Cambrian and Tremadocian body fossils had been recorded (Henningsmoen 1961), was also an important step forward.

As mapping progressed on Varanger Peninsula, it became clear that the oldest sedimentary rocks in the TVR lay in the south, namely the Vadsø Group. The lowest Veidnesbotn Formation, of fluvial origin, is exposed at the southwestern end of Varangerfjord where it lies with marked unconformity upon Neoarchaean orthogneisses (Siedlecka & Roberts 2016). Just a few kilometres to the east, a 75 m-thick isolated unit of sandstones (termed the Lattanjárga unit; Rice et al. 2001) also lies directly upon the gneisses and may possibly be slightly older than the Veidnesbotn Formation. Whatever the case, the oldest sedimentary rocks of the Vadsø Group, which derive from a southerly source area, are clearly overlying Neoarchaean basement.

In the TVR, the base of the Vadsø Group also represents a sequence boundary marking a prominent hiatus with extensive erosion of the gneissic substratum. Within the Vadsø Group as a whole there are at least three depositional sequences separated by erosional surfaces or angular unconformities (Siedlecka et al. 1995a). The Ekkerøy Formation alone is a separate depositional sequence, preceded by subaerial exposure and erosion prior to marine flooding. Another unconformity occurs at the top of the Ekkerøy Formation, at the base of the Grønneset Formation of the Tanafjorden Group (Fig. 3). The sequence-stratigraphic architecture of the Tanafjorden Group is complicated by several transient retrogradational-progradational phases and terminates with a very well-defined sequence boundary beneath the tillite of the Smalfjord Formation. The old land surface beneath this unconformity is characterised by deeply incised palaeovalleys (Edwards 1984), carved out in a long-lasting erosional event that has removed large parts of the Vadsø Group. Erosion beneath the Mortensnes diamictite has locally resulted in this unit lying directly upon the Smalfjord Formation, excising the Nyborg, whilst elsewhere in areas close to innermost Varangerfjord the Nyborg Formation is sitting with primary contact directly upon Archaean basement (Siedlecka & Roberts 2016). The Varangerian glaciogenic period was clearly one characterised by both variable topographic relief and upper-crustal instability, and probably signifying the early stages of the encroaching Timanian orogeny farther to the northeast.

In the basinal domain of the Barents Sea Region, northeast of the TKFZ, no basement of any kind has been found beneath the 9-10 km-thick Barents Sea Group (Siedlecka 1972). The basal Kongsfjord Formation comprises deep-marine submarine-fan turbidites succeeded upwards by deltaic to delta-plain deposits of the Båtsnæringen Formation (Siedlecka & Edwards 1980) and intertidal to supratidal pond successions of the lower, Ánnejohka Member of the Båtsfjord Formation with non-columnar stromatolites (Siedlecka 1978, 1982). In the upper, Skovika Member of the Båtsfjord Formation there are sandstones, shales and thin dolomites which pass up into pink and red sandstones of the Tyvjofjellet Formation, either of shallow-marine or fluvial origin.

Stratigraphic relationships between the successions of the BSR and TVR are found only in the Lille Molvika-Mánjunnás area in the northwesternmost part of the TVR in the Gaissa Nappe Complex (Fig. 2). There, a unit informally named the Lille Molvika formation in the early 1970s was subsequently identified as the Ekkerøy Formation (Johnson 1978), which lies with angular unconformity (Rice 1994) upon the Skovika Member of the Båtsfjord Formation (Siedlecka &

Roberts 2009). Detailed geological mapping in that area had thus shown that the 'missing link' had been revealed, and that several members of the Båtsfjord and Båtsnæringen formations occur to the southwest of the TKFZ beneath the basal unconformity of the Ekkerøy Formation. Restoration studies of the Gaissa Nappe based on balanced sections have indicated that the rocks of the Lille Molvika-Mánjunnás area would have been situated roughly 100 km to the northwest of their present position, but southwest of the TKFZ, prior to Caledonian thrusting (Townsend et al.1986. Townsend 1987, Gayer et al. 1987). Rocks northeast of the TKFZ in the BSR basinal domain, on the other hand, would have then been located c. 100 km even farther to the northwest, beyond where Magerøya is positioned today, with the Rybachi basinal successions lying approximately where we see the Nordkinn Peninsula today (Roberts & Siedlecka 2012, figure 8; see also Rice 2014, figure 5). Interestingly, an outlier of the Timanide orogenic belt has been reported from southern Spitsbergen (Mazur et al. 2009) and Timanide volcanic rocks from North Greenland (Estrada et al. 2018).

The relationship between rocks of the BSR and TVR described above indicates that the formations of the BSG were lithified and weakly deformed prior to uplift and erosion before the major transgression that gave rise to deposition of the Ekkerøy Formation. The age of this comparatively minor deformation phase and ensuing uplift is likely to be Early Cryogenian based on data gained from detrital zircon studies (Orlov et al. 2011, Roberts & Siedlecka 2012, Zhang et al. 2015). This deformation event, with tilting of lithified formations of the Barents Sea Group, is also recognised in the Båtsfjorden area of the BSR where the Sandfjorden Formation of the Løkvikfjellet Group lies with angular unconformity upon the BSG (Fig. 7). Deposition of the Løkvikfjellet Group is likely to have occurred at several tens of kilometres to the northwest of the present-day island of Magerøya, prior to the dextral strike-slip translation of the rocks of the Barents Sea and Løkvikfjellet groups to their present position during the Caledonian orogeny (Rice et al. 1989b, Bylund 1994, Roberts & Siedlecka 2012, Rice 2014). It is of interest here to recall that Kirkland et al. (2006) have recorded geochronological evidence in the Kalak Nappe Complex in western Finnmark for a deformation event at 710 Ma, i.e., in earliest Cryogenian time.

The general situation regarding the relationship of lithostratigraphic successions to basement in the platformal and basinal domains of the Sredni and Rybachi peninsulas is similar to that on Varanger Peninsula. On Sredni, the basal pebbly sandstones of the fluvial Kutovaya Formation (Fig. 9) lie nonconformably upon a Palaeoproterozoic gneissic granite (Negrutsa 1971); and in the entire lithostratigraphic succession four depositional sequences have been recorded (Siedlecka et al. 1995). On Rybachi, however, in the deep-marine basal domain, there is no crystalline basement exposed, akin to the situation in the BSR. The oldest unit, the Motovskaya Formation, is for the most part a spectacular olistostrome-breccia (Fig. 11) deriving from fragmentation of the footwall to a precursor fault of the SRFZ, and most likely ascribed to seismic activity at that time.

Carbonate rocks are scarce in all the successions described above both in the Varanger Peninsula and in Sredni, Rybachi and Kildin, but where present commonly contain stromatolites; either the columnar algal type in bioherms (e.g., Grasdalen Formation and in formations on Kildin Island) or non-columnar domal forms (e.g., Ánnejohka Member, Båtsfjord Formation). The stromatolites are indicative of a warm, subtropical climate and in the TVR they occur just a few metres below the lower glaciogenic diamictite formation. Even allowing for a long-lasting hiatus beneath the Smalfjord Formation, the climatic fluctuations must therefore have been quite rapid and dramatic in this latest Cryogenian to early Ediacaran time period, with warm interglacials oscillating with the cold glacial periods. This is a topic that has been discussed in many publications, of which the following are merely a brief selection (Kirschvink 1992, Evans 2000, Rieu et al. 2007, Hoffman et al. 2007).

In summary, the mapping and stratigraphical and sedimentological studies undertaken on Varanger Peninsula over the last half century have revealed a succession of events that affected the northeastern margin of the Fennoscandian Shield in Tonian-Cryogenian and into Ediacaran time, predating the Caledonian orogeny. Movements along the major marginal extensional fault, the TKFZ/SRFZ and Central Timan fault farther southeast in the Timans, led to long-lasting denudation of the shield. Sediments sourced in the Archaean complexes of the shield were transported northwards by many rivers into a shallow-marine platformal domain and in turn across the steep, faulted, shield margin into a deep-marine basin as turbiditic submarine fans which gradually gave way in time to deltaic and delta-plain deposition. Many transgressions and regressions are recorded arising from vertical crustal movements that led to the development of several minor and major unconformities in both the platformal and the basinal successions. In early Cryogenian time, one particular unconformity on Varanger involved deposition of the Ekkerøy Formation upon lithified, eroded and weakly deformed strata of the BSG in a zone of overlap between the BSR and the TVR.

Sedimentation in the Barents Sea Region and the Rybachi Peninsula occurred at least 200 km to the northwest of where these successions lie today and were translated into place by dextral strike-slip movements along the TKFZ at an early ductile stage of the Caledonian orogeny (Rice et al. 1989b, Roberts & Siedlecka 2012, Rice 2014). Towards the end of the Cryogenian period a warm subtropical climate favoured the production of stromatolite bioherms in carbonate-bearing formations, but this changed quite dramatically with the sudden advent of the Varangerian glaciations in latest Cryogenian to early Ediacaran time.

Conclusions

Bedrock mapping at 1:50 000 scale on Varanger Peninsula commenced in the 1960s and heralded a period of intense research which has now continued for more than half a century. The entire peninsula is now covered by modern colour-plot bedrock maps at this scale. An initial discovery of the Trollfjorden-Komagelva Fault Zone paved the way for differentiating between a platformal, fluvial to shallow-marine, Neoproterozoic succession in the TVR and a retrogradational, deep-marine, turbiditic to deltaic, basinal succession in the BSR. Based mainly on biostratigraphy and more recently on detrital-zircon analytical data, the successions in both regions range in age from Tonian to late Cryogenian, an exception being the Vestertana Group of the TVR which is mainly Ediacaran, including two diamictites near the base, and ranges up into the lower Cambrian. The diamictites have been considered to correspond with the worldwide Marinoan and Gaskiers glaciogenic events but recent U-Pb geochronology has shown that both the Smalfjord and the Mortensnes formations are likely to pre-date 596 Ma and relate to the two-stage Varangerian glaciation.

The siliciclastic deposits of the TVR were sourced mostly to the south and southeast on the Fennoscandian Shield but a routing reversal (northeast source) occurred close to the top of the Vestertana Group in a foreland basin situation ahead of the rising topography of the Ediacaran Timanide Orogen. In the BSR, the turbiditic to deltaic successions were also sourced from a southerly quadrant prior to an epeirogenic event in inferred early Cryogenian time which led to mild deformation, uplift and erosion of parts of the Barents Sea Group and deposition of the Løkvikfjellet Group above a major angular unconformity.

The relationship between the rocks of the TVR and the BSR can be seen in the Lille Molvika-Mánjunnás area in the northwest of the TVR in the Gaissa Nappe Complex where the Ekkerøy Formation overlies the Skovika Member of the Båtsfjord Formation above an angular unconformity. This unconformity marks a major hiatus, also of inferred early Cryogenian age, whereby the sedimentary rocks of the BSG were lithified, weakly deformed, uplifted and eroded before deposition of the Ekkerøy Formation.

In nearby Northwest Russia, the Tonian to Cryogenian, platformal, sedimentary successions on Sredni Peninsula compare reasonably well with those in the TVR. The Kildinskaya and Vadsø groups may be broadly time-equivalent whilst the Volokovaya Group has features in common with lower formations of the Tanafjorden Group. No tillites have been recorded on Sredni. The siliciclastic strata on Rybachi Peninsula are mainly of retrogradational submarine-fan origin, similar to the Kongsfjord Formation in the BSR, terminating with upper-slope deposits. A distinctive olistostrome-breccia marks the very base of the succession on Rybachi, deriving from disintegration of the footwall of the precursor fault to the SRFZ.

The succession on Rybachi was deformed and weakly metamorphosed during the Ediacaran Timanian orogeny, which involved inversion of the deep-water basin. Comparable NW-SE-trending folds and associated slaty cleavage are ubiquitous in the easternmost thrust sheet of the BSR. These structures are overprinted by NE-SW-trending, Caledonian folds and small thrusts which become more dominant farther to the northwest in higher thrust sheets of the BSR. In Ediacaran time, the epicontinental basin southwest of the TKFZ functioned as a foreland basin in receiving detritus from the developing Timanide orogen.

Clearly, enormous progress has been made over the last five decades in our understanding of the geology of Varanger Peninsula, and in more recent time also in the Neoproterozoic successions of the Rybachi and Sredni peninsulas and Kildin Island. It is therefore hoped that this state-of-the-art review will stimulate research among the next generation of geoscientists working in these Arctic regions.

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