Late Precambrian Stratigraphy and Structure of the North-Eastern Margin of the Fennoscandian Shield (East Finnmark - Timan Region)

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Late Precambrian (Riphean and Vendian) rocks occur along the north-eastern margin of the Fennoscandian Shield and the Russian Platform in three zones: 1) the Varanger–Kildin, 2) the Timan–Kanin and 3) the Southern Barents Shelf zones. The last occupies an intermediate position and is entirely covered by the sea.

Varanger–Kildin and Timan–Kanin inter-zonal sedimentary facies comparisons suggest a correlation between the miogeosynclinal sequence of the former zone and the succession of strata of the Central Timans regarded as marginal miogeosynclinal in origin. The internal miogeosynclinal facies of the Timans may be expected to occur in the deep substratum of the Southern Barents Shelf while equivalents of the pericratonic deposits of the Varanger–Kildin Zone may possibly be hidden beneath the Palaeozoic strata of the Russian Platform, assuming that the SW–NE margin-to-basin facies distribution constitutes a regional feature. The linear macro-facies distribution is suggested to reflect the development of a NW–SE trending continental margin to the Fennoscandian Shield at the beginning of the Middle Riphean; the basin has been filled with sediments during the Middle and Upper Riphean.

Geochronological investigations have shown that an early metamorphism of the accumulated deposits in the Kanin–Timan region and of intrusions of gabbroic rocks was essentially completed around 640–620 m.y. Igneous activity extended until ca. 500 m.y. with a second metamorphism around 525–520 m.y. This outline of the sedimentary and structural history of the Varanger–Kanin–Timan Region indicates that the Timanian Fold Belt, embracing the Timans proper, the Kanin Peninsula and its northwestward continuation, has originated during the Baikalian Orogeny pre-dating the Caledonian orogenic movements. The continuation of the internal portion of the orogen is inferred to be hidden beneath the southeastern Barents Shelf, its outer, peripheral portion cropping out in the Varanger–Kildin zone.

The lateral, cross-strike extent of the Timanian Baikalides is as yet uncertain. Alternative structural models suggested by Russian workers for the area embracing not only the Timans but also the Northern and Polar Urals and the Barents Shelf are essentially dependent upon the interpretation of the nature of the Pechora Basin substratum. According to one model, the miogeosynclinal Riphean beds of the Timans have their eugeosynclinal equivalents in the substratum of the Pechora Basin and in the Urals and are thought to have been deposited in an extensive Timanian–Uralian geosyncline. A second model, accepted here, suggests the substratum of the Pechora Basin to be pre-Riphean in age, thus inferring the occurrence of two depositional basins, Uralian and Timanian, separated from each other by an older craton.

The narrow orogenic belt of the Timanian Baikalides is oriented roughly transversely to the Scandinavian Caledonides in the west and to the Uralides in the east. In their relatively simple and short history the Timanides contrast with these major Caledonian and Uralian orogenies which were related to two extensive ancient oceans. Both the Proto-Atlantic and Uralian Oceans opened sometime in the Upper Precambrian; the opening of the Timanian basin probably occurred at approximately the same time, although this basin was infilled and then closed by about the end of the Precambrian. The Timanian basin has been designated in Russian literature as the *Timanian Aulacogen*, a sedimentary basin genetically related to and branching off the pre-Uralian geosyncline. In the west, the near-perpendicular trend of the Timanian Aulacogen relative to the Caledonides is also striking, and it is thought that the part of the Timanian Aulacogen related to the Uralian geosynclinal area extended longitudinally northwestwards towards the east margin of the northern Proto-Atlantic. It is further suggested that the presence of a triple junction of intracontinental spreading led to the development of the Timanian–Uralian dynamic system, with subsequent rapid activity and opening along two of the three spreading zones so producing the Uralian basin. On the other hand, active dilation in the third arm was slower and diminished fairly quickly, and this resulted in the preservation of a comparatively undeveloped spreading zone – the Timian Aulacogen.

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Introduction

Late Precambrian (Riphean and Vendian) rocks crop out in Finnmark, Northern Norway, where they are most completely preserved on Varanger Peninsula. Further east, in Russia, they underlie the Rybachiy–Sredniy Peninsula and the Aynov and Kildin islands, and also appear on Kanin Peninsula and in the Timan Mountains (Fig. 1). Their subsurface occurrence has been detected in the Southern Barents Sea and in the Pechora Basin. In general, they appear to form an extensive NW–SE trending belt fringing the Fennoscandian Shield and its southeastern subsurface continuation. This belt is bordered by the Northern Scandinavian Caledonides in the north-west, while in the south-east it terminates against the Northern Urals.

The present paper is essentially a review of recent knowledge of the Late Precambrian geology of this *East-Finnmark–Timan Region*, its origin, stratigraphy and structure, with special attention paid to the Riphean rocks. It is also intended to be a partial guide to the Russian literature, partial because the literature survey is incomplete. Information has often had to be obtained from summaries and reviews in which ideas, rather than basic data, have been reproduced. The possibility of appraising the ideas has thus often been restricted, and consequently some of the presentations and conclusions may not be entirely correct. I have, however, tried to select and present the most important data and ideas of various workers and have attempted to outline the main geological events which have occurred in this region in Late Precambrian time.

For convenience of description the East Finnmark–Timan region will here be subdivided into three geographical zones: 1) the Varanger–Kildin Zone, 2) the Kanin–Timan Zone and 3) the Southern Barents Shelf Zone.

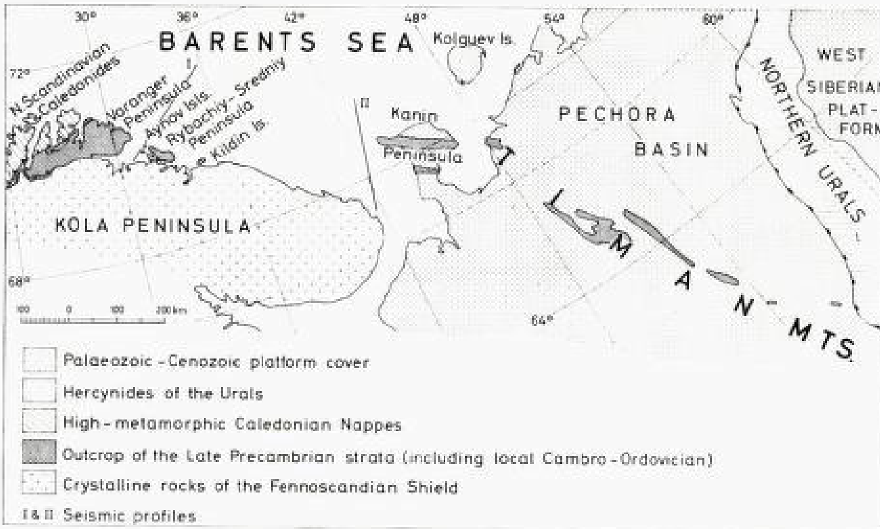

Fig. 1. Location of the East Finnmark–Timan Region (geology mainly after Atlasov 1964 and Markov 1966).

The Varanger–Kildin zone

The Varanger Peninsula, Aynov Islands, Rybachiy–Sredniy Peninsula and Kildin Island constitute a common geological region underlain by Riphean and Vendian (Eocambrian) sedimentary sequences, which contrast sharply with their substratum, i.e. with the igneous and metamorphic rocks of the adjacent northern margin of the Fennoscandian Shield (Fig. 2). Lithological similarities between the strata underlying the various areas of the Varanger–Kildin Zone have previously been pointed out by several authors and attempts at lithostratigraphic correlation have been made (e.g. Holtedahl 1918, 1960; Polkanov 1934; Keller et al. 1963, p. 605; Siedlecka & Siedlecki 1967, 1972; Bekker et al. 1970; Chumakov 1971). Detailed correlation has been and still is difficult to attain, however, mainly because of differences of terminology and the fragmentary character and often insufficient accuracy of lithostratigraphical descriptions.

Varanger Peninsula and adjacent areas of East Finnmark have been studied by many geologists (e.g. Holtedahl 1918; Føyn 1937, 1960, 1964, 1967, 1969; Rosendahl 1931, 1945; Reading 1965; Reading & Walker 1966; Beynon et al. 1967; Bjørlykke 1967; Siedlecka & Siedlecki 1967, 1969, 1971, 1972; Røe 1970; Edwards 1972; Roberts 1972; Siedlecka 1972, 1973; Teisseyre 1972; Banks et al. 1972, 1974) and our recent knowledge of the main features of the geology of this region may be summarized as follows.

Varanger Peninsula is underlain by Late Precambrian and lowermost Cambrian strata resting with a sedimentary contact on crystalline basement. A large NW–SE trending fault-zone, *the Komagelv–Trollfjord Fault Zone*, divides the peninsula into two geological regions (Siedlecka & Siedlecki 1967). South-west of the disturbance there is a ≤ 4000 m thick sequence of fluvial

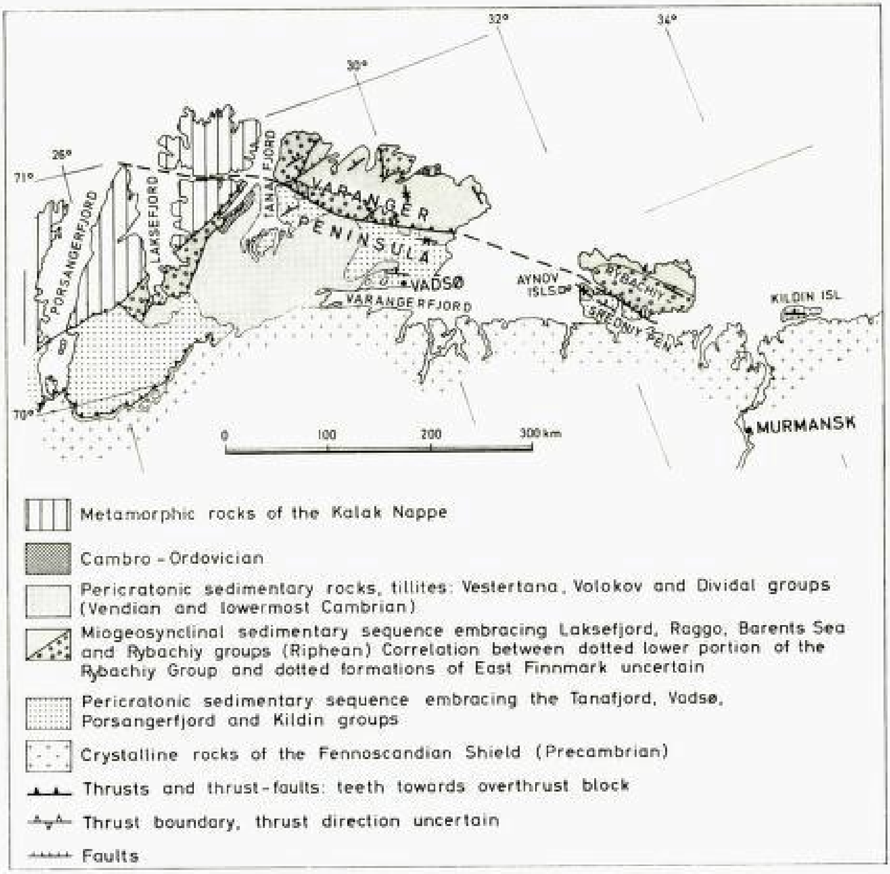

Fig. 2. The Varanger–Kildin Zone (mainly after Agapiev & Vronko, *in* Kharitonov 1958; Bekker et al. 1970, 1970a; Bogdanov, *in* Kharitonov 1958; Siedlecka & Siedlecki 1972).

and shallow-marine Riphean, Vendian and lowermost Cambrian strata. The Riphean rocks (Vadsø and Tanafjord Groups, total maximum thickness ca. 2300 m) are mostly terrigenous, although at the very top they include a carbonate unit containing columnar stromatolites. The Vendian and lowermost Cambrian strata (Vestertana Group) start with Varangian tillites, and there is a 2° unconformity between the Riphean and Vendian rocks, the former being successively removed southwards by a pre-Vendian erosion. Pringle (1973) has reported Rb/Sr whole rock isochron ages (sedimentation ages) of 668 ± 23 m.y. for shale samples from the lower Vestertana Group (Nyborg Formation) and 810 ± 90 m.y. for the Vadsø Group (*not* Tanafjord Group as incorrectly reported by the author mentioned).

North-eastern Varanger Peninsula is underlain by Riphean rocks (younger beds are absent) occurring in two rock-units separated by a tectonic contact and referred to as the Barents Sea and Raggo Groups (Siedlecka & Siedlecki 1967). Strata from parts of these two groups have been correlated (Siedlecka & Siedlecki 1972), and they are thought to represent a continuous, several thousand metres thick sequence of fluvial, shallow-marine, slope and base-of-slope deposits followed by sediments of a large deltaic system which then gave way to shore-zone terrigenous strata and, subordinately, carbonate deposits containing domal stromatolites. A fluvial regime was partly re-established at the top of this sequence. The substratum to this sedimentary succession is nowhere exposed on Varanger Peninsula; however, based on lithostratigraphic correlations (Føyn 1969; Siedlecka & Siedlecki 1972) it is thought that glacial and fluvial deposits of the lower Laksefjord Group, resting on crystalline rocks belonging to the Fennoscandian Shield at Laksefjord (Føyn 1960; Laird 1972), constitute the oldest record of the Late Precambrian deposition of East Finnmark (Siedlecka & Siedlecki 1972). An alternative correlation between glacial deposits of the Laksefjord and Vestertana Groups has been proposed thus suggesting a Vendian age also for the former group (Reading 1965; Laird 1972; Gayer 1973). Although there is no conclusive evidence to support either of the suggested correlations, data obtained from mapping and comparisons with the Rybachiy–Sredniy sedimentary successions seem to support the first of the correlations. The upper surface of this thick pile of sedimentary rocks is erosional and the sequence is unconformably overlain by Riphean rocks of the Tanafjord Group. This unconformity may be observed only in a restricted area located close to the NW side of the Komagelv–Trollfjord Fault Zone (Siedlecki, in prep.).

In general, the Riphean strata of Varanger Peninsula and adjacent areas of East Finnmark appear to have formed an extensive wedge thickening towards the north-east; in the south-west there is an up to 2500 m thick continuous sedimentary sequence representative of a platform cover, while in the north-east the equivalent succession reaches more than 9000 m in thickness, or even more if one accepts the correlation between the Laksefjord, Raggo and Barents Sea Groups, and represents a miogeosynclinal sequence.

Folds and faults showing an approximate SW–NE trend and broadly parallel to the Caledonian front of northern Scandinavia are prominent in the western and northern parts of Varanger Peninsula; to the south-east, in the Vardø area, these folds gradually swing into a roughly N–S trend and later, gentle, ca. NW–SE cross-folds are present (Roberts 1972). NW-trending folds probably belonging to a separate deformation episode from that of the main folding also occur in the vicinity of the Komagelv–Trollfjord Fault Zone (Siedlecka & Siedlecki 1971), and similarly oriented structures are present in the south-eastern part of the peninsula although the tectonics of this area have not been studied in detail (Siedlecki, pers. comm.).

The Komagelv–Trollfjord Fault Zone is not understood in detail: this is a complex major fracture in which reverse faults resulting from SW-directed movement constitute a dominant deformation feature. Evidence of important strike-slip movements has also been presented by Roberts (1972). Displacement along the fault-zone is greatest in the south-east (some 4000 m), while in the north-west sets of minor reverse faults of tens to hundreds of metres displacement are present along with some subordinate strike-slip faults

(Siedlecka & Siedlecki 1967; Siedlecki, in prep.). Younger normal dip-slip movements have also occurred along this fault zone.

Doleritic dykes constitute the only trace of igneous activity on Varanger Peninsula. A SW–NE trending swarm of dykes is present in the north-eastern region of the peninsula; in its south-western part there occur only a few N–S oriented post-folding dykes. Roberts (1972) has suggested an early-Caledonian age for one episode of syn-folding dykes in the Barents Sea Region. Preliminary K/Ar age determinations for the dykes from both sides of the Komagelv–Trollfjord Fault Zone, however, fall into three groups: (A) 340 m.y., (B) ca. 542 m.y. to 640 m.y. and (C) $>$ 1000 m.y. (Beckinsale et al., in press). Further investigations are needed for a precise understanding of these figures which, according to Beckinsale et al., suggest the occurrence of a pre-Caledonian deformation and an Upper Devonian intrusive phase and, in general, are indicative of different geological histories for the south-western and north-eastern regions of the Varanger Peninsula.

Riphean and Vendian strata of the south-western Varanger Peninsula (the platform cover type) continue towards the west, and their lithostratigraphic correlatives may be traced into West Finnmark; the thick miogeosynclinal succession underlying the north-eastern part of the peninsula cannot be recognized with any certainty west of Laksefjord.

The Rybachiy–Sredniy Peninsula has been investigated, and its geology discussed, by some Finnish and numerous Russian geologists (e.g. Fieandt 1912; Lupander 1934; Polkanov 1934, 1936; Tenner 1936; Agapiev & Vronko, *in* Kharitonov 1958; Negrutsa, *in* Shamoida 1968; Keller & Sokolov 1960; Keller et al. 1963; Polkanov & Gerling 1968; Bekker et al. 1970). As on Varanger Peninsula, the Rybachiy–Sredniy is divided by a NW–SE trending fault zone into two separate geological regions. The south-western (Sredniy) region is underlain by Riphean and Vendian strata resting with a sedimentary contact on an erosional surface of the crystalline basement. A suggestion that this contact is tectonic (Fieandt 1912; Holtedahl 1918; Polkanov 1934, 1936; Atlasov 1964, and others) has not been confirmed. It may be noted that observed relationships at the head of Varangerfjord are indicative of a sedimentary contact, and new aeromagnetic data reject the idea that a tectonic discontinuity or fault may be present along the Varangerfjord (K. Åm, pers. comm.). On Sredniy, observations by Lupander (1934), Agapiev & Vronko (*in* Kharitonov 1958, and *in* Keller et al. 1963) and Keller & Sokolov (1960) revealed a sedimentary contact between the basement gneisses and the basal conglomerate of the Riphean Kildin Group.

The Kildin Group, 1500 m thick, is composed predominantly of terrigenous deposits and contains a carbonate unit at the top. On the basis of available descriptions, strata of this group may be thought to have originated in the shallow-water environment of a sea encroaching upon the crystalline rocks of the Fennoscandian Shield. K/Ar radiometric age determinations from glauconite present in the lower Kildin Group have given figures ranging from around 1000 m.y. to 619 m.y. (Polkanov & Gerling 1960; Bekker et al. 1970a). These Riphean strata are overlain by the Volokov Group, up to ca. 500 m thick, which is composed of arenaceous terrigenous rocks with a basal conglomerate. There is a transgressive contact between the two groups of strata, yet no angular unconformity has been reported. A K/Ar whole rock age for a dolerite dyke cutting the Volokov Group sediments has given a figure of ca. 600 m.y. (Bekker et al. 1970a). Lithologies of the Kildin and Volokov Groups also appear on the *Aynov Islands* where terrigenous and carbonate rocks of the upper Kildin Group (45 m) are overlain with a slight angular unconformity by 240 m of shallow-marine (? and fluvial) terrigenous deposits of the (Vendian) Volokov Group (Bekker et al. 1970).

The north-eastern part of the Rybachiy–Sredniy Peninsula, i.e. the Rybachiy Peninsula proper, is underlain by a several thousand metres thick, presumably continuous pile of terrigenous deposits, *entirely different* from those of Sredniy and the Aynov Islands. The sequence of strata, the Rybachiy Group, starts with a coarse polymict diamictite (Agapiev & Vronko, *in* Kharitonov 1958), the Motov Formation of Keller & Solokov (1960), and Keller et al. (1963). This formation underlies the isthmus between the Sredniy and Rybachiy parts of the peninsula and is strongly influenced by the tectonic disturbance present along this depression. The origin and the stratigraphic position of the diamictite have been very controversial: the idea of a glacial origin has been forwarded by Wegmann (1928) while other geologists (e.g. Keller & Sokolov 1960) have been inclined to interpret it as a grain-flow deposit. According to Agapiev & Vronko (*in* Kharitonov 1958) the Motov Formation rests with a sedimentary contact *on* the Volokov Group. Consequently, the whole Rybachiy Group was regarded as younger than the Sredniy Group, occurring in the ca. 350 m downfaulted Rybachiy block. This suggested situation was shown on a cross-section (*in* Kharitonov 1958), but it does not appear on the geological map produced by Agapiev & Vronko; since no further observations supporting this idea have been reported it is here considered only as an alternative and hypothetical interpretation. Correlation with the Volokov Group of Sredniy has also been suggested (Keller & Sokolov 1960; Keller et al. 1963), but this is not supported by any firm data. The Motov conglomerate, ca. 250–470 m thick, is overlain by 3600 m of coarse arenaceous and conglomeratic sediments with diamictite lenses followed by some 900 m of greywacke and shale (a flysch sequence according to Sergeeva 1964). Arenaceous and clayey shale, strongly cleaved and ca. 500 m thick, constitutes the uppermost unit. Lupander (1934) recorded one basic dyke dissecting this formation.

The nature of the tectonic disturbance separating Rybachiy from Sredniy is not quite clear: most authors, however, have interpreted it (or accepted this interpretation) as a reverse fault zone which resulted from a south-west directed stress, the Rybachiy having been lifted up and pushed against the Sredniy (Wegmann 1928, 1929; Lupander 1934; Polkanov 1934 ,1936; Keller & Sokolov 1960; Keller et al. 1963, pp. 103–113).

Strata underlying the Sredniy–Rybachiy Peninsula have been only slightly folded; they dip gently northeastwards over most of the area. Open cylindrical folds are present, especially on Rybachiy, and many of them are asymmetrical, their axial planes dipping steeply towards the north-east. A somewhat more advanced deformation with a pervasive cleavage has been reported from the northeastern part of Rybachiy.

Kildin Island is underlain by a 1000 m thick sequence of sediments, the Kildin Group. This is composed of terrigenous deposits with subordinate carbonate lithologies appearing in its lower part. The carbonate rocks contain columnar algal stromatolites (*Gymnosolen ramsayi* Steinm., *Collenia buriatica* Maslov) and oncolites (Artemiev 1933; Bogdanov 1933; Gurbich 1934; Polkanov 1936; Kharitonov 1958; Krylov 1959: Keller et al. 1963; Bekker et al. 1970a). An erosional surface is thought to be present in the lower–middle part of the Kildin Group (Bekker et al. 1970). K/Ar radiometric ages obtained from glauconite collected from different horizons in this group range from 849 to 759 m.y. (Bekker et al. 1970a). The lithologies occurring on Kildin Island seem to be of shallow-marine origin although the presence of some fluvial deposits cannot be excluded. The beds dip gently northeastwards, and neither the bottom nor the top surface of the Kildin Group is exposed.

CORRELATION

The Tanafjord–Varangerfjord region of Varanger Peninsula, the Aynov Islands, the Sredniy region and Kildin Island are all situated close to the margin of the Fennoscandian Shield, and are underlain by some 2000–4000 m of fluvial and shallow-marine sediments resting with an erosional contact on the crystalline basement; glacial deposits of the 'Varangian Ice Age' are widespread west of the Aynov Islands. These strata are not metamorphosed and are only gently folded over most of the region with the exception of the north-westernmost area close to the Caledonian front. Along with the fluvial and shallow-marine origin of the sediments, this indicates that they were accumulated in a *pericratonic zone* of the Late Precambrian sedimentary basin on a relatively rigid substratum and are representative of platform-cover type deposits. Palaeocurrent directions (data from the south-western part of Varanger Peninsula only), thicknesses and facies distribution indicate that the basin was located to the north-east or east.

The few radiometric age determinations so far available indicate an Upper Riphean and Vendian age for the bulk of the strata of the pericratonic zone. The Riphean/Vendian boundary is usually placed at the interface between the Kildin and Volokov Groups and between the Tanafjord and Vestertana Groups, although this is not quite consistent with the radiometric age boundaries introduced by the Russian workers (Garris et al. 1964). This is, however, an important geological boundary marked by erosion (Sredniy) and an angular unconformity (Aynov Is. and East Finnmark), and by the appearance of Varangian tillites in Norway. The tillites are absent in the Vendian Volokov Group on the Aynov Is. and on Sredniy; these areas probably constituted topographic highs subjected to erosion during the Varangian glaciation.

The Kildin Group on Kildin Island contains carbonate rocks with columnar stromatolites in its lower part, not at the top of the sequence as in the case on Sredniy and in the Tanafjord Group on Varanger, and this seems to have been the result of a facies change. An age correlation between these 'upper' and 'lower' carbonates does not seem to be possible especially as the K/Ar age (on glauconite) of the carbonate-bearing part of the sequence of Kildin Is. is 849 m.y. and the ages of the terrigenous sediments overlying these carbonate rocks exceed 750 m.y. (Bekker et al. 1970). These former strata thus cannot be correlated with the Vestertana and Volokov groups. It is possible that a carbonate unit may have been present at the top of the Kildin Group on Kildin and has since been eroded. Alternatively, such a unit may still be present beneath the surrounding sea-covered areas.

The north-eastern (Barents Sea) region of Varanger Peninsula and the Rybachiy region have a similar geological setting being located outside the marginal zone reviewed above, and are underlain by several thousand metres thick terrigenous sequences (Siedlecka & Siedlecki 1967). These rock sequences represent a *miogeosynclinal zone* of the Late Precambrian sedimentation basin. The presence of flysch-like sequence in both regions is very helpful for comparison purposes, but nevertheless two alternative lithostratigraphic correlations may be suggested depending on the genetic interpretation of the Motov diamictite and conglomerate lenses of the lower Rybachiy Group:

1) If the Motov diamictite and the slightly younger conglomerates (in the Ejna Formation) are glacial (and glacifluvial) in origin, they could be correlated with the lower Laksefjord Group of East Finnmark (the Ifjord Formation). A thick sequence of fluvial and shallow-marine sediments subjacent to the flysch-like deposits of East Finnmark would then be absent or considerably reduced on Rybachiy. This correlation would suggest the occurrence of a widespread glaciation older than the Varangian Ice Age.

2) If, on the other hand, the Motov diamictite and the conglomeratic lenses are representative of grain flow deposits, together with the rest of the Rybachiy Group they should be comparable to the flysch-like strata of the north-eastern region of Varanger Peninsula. This correlation would imply that subaqueous mass movement processes were much more active in the Rybachiy region than further to the north-west. Except for the Løkevik Tilloid of suggested composite glacial and mudflow origin (Siedlecka & Roberts 1972), coarse polymict conglomerates are unknown in the flysch-like sequence on Varanger Peninsula.

The above correlation alternatives, based on structural setting and on comparisons of the sedimentary succession of Rybachiy with those of East Finnmark are different from the previously suggested stratigraphic relationship between the groups of rocks of Srednyi and Rybachiy (see p. 319). The interpretations of the Rybachiy–Sredniy stratigraphic relationship suggested by Agapiev & Vronko (*in* Kharitonov 1958) and by Keller & Sokolov (1960) imply Vendian and younger ages for the Rybachiy Group. This has not been confirmed by radiometric age determinations (Polkanov & Gerling 1960,

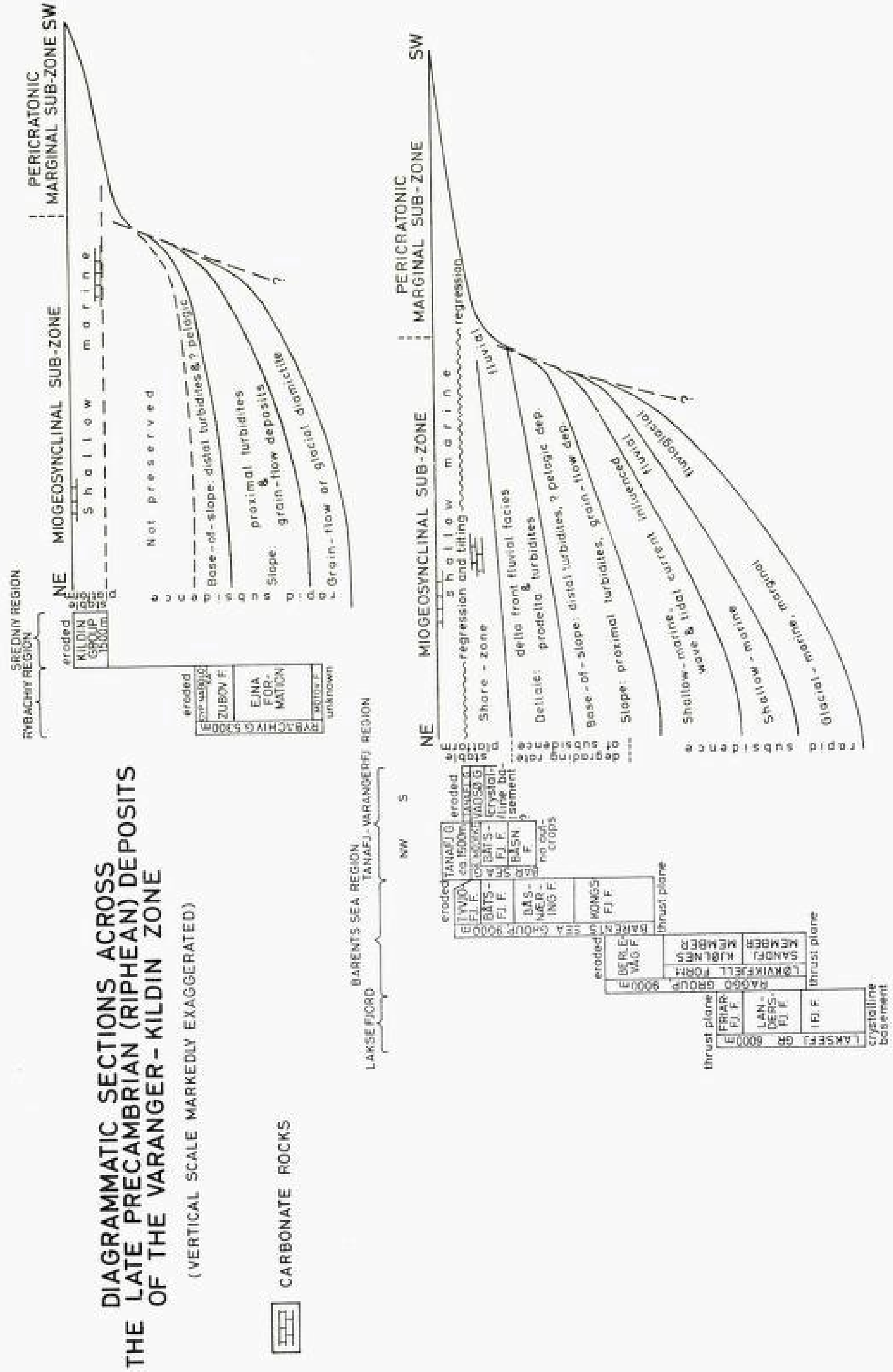

Fig. 3. (Explanation written on the illustration).

1961) which, although uncertain and ambiguous (Bekker et al. 1970a) give figures ranging from 900 to 686 m.y. (K/Ar whole rock ages).

The correlation alternatives (1) and (2) have been indicated on Fig. 3, which also shows diagramatically the supposed relationship between the marginal and internal zones of Riphean sedimentation within the Varanger–Kildin Zone. This correlation is a matter of broad geological interpretation rather than a simple facies comparison. The sub-zones are now in tectonic contact along the Trollfjord–Komagelv–Rybachiy Fault Zone and the transitional strata which are assumed to have existed are not exposed. This structural situation is the main reason for uncertainty over the marginal-to-basinal facies relationships. The sedimentary contact and slight angular unconformity between the Barents Sea and Tanafjord Groups observed in north-western Varanger Peninsula (Siedlecka & Siedlecki 1972; Siedlecki, in prep.) provide the most important data on this topic, in particular if one remembers that this same Tanafjord Group in the marginal zone is underlain only by the ca. 800 m thick Vadsø Group. This suggests that during most of the time of deposition of the basinal facies, the marginal sub-zone constituted an erosional and/or non-depositional area across which sediment supply to the basinal zone has occurred. Analysis of the overall facies succession in the miogeosynclinal zone indicates a particularly rapid basin subsidence in the first stage up to the development of a prominent slope. The true nature of this slope is unknown, and the fault indicated in Fig. 3 is a purely hypothetical feature. However, suggestions of the existence of a structural, fault-bound margin are to be found in the Timans, where deep-seated fractures delineate the margins of the basin and/or different zones of Riphean sedimentation (see e.g. Zhuravlev 1972 and pp. 333–335 in this paper).

The rate of subsidence of the depositional basin gradually decreased in the *Varanger–Kildin Zone*. The basin was filled in and a paralic sedimentation was established throughout the area of both sub-zones, which, together, then represented a broad depositional shelf. This was followed by some intra-Riphean movements which resulted in a regional regression and erosion and also in a tilting of the western part of the basinal deposits; data on the existence of this tilting further to the east are lacking. A new transgression then re-established the paralic conditions in which the Riphean sedimentation had been completed. This was subsequently followed by regression and tilting and by glaciation initiating the Vendian period.

The Timan–Kanin zone

In this zone Riphean rocks crop out in anticlines protruding through the younger platform-type cover and in elevated, fault-bound blocks arranged in a chain running from the Paye Ridge and Mysy Lyudovatye on the Kanin Peninsula in the north-west to the Ksenofontovskoye and Polyudov Ridges in the south-east (Fig. 4). A sharp angular unconformity occurs between the folded and metamorphosed Riphean rocks and the cover, the latter starting with

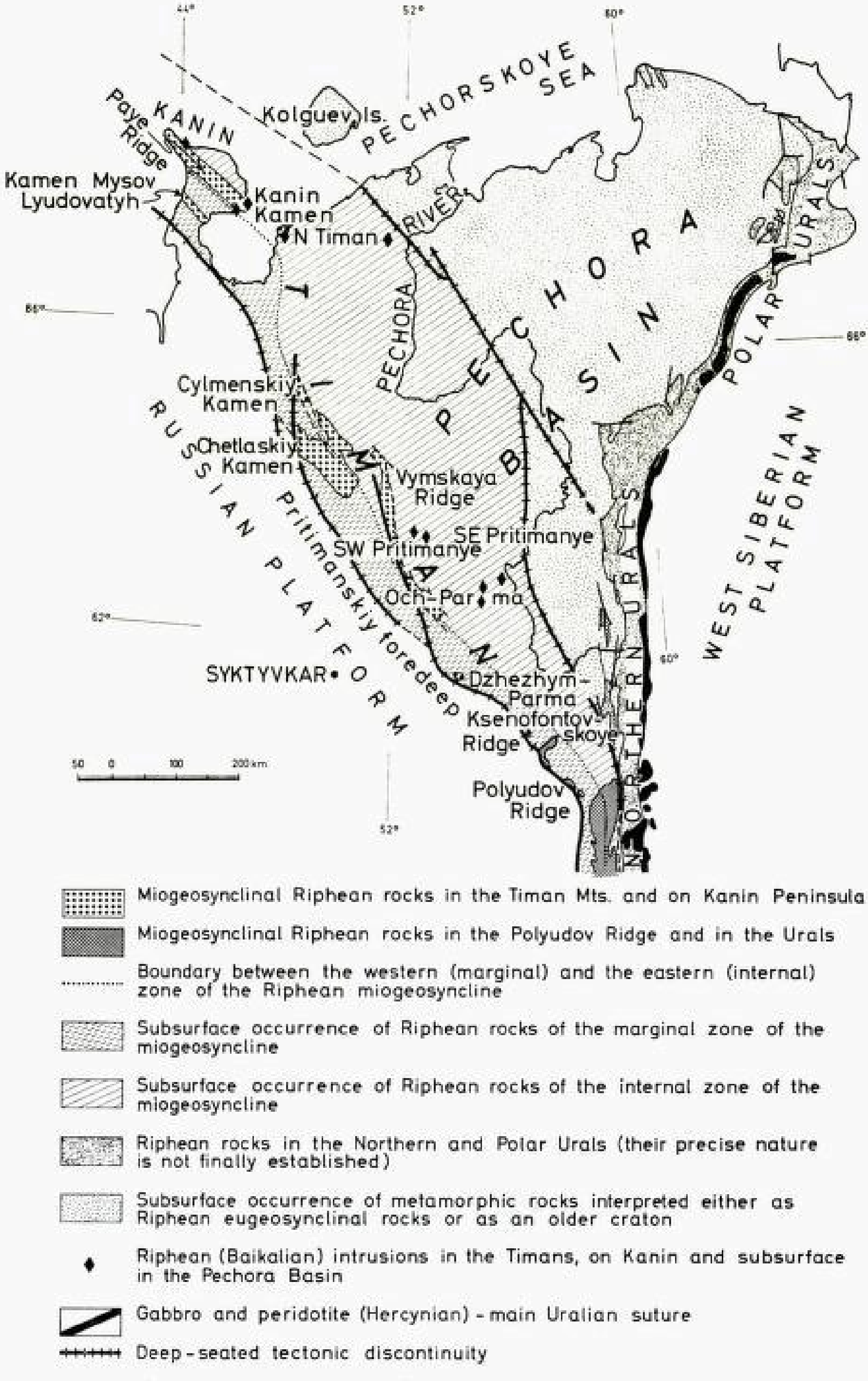

Fig. 4. Sketch-map of the Riphean of the Timans, the Pechora Basin and the Urals (mainly after Zhuravlev & Osadchuk 1960; Zhuravlev 1972).

Ordovician, Silurian or Devonian (Shamoida 1968, p. 153; Zhuravlev 1972; Getsen & Naumov 1973). The Riphean strata are cut by numerous pre-Palaeozoic bodies of igneous rocks, more especially in the northern areas.

The Riphean of the Timan Mountains and Kanin Peninsula is in general represented by metasedimentary, mostly terrigenous rocks, with subordinate limestone and dolomite. The total thickness is about 13,500 m (Zhuravlev et al. 1966, p. 54); neither the bottom nor the top surface of this Riphean sequence is known. Numerous sections have been measured and lithostratigraphic units erected in the various parts of this Timan–Kanin zone (see Zhuravlev 1972, p. 21 for a review of older publications), and different correlation schemes between these measured sections have been proposed (e.g. Zhuravlev & Osadchuk 1960, 1962, 1963; Raznitsyn 1962, 1962a, 1965, 1969; Kochetkov 1963; Zhuravlev et al. 1966; Volochayev et al. 1967). These have subsequently been correlated with sections through the miogeosynclinal Riphean of the Urals.

Vendian strata seem to be absent from most of the Timans; there is still some uncertainty here, however, and some pre-Palaeozoic strata of the Central Timans and Polyudov Ridge have been considered Vendian in age (Borovko et al. 1964, *vide* Zhuravlev 1972; Getsen 1972). The presence of Vendian tillites has been reported from the Polyudov Ridge by Borovko (1967, *vide* Chumakov 1970). Getsen & Naumov (1973) have suggested a Vendian age for some slates present on Kanin Peninsula; there is, however, no firm evidence to support this suggestion.

Central Timans. The most complete section through the Riphean sequence is exposed in the Chetlaskiy Kamen Anticline (Fig. 4), where the lithostratigraphy of the Riphean strata of the Timans was first established. This stratigraphy was then extended to other sections in the Central and Southern Timans and correlated with that in the Northern Timans and Kanin Peninsula. Five formations have been differentiated (Zhuravlev & Gafarov 1959; Zhuravlev & Osadchuk 1960, 1962: Zhuravlev et al. 1966): The lowermost, the 1850 m thick *Svetlinskaya Formation*, consists of grey quartzite with subordinate interbeds of siltstone and quartz–sericite slate. This is overlain with a slight angular unconformity by conglomerates of the *Chetlaskaya Formation* (up to 2700 m), which also contains grey quartzitic sandstone, slate and some calcareous sandstone. Succeeding this with an erosional boundary (Zhuravlev & Osadchuk 1960, p. 93) is the *Dzezhymskaya Formation* which consists of alternating quartzite and siltstone with lenses of feldspathic sandstone and conglomerate; this formation is characterized by its variable thickness (250–$>$ 850 m) and by facies changes which result in the sequence being more conglomeratic in sections situated closer to the edge of the Fennoscandian Shield. The next unit, the *Bystrynskaya* (*Bystruhynskaya*) *Formation* (up to 4200 m) is composed of carbonate rocks in its lower part; bedded and stromatolitic dolomites are present, these being overlain by multicoloured slates containing some lenses of carbonates. The fifth lithostratigrapic unit, the

Kislorucheskaya (Och–Parminskaya) Formation (ca. 4000 m) consists essentially of phyllite with subordinate quartzite layers and is considerably more metamorphosed (biotite–chlorite subfacies of the greenschist facies according to Zhuravlev 1972, p. 27) than all the other formations. The stratigraphic position and extent of the Kislorucheskaya Formation remains controversial. Originally its lithologies were thought equivalent to the Chetlaskaya Formation (Kalberg 1948) and subsequently considered by Zhuravlev & Osadchuk (1960) as a facies equivalent of the rest of the Riphean strata, deposited in a deeper basinal zone. Later these same authors (Zhuravlev & Osadchuk 1962) regarded it as the youngest unit and the facies zonation model was replaced by one of tectonic zonation. Raznitsyn (1965) suggested that the Kislorucheskaya Formation is older than all other Riphean formations of the Central Timans. Neither of the two last-mentioned suggestions seems to have been accepted, and the more recent models in general support the original idea (e.g. Volochayev et al. 1967; Raznitsyn 1969). Zhuravlev (1972), however, has retained his tectonic zonation model.

Northern Timans and Kanin Peninsula. Riphean rocks of the Northern Timans, the Barmin Formation of Barkhatova (1936), are represented by a several kilometres thick series of dark-coloured, greenish-grey phyllite and schist. These lithologies have more recently been studied in some detail by Getsen (1968), who introduced a new lithostratigraphy (Malochernoretskaya and Yambozherskaya Formations) and reported the presence of widespread graded bedding in these metasedimentary rocks. An analogous metamorphic series of Riphean quartzite and schist underlies the Paye Ridge on Kanin Peninsula, while at Mysy Lyudovatye there are metamorphosed stromatolitic dolomites and some slaty argillaceous lithologies (Tschernyschev 1901; Ramsay 1911; Lyutkevich 1953; Malkov & Puchov 1963; Malkov 1966; Getsen 1968, 1971, and others). Getsen (1971) measured a coastal section of the Riphean rocks at Kanin Kamen (Fig. 4) and differentiated two groups of rocks. The lower, Tarkhanov Group (4400–5000 m), consists of schists and quartzites (the epidote–amphibolite metamorphic facies of Russian workers), which in spite of metamorphic alteration have retained a variety of sedimentary structures and have been defined by Getsen (1971) as 'flyschoid'. This unit is overlain by the somewhat less metamorphosed Tabuyev Group (3800 m) composed of feldspathic and oligomict sandstone in the lower part and arenaceous and argillaceous graded-bedded lithologies higher up. The latter contains subordinate limestone, the amount of which increases upwards. Getsen (1971) suggested a correlation between this upper carbonate-bearing portion of the Tabuyev Group and the lower part of the Mysy Lyudovate Dolomite (1450 m). The total known thickness of the Riphean strata on Kanin has been estimated by Getsen (1971) at 8500–9000 m.

The general stratigraphy of the Riphean rocks of the Timans is essentially based on (1) lithostratigraphic correlations between the separate outcrops within the Timan–Kanin zone, (2) lithostratigraphic correlations with classical profiles of the miogeosynclinal Riphean of the Urals and (3) algal stromatolites, oncolites and catagraphs. Results obtained by the adoption of these methods have been checked by radiometric age determinations. Thus, the Mysy Lyudovate Dolomite and the Bystrynskaya Formation have been considered as chronostratigraphic equivalents and a study of stromatolites has indicated an Upper Riphean age for the carbonate formations (Raaben & Zhuravlev 1962; Raaben 1964; Zhuravlev et al. 1966; Raaben 1968). However, a K/Ar age determination of a diabase sill cutting the shaly portion of the Bystrynskaya Formation gave a figure of 1220–1230 m.y. (Malkov 1969)! On the other hand, the Barmin Formation of the Northern Timans has been tentatively compared with the Kislorucheskaya Formation (Zhuravlev & Osadchuk, *in* Keller 1963, p. 231), this being quite different from Getsen's (1971) correlation between the Northern Timan and Kanin sections (see p. 326). In spite of these and other existing controversies and uncertainties, it seems almost indisputable that Middle and Upper Riphean strata are represented in the Timan–Kanin zone.

TECTONIC DEFORMATION OF THE TIMAN–KANIN RIPHEAN

Many geologists have written about the structure of the Timans and Kanin, and the following brief review of the pre-Palaeozoic deformation of this region is based mainly on summaries given by Raznitsyn (1968, 1969), Getsen (1972) and Zhuravlev (1972).

The Riphean strata of the Timan–Kanin Zone are exposed in separate fault-bounded blocks and are folded, the fold axes exhibiting regional northwesterly trends (Fig. 4). In the Central Timans, the structure of the Chetlaskiy Kamen horst is dominated by an open asymmetrical anticline and the degree of metamorphic alteration of the Riphean strata is low. The anticline plunges north-west, and its axial plane dips to the south-west. The steeper NE limb of the fold is dissected by a set of NW-trending pre-Palaeozoic faults and the Riphean strata adjacent to this fault-zone in the north-east (the Kislorucheskaya Formation) are characterized by a more intense tectonic deformation and metamorphism than the bulk of the rocks of the Chetlaskiy Kamen. Numerous dykes of basic alkaline rocks are associated with this fault-zone. South-east of the Chetlaskiy Kamen (SW Pritimanye) and in Dzhezhym–Parma, weakly metamorphosed Riphean strata dipping gently southwestwards have been reported from subsurface investigations. The Och–Parma and Vymskaya ridges are dominated by isoclinal folds with NE-dipping axial planes and the Riphean sedimentary rocks are altered into slates. In the north, deformation of Riphean strata at Mysy Lyudovate may be roughly compared to that of the Chetlaskiy Kamen while rocks underlying the Paye Ridge and cropping out in the Northern Timans are altered into slates and schists, folded in steep tight or isoclinal folds, characterized by a variety of micro-tectonic structures and dissected by numerous igneous intrusions. However, the degree of metamorphism does not appear to have exceeded upper greenschist facies.

In general, two contrasting degrees of tectonic deformation and metamorphism may be differentiated in the Timan–Kanin Zone: 1) slight deformation and low metamorphism, as exemplified by the Chetlaskiy Kamen structure; 2) stronger deformation and metamorphism, this being most conspicuous in the north. Exposed areas of the (1) weakly and (2) strongly deformed Riphean strata seem to be arranged in two parallel NW–SE belts (Fig. 4) related to two different sedimentary and tectonogenic regimes.

Further data on the subsurface structure of the Timan–Kanin Zone and neighbouring areas have been provided by drillings and by geophysical work. Several drill-holes located east of the central and southern Timans have penetrated Riphean slates and schists (and associated intrusions), while the distribution of magnetic and gravimetric anomalies has indicated the existence of deep-seated NW–SE trending fracture zones bounding the belt of Riphean occurrences in the south-west and north-east (Fig. 4). Ideas on the origin and structural history of this belt have been and still are developing following two basic alternative models: 1) a model of a Timan–Ural geosyncline with subdivision into Timanian miogeosynclinal and Uralian eugesynclinal parts; and 2) a model of two independent sedimentary basins separated by a craton. The development of these controversial concepts will be reviewed later in this paper together with ideas on the broad regional framework of the north-eastern border of the Fennoscandian Shield and its eastern subsurface continuation.

PRE-SILURIAN IGNEOUS ACTIVITY AND METAMORPHISM IN THE TIMAN–KANIN ZONE

The intrusion of gabbroids, particularly common in the Northern Timans and on Kanin, represents the oldest period of regional igneous activity. Radiometric ages (K/Ar, mostly whole rock) of the metamorphism of the gabbroic rocks are around 640–620 m.y. (Malkov & Puchkov 1963; Malkov 1966). On Kanin the gabbroids are dissected by syenites and granites which give ages of 550–480 m.y. (Polkanov & Gerling 1961; Ivensen 1964). According to Malkov & Puchkov (1963) and Malkov (1966) these younger ages must be due to greisenisation since the age of a pegmatite dyke dissecting the granite is 640 m.y. The granite is considered comagmatic with granitic bodies detected in the subsurface in the Southern Timans (Malkov 1966). A younger group of igneous rocks comprises essexite gabbro of the Northern Timans and later granites and syenites dissect this particular gabbro. A great variety of basic dykes (e.g. lamprophyres, camptonites, picrites, porphyrites) is genetically related to the essexite gabbro. This suite of basic rocks is metamorphosed, and dykes boudined and amphibolitised: the age of their metamorphism is around 525–520 m.y. (Malkov 1966). The granites which dissect these gabbroic rocks gave intrusive ages ranging from 540 m.y. to 534 m.y. This inconsistency with the geological evidence may perhaps be due to different material being used for the determination of radiometric ages (K/Ar whole rock analyses for the basic rocks; biotite, muscovite or whole rock samples for the acid varieties).

Numerous syenite–aplites and granite–aplites transect the granites and syenites of this younger group: these give quite variable ages of 550 m.y., 520 m.y. and 445 m.y. (Malkov 1966). Finally, a swarm of SW–NE trending diabase dykes cross-cuts the older igneous bodies in the Northern Timans; only two ages have been reported, 516 m.y. and 505 m.y. (Malkov 1972), but no analytical data are given.

In a summary and interpretation of radiometric age data for the Riphean rocks of the Timans given by Raznitsyn (1965), two older periods of metamorphism have been indicated for the Southern Timans in addition to the two above-mentioned metamorphisms: an older one at 1130 m.y. (uncertain) and a second characterized by figures of 790 m.y., 768 m.y., 700 m.y. and 687 m.y. Other age determinations have been obtained which do not readily fit in with the age patterns outlined above: an intrusive age of 1300 m.y. has been indicated for granite in the Northern Timans (Malkov & Puchkov 1963); while a diabase sill cutting the Bystrynskaya Formation in the Central Timans provided a rather anomalous age of 1220–1230 m.y. (Malkov 1969).

Getsen (1970, 1971, 1971a), summarizing data on the radiometric ages of the Timans, has differentiated: a) intrusions with an age range of 665–445 m.y. and b) an age of metamorphism(s) of 620–483 m.y. Difficulty arises, however, in understanding the precise significance of the ranges of age given in Getsen's papers.

The southern Barents Shelf zone

This embraces the offshore area located between the Varanger Peninsula in the north-west and the Kanin Peninsula in the south-east (Fig. 1). Of interest here is the possible occurrence of Late Precambrian rocks and structures forming a link between the Varanger–Kildin and Timan–Kanin zones.

Published information on the structural framework of the Barents Shelf is based on sparse geophysical studies combined with data on the stratigraphy and structure of the bordering land areas and of islands located along the western and northern edge of the shelf. The geophysical data show that the continental crust of the Barents Shelf is ca. 30–40 km thick and is composed of a basement with a sedimentary cover (e.g. Beliayevsky et al. 1968; Demenitskaya et al. 1968; Litvinienko 1968; Demenitskaya & Hunkins 1970; Eldholm & Ewing 1971; Emelyanov et al. 1971). According to the geological information the basement/sedimentary cover interface reflects the boundary between 1) the Caledonian and older cratonised substratum exposed in Devonian time, and 2) the Devonian and younger strata. The thickness of the cover has been roughly estimated as some 4–5 km (e.g. Harland 1967; Eldholm & Ewing 1971). An uneven subsidence of the basement, inferred on the basis of geological data (Frebold 1951; Harland 1960, 1967) has been confirmed by differences in cover thicknesses under the sea areas (e.g. Eldholm & Ewing 1971), and a subdivision of the cover has been suggested on the basis of seismic velocity changes combined with geological information (e.g. Eldholm

& Ewing 1971; Emelyanov et al. 1971; Vogt & Ostenso 1973; Sundvor 1974). This same sedimentary cover continues into the Pechora Basin, where numerous gas and oil reservoirs have been discovered, in particular in the middle–upper Palaeozoic strata. Analogous horizons and structures may be expected to occur in the northwestern submarine continuation of this cover (e.g. Krems et al. 1968; Semenovich et al. 1973).

The nature and structural framework of the basement is much more uncertain; seismic records (DSS) reaching the deep portions of the crust are scarce and interpretations of these much more difficult. Dementskaya et al. (1968, their Fig. 2.1) have suggested that the crust is composed of a 'basaltic' layer overlain by a 18 km thick pile of sedimentary rocks which in its lower part is representative of the Riphean complex. The supposed Riphean portion of the strata is characterized by seismic velocities of around 5.5 km/sec., while a velocity of 4.7 km/sec. marks the bottom surface of the younger (i.e. post-Riphean) sedimentary cover. A 'granitic' layer indicated in this interpretation south of the Barents Shelf wedges out rapidly north of the southern shorelines of the Barents Sea. Belayevsky et al. (1968) have in the generalized trans-continental section of crust included the Riphean complex into the 'granitic' layer. The model of Demenitskaya et al. (1968) assumes that the Riphean complex underlies the Barents Shelf from Kola Peninsula in the south to Franz Joseph Land in the far north. This is probably based on one of two alternative geological models of the Timan–Ural geosyncline(s), discussed later in this paper (p. 333).

If one now considers the southern Barents Shelf, keeping in mind the 'Riphean' 5.5 km/sec. velocity, the results of the seismic work of Litvinienko (1968), Eldholm & Ewing (1971) and Emelyanov et al. (1971) appear to be of particular interest. The SW–NE trending seismic crustal profile of Litvinienko (1968) crosses the Kola Peninsula and southern Barents Shelf between the Varanger and Rybachiy–Sredniy peninsulas (Fig. 1). In this profile the crystalline rocks of the Fennoscandian Shield are characterized by velocities of 6.0 km/sec. A distinct 5.5 km/sec. refractor appears beneath the sea-covered areas, this being followed by horizons characterized by 4.7, 3.2 and 2.2 km/sec. The 5.5 km/sec. horizon comes close to the sea bottom near the Rybachiy–Sredniy Peninsula indicating that this particular velocity is indeed characteristic of the buried Riphean complex. In addition a 6.0–6.1 km/sec. horizon appears some 150 km NE of the shore-line suggesting a shallow occurrence of crystalline basement beneath the post-Riphean cover, characterized in this profile by 4.7 km/sec. and lower velocities. Figures obtained by Eldholm & Ewing (1971) from their refraction work in the southern Barents Shelf are in agreement with those published by Litvinienko (1968). Velocities in the range 5.0–5.5 km/sec. recorded in the western portion of the surveyed area may, according to Eldholm & Ewing (1971), be related to offshore continuation of the Caledonian orogen, while those from the eastern part of the area are probably associated with the Riphean structural complex. A distinct change in the magnetic and gravimetric anomalies appears in the area of the possible junction between the Caledonian and Riphean structural complexes (Eldholm & Ewing 1971).

The paper by Emelyanov et al. (1971) constitutes the most recent Russian summary of the geology of the Barents Sea. Of new data published in this article a seismic profile located north-west of the Kanin Peninsula is of particular interest for an understanding of the deep structure of the Southern Barents Shelf Zone. An approximately 500 m high structural elevation located along the NW extension of the Riphean Paye Ridge on Kanin Peninsula is indicated in this profile, and there also occurs a distinct structural depression south-west of the elevation. Along this same profile the post-Riphean sedimentary cover of Devonian to Quaternary strata reaches the considerable thickness of some 3.5 km. This profile subdivision has presumably been based on the stratigraphy of the platform cover of the Pechora Basin and the Timan–Kanin Zone.

Summarizing the above information, the following points should be emphasized with regard to the structure of the Southern Barents Shelf zone:

1) There is no direct geological evidence available on the structure and lithostratigraphy of the Barents Shelf.
2) Geophysical and indirect geological information is indicative of the existence of a 4–5 km thick platform-type Palaeozoic–Cenozoic sedimentary cover starting with Devonian or Carboniferous strata. Considerations of the stratigraphy and structure of this cover are outside the scope of this paper.
3) The structure of the basement is uncertain. A seismic velocity of around 5.0–5.5 km/sec., intermediate between velocities characteristic for the Fennoscandian Shield and those for the cover, can be related to different structural complexes; these are indicative either of Caledonian or of Riphean (Baikalian) basement.
4) The thickness of the Riphean complex underlying the Palaeozoic and younger cover and resting on the 'basaltic' layer may be estimated at ca. 12–13 km, assuming the thickness of the sedimentary cover as being around 4–5 km. The recently reported 7 km thickness of the Riphean complex in the area of Varanger Peninsula (K. Åm, this volume) presumably refers to the depth down to a major surface of tectonic discontinuity beneath the Barents Sea Region.

Outline of inter-zonal correlation

The occurrence of an extensive NW–SE trending belt of Late Precambrian rocks bordering the NE margin of the Fennoscandian Craton seems to be now well established, and the available data are also indicative of a differentiation of sedimentary environments and structural and metamorphic events within this belt. There is unfortunately insufficient evidence of a detailed inter-zonal, i.e. longitudinal, stratigraphic correlation, and difficulty is also encountered in determining the stratigraphic relations across the belt both in the Varanger–

Kildin and in the Timan–Kanin zones. However, if the above-mentioned internal differentiation of the belt of Late Precambrian rocks is taken into account, in particular with respect to thicknesses of the sedimentary sequences and facies development, structure and metamorphism, an inter-zonal 'en gros' correlation may be successfully reached.

In the Varanger–Kildin zone the Riphean deposits are related to two sedimentary regimes; one with a relatively stable rigid substratum and the other with a subsiding mobile substratum. The thick sequence of strata associated with the mobile subzone did not suffer any pronounced pre-Caledonian structural deformation or metamorphic alteration, and in its overall appearance it is similar to the Riphean sequences cropping out in the Chetlaskiy Kamen in the Central Timans and to equivalent sequences of Dzhezym Parma, the Ksenofontovskoye Elevation and Kamen Mysov Lyudovatych on Kanin (Fig. 4). Nowhere in the Varanger–Kilin zone are there rocks and structures which could be compared to the strongly disturbed rocks of the Paye Ridge or Northern Timans, nor are there known intrusions other than diabase dykes. Equivalents of this strongly disturbed Riphean basement, if they exist, would have to occur beneath the Barents and Pechora Seas and the obtained offshore seismic velocities interpreted as related to the Riphean Timanian complex would have to be associated with these considerably disturbed and intruded Riphean strata. The general structural trend is also suggestive of this situation.

The pericratonic deposits of the Varanger–Kildin zone, accumulated on a relatively stable substratum, do not seem to have any direct equivalents in the rock succession of the Timans. South-west of the Timans, however, beneath the Moscow Syneclise, very slightly disturbed Late Precambrian (Riphean and Vendian) strata have been detected resting on the pre-Riphean crystalline substratum and regarded as belonging to the platform cover of the Russian Platform (e.g. Bruns, *in* Keller 1963). These strata could possibly be equivalent to the epicontinental marginal sequence of the Varanger–Kildin Zone. If the upper part of the Riphean portion of these strata has once extended towards the Timans overlying the miogeosynclinal Riphean succession, as is the case on Varanger Peninsula, it would have had to have been completely eroded and removed in pre-Ordovician time.

The comparisons outlined above suggest that a regionally extensive longitudinal zonation of the sedimentary basin occurred in Riphean times with the different sedimentary and structural regimes forming belts along the edge of the craton. This is a development and modification of some earlier ideas (Zhuravlev & Osadchuk 1960; Raznitsyn 1962), a modification in which strata of the Varanger–Kildin Zone are shown to be related not to one but to two sedimentary regimes, only one of these regimes being comparable to the bulk of the Riphean strata of the Timan–Kanin Zone. Consequently, the East Finnmark–Timan Region of Riphean sedimentation embraced not two but three, main, depositional regimes: (1) external (pericratonic), (2) intermediate and (3) internal. Sediments associated with the external and intermediate belts crop out extensively in the Varanger–Kildin Zone, while those of the intermediate and internal belts appear in the Timan–Kanin Zone.

Ideas on the structure of the Pre-Palaeozoic basement of the Timan - Pechora - Ural Region and its extension beneath the Barents Sea

Investigations of the Riphean rocks and structures of the Timans have been fundamental not only for the notions of facies and tectonic zonation but also in providing some general ideas on the structure and age of the Timan–Pechora–Northern Urals region. These ideas and interpretations reviewed briefly below, have been extended by various Russian workers to the deep structure of the Barents Shelf.

Two alternative models have been forwarded for the basement structure of this region and both seem to have been originally suggested by Schatsky (1935, 1964). In general terms, the main features of the models are as follows: 1) the development of one broad Riphean geosyncline oriented NW–SE and embracing the Timans, the substratum of the Pechora Basin and the Urals; 2) the existence in Riphean time of two independent depositional basins: Timanian and Uralian. Subsequently, two schools of thought have developed among Russian geologists supporting one or other of the models, and the problem is still far from being solved.

Zhuravlev, Osadchuk, Gafarov and others in a series of papers have developed the model of the *Timan–Ural Riphean Geosyncline* (e.g. Zhuravlev & Gafarov 1959; Zhuravlev & Osadchuk 1960, 1962; Gafarov 1966; Zhuravlev 1964, 1972; Zhuravlev et al. 1965; Vasserman et al. 1968; Morkrushin & Tarbayev 1973). South-western miogeosynclinal and north-eastern eugeosynclinal parts have been differentiated in this broad depositional basin, which is thought to be present beneath the Pechora Basin and the Pechora and Barents Seas (Figs. 4; 5a).

As shown in Fig. 4 the miogeosynclinal portion of the Timan–Ural geosyncline has been further subdivided into 1) *western marginal* and 2) *eastern internal* zones based on differences in lithology and the degree of structural deformation, which is much more advanced in the eastern zone. Sequences in these two zones were initially considered as facies equivalents (Zhuravlev & Osadchuk 1960) but later the idea of tectonic zonation was forwarded (Zhuravlev & Osadchuk 1962), the marginal and internal zones being thought to represent diachronous deposits related to stages of tectonic development of the miogeosyncline. Carbonates of the Bystrynskaya Formation (see p. 325) have been regarded as having developed at the junction between the two zones (Getsen 1970, 1971b; Zhuravlev 1972). The miogeosynclinal Riphean structural complex is characterized by distinct negative magnetic anomalies and both magnetic and gravimetric surveys have indicated that is is bordered to the south-west by a system of deep-seated en échelon lines of discontinuity – the marginal suture of Russian geologists – while the so-called East Timan

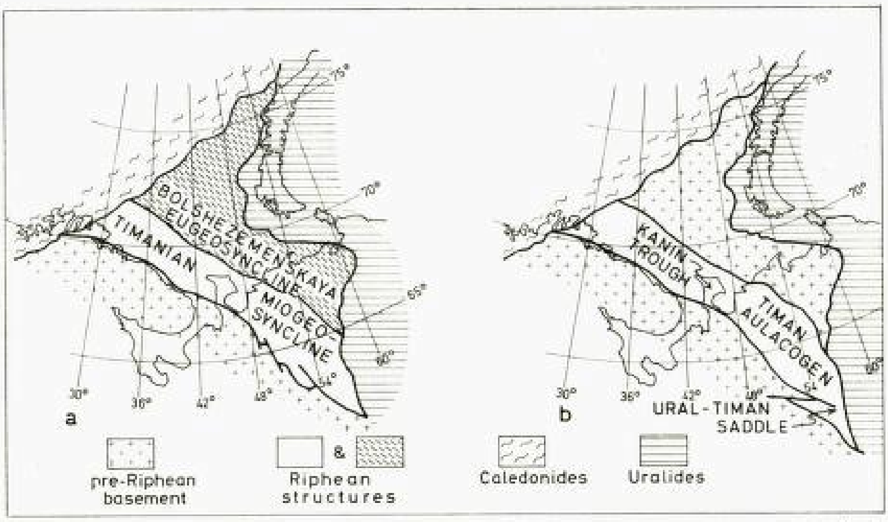

Fig. 5. Alternative interpretations of the structure of the pre-Palaeozoic basement of the Timan–Pechora–Urals Region (after Bogdanov 1965; Gafarov 1966; Siedlecka & Siedlecki 1967; Provodnikov 1970). (See text for detailed explanation.)

deep fracture delineates the Timanian fold belt in the north-east bordering the proposed Riphean eugeosyncline (Zhuravlev & Gafarov 1959; Gafarov 1963, 1966).

According to the second model, the Timan–Kanin Zone represents a post-Karelian, intracratonic, deep trough which has been variously described as an orthogeosyncline, intracratonic geosyncline, miogeosyncline or aulacogen (Stille 1955; Bogdanov 1961, 1965; Offman 1961; Schatsky 1955, 1964; Raznitsyn 1962, 1965, and others (Figs. 4; 5b). More recently Provodnikov (1970, p. 40) has worked out a more detailed structural picture of the Timan–Kanin Zone subdividing it into the Timan Aulacogen, the Kanin Trough, the Ural–Timan Saddle and the Timan Foredeep and has suggested that this structural framework is Karelian in age – a view which is not consistent with geological data. His structural model is in line with Schatsky's (1964) general idea, and this constitutes a contribution to the principal discussion on the structure of the basement of this region; his suggestions on age must obviously be rejected, however.

The present author is in favour of the second model for the following reasons: 1) Some new data on the nature of Riphean strata from the western part of the Northern Urals indicate that they are representative of trough (or miogeosynclinal) deposits rather than of a eugeosynclinal facies (e.g. Provodnikov 1970; Puchkov & Raaben 1972), and thus the postulated continuation of the 'eugeosynclinal' Riphean of the Urals beneath the eastern Pechora Basin (the Bolshezemenskaya Tundra) does not seem to be applicable any longer; 2) The Timan–Kanin Zone has represented a tectonically active (mobile) belt over a relatively short time-span in comparison with the Uralian fold belt. This situation is easier to explain if one assumes the existence of two separate zones of different mobility, and the known dynamic relations between the geosynclines and associated aulacogens, for example from the substratum of the Siberian Platform, (e.g. Salop & Scheineman 1969), appear to provide a satisfactory comparative model; 3) The field of positive magnetic anomalies characteristic of the Pechora Basin separates the Urals from the Timans which both represent quiet magnetic zones (see Demenitskaya 1967); 4) An explanation for the prominent deflection of structures of the Polar Urals towards Novaya Zemlja becomes simpler if one accepts the presence of an irregular rigid plate west of the Polar and Northern Uralian orogenic belt rather than the occurrence of a common broad Timan–Ural eugeosyncline; 5) Seismic data published by Litvinienko (1968) also support the idea of the existence of a pre-Riphean craton north of the Riphean complex detected in the southern Barents shelf (see p. 330 in this paper). It should be said, however, that none of the above points dismisses the first hypothesis and that conclusive evidence in favour of one or other of the theories is still lacking.

Returning to the subject of linear zonation of the sedimentary facies and structure development of the East Finnmark–Timan Region, a more or less symmetrical zonal arrangement of the depositional regimes has to be assumed to be present at depth beneath the Pechora Basin if one accepts the hypothesis of the occurrence of an independent Timanian sedimentary basin, although some asymmetry in this theoretical distribution pattern may of course be allowed. On the other hand, in moving from the continental margin located close to the Timans towards the Uralian basin one should expect an asymmetrical facies distribution if one accepts the first hypothesis.

Relationship of the Timanian Baikalides and Scandinavian Caledonides

Ideas on the occurrence of a major orogenic belt along the north-eastern margin of the Fennoscandian Shield have developed since the end of the nineteenth century. Ramsay (1899, 1911), Reusch (1900) and Tschernyschew (1901) have already suggested the presence of an old orogen, the Timanian Fold Belt, stretching from the Timans to Varanger. Schatsky (1935, 1958, 1960) later elaborated on the geological implications of this idea of the early explorers: he defined the Timanides as a Riphean Fold Belt deformed during the Baikalian Orogeny which predated the Caledonian diastrophism. Several Russian geologists have also suggested alternative interpretations for a further westward continuation of this orogenic belt, i.e. its relationship to the Scandinavian Caledonides. Some (e.g. Polkanov & Gerling 1960) have suggested that the Timanian Baikalides bend south-westwards and have in general the same trend and extent as the superimposed Scandinavian Caledonides. There is, however, no field evidence to support this hypothesis and it has been completely abandoned by later Russian students, who in turn have forwarded an alternative interpretation according to which the NE extension of the Scandinavian Caledonides crosses the Timanian Baikalides beneath the platform cover of the Southern Barents Shelf (e.g. Atlasov 1964; Gafarov 1966; Emelyanov 1971; Zhuravlev 1972). Raznitsyn (1962) has independently suggested an intermediate model.

Geologists dealing with problems of Late Precambrian geology in Scandinavia have not been very much involved in the discussion of a possible continuation of the Timanian Baikalides within and off the coast of northern Norway. Holtedahl (1918, 1960) has been inclined to believe that some structural features of eastern Varanger Peninsula might have constituted relics of the Timanian structural trend, and he was aware of the overall lithological similarity between the Varanger, Rybachiy–Sredniy and Kildin succession. This is in full agreement with the recent geological data collected by Siedlecka & Siedlecki (1967, 1972).

In the Varanger–Kildin Zone distant Baikalian movements have caused periods of tilting and erosion. These are recorded by the angular unconformity within the Riphean sequence (on Varanger Peninsula) and that occurring between the Riphean and Vendian successions (Varanger and Aynov Islands). As mentioned earlier (p. 317), although the NW–SE oriented cross-folds of the Vardø area are, according to Roberts (1972), essentially Caledonian, similarly trending folds in the central and south-eastern parts of Varanger Peninsula have not been studied in detail. It could be suggested, therefore, that some of these open NW–SE structures may be related to the Baikalian folding, which is quite well developed on Rybachiy–Srednyi. The high K/Ar ages of some dolerite dykes on Varanger Peninsula (Beckinsale et al., in press) should also be kept in mind in considerations of the tectonic deformation of the area, but a final solution of this problem must wait until more data are available. In general, the pre-Caledonian structure of the Varanger–Kildin Zone is not especially complex and the zone may therefore be regarded as representing the peripheral belt of the Timanides, the central more strongly deformed zone of which probably lies buried beneath the Barents Shelf.

The Trollfjord–Komagelv–Rybachiy Fault Zone is considered by the present author as a structure genetically related to a primary fracture zone, which helped to initiate the Upper Precambrian depositional basin, this idea being based on comparison with the deep structure of the Timans. Assuming that this fracture has been a zone of weakness in the crust, subsequent upthrusting, down-faulting and strike-slip multiphase movements may be envisaged to have occurred along this essentially ancient feature. Some of the strike-slip movements, suggested on the basis of regional geological and structural data (Laird 1972; Roberts 1972; Harland & Gayer 1972), could have occurred very late (? Cenozoic), at much the same time in fact as the parallel fault zones detected offshore which follow the ancient structural trend (e.g. Klenova 1960; Emelyanov et al. 1971; Åm, *vide* Roberts 1972).

Harland & Gayer (1972) and Gayer & Roberts (1973) have suggested the name 'Southern Barents Sea Caledonides' or 'Barents Sea Caledonides', respectively, for NW–SE oriented structural complex underlying the north-eastern parts of the Varanger and Rybachiy Peninsulas. These 'Southern

Barents Sea Caledonides' in general trend and extent correspond to what has been considered as a continuation of the Timanides and later, more specifically, as an outer structural portion of the Kanin–Timan Baikalian Orogenic Belt (e.g. Atlasov 1964).

The two principal orogenic belts — the older Baikalian Timanides and the younger Scandinavian Caledonides — have resulted from several pulses of crustal deformation, and by definition there exists a certain overlap of movements in time. The Baikalian orogeny has been assumed by Schatsky (1960) to have been completed by Middle Cambrian, while Harland (1965) has suggested that the duration of the Caledonian diastrophism might extend from 800 ± 100 to 350 m.y., although usually the Caledonian orogeny is understood as a lower Palaeozoic period of crustal movements. In north-western Norway there is now good evidence that the main *Caledonian* metamorphism and folding occurred in late Cambrian to early Ordovician times, 530–500 m.y. (Sturt et al. 1967; Pringle & Sturt 1969; Pringle & Roberts 1973), with a second metamorphic event in the Silurian, 420–384 m.y. There are as yet no data on the age of the Caledonian deformation in the north-easternmost part of Norway; Roberts (1972) has argued that although Tremadocian fossils are present in one area such that the main deformation may possibly be regarded as Silurian, structural continuity towards the south-west suggests that the main folding and metamorphism in the Barents Sea Region could very well be late Cambrian/early Ordovician, as in west and central Finnmark.

On the other hand, the K/Ar ages of syn-tectonic and partly post-tectonic basic dykes of the Barents Sea Region (Beckinsale et al. in press) fall generally within the range 542 m.y. to 1000 m.y. These data, although only preliminary, are indeed indicative of some pre-Caledonian, early-Baikalian disturbances.

The last *Baikalian* metamorphic event in the Timans and on Kanin took place around 525–520 m.y., i.e. contemporaneously with the peak of Caledonian orogeny in north-western Norway. The angular unconformity at the Riphean/Vendian interface in north-eastern Norway must be thus thought either as the last definite trace of the Baikalian orogeny or as reflecting an initial stage of the Caledonian diastrophism. It is evident that there is no time gap between the Caledonian and Baikalian orogenies to make these positively distinguishable, nor are they spatially distinctly separated. The precise character of the junction between the two fold belts, the Scandinavian Caledonides and the Timanian Baikalides, is not known because the critical land areas of East Finnmark embrace only the peripheral parts of these fold belts and require further detailed investigation. The overlap in time, no matter what is the structural pattern of the junction between the more central parts of the two discussed orogenic systems (i.e., either a transection of structural trends or a bending), is indicative of: (1) the occurrence, in the vast Finnmark–Timans region, of several pulses of crustal movement which have been somewhat artificially assigned to two separate orogenies and, (2) a gradual shift of intensity of movements towards the west and south-west (the Timans→Northern-Scandinavian Caledonides→Central Scandinavian Caledonides), this reflecting changes in the pattern of mobile and stable areas of the crust.

Suggested genetic relationships between the Uralian, Timanian and Scandinavian orogenic belts

Because the problem of the deep structure of the SE Barents Shelf and the Pechora Basin has not been finally solved (see pp. 333, 335), in these further general consideration I have assumed that one of the two existing alternative models is more credible than the other. For the reasons presented above (p. 334) I have accepted the reconstruction in which the Timanian and Uralian basins have been independent palaeogeographically and the Fennoscandian Shield has been separated from the Barents Shield by the Timan Aulacogen (Fig. 5b). Following from this, assuming continental drift to be a phenomenon of general application I have then attempted to translate the relationships between Scandinavian Caledonides, Uralides and Timanides into the language of plate tectonics.

Although controversial models exist, the concept of continental drift has been shown to be applicable to the early history of the North Atlantic Ocean (Wilson 1966; Harland 1967, 1969, 1973). The proto-North Atlantic is considered to have opened probably sometime in the Precambrian (?Middle/ Upper Precambrian) and to have existed through to late Palaeozoic time. Modifications of the ocean topography and of the distribution of geosynclines have occurred due to changes of relative plate movements, and zones of plate convergence are recorded by fold-belts.

Harland & Gayer (1972), in an analysis of the early stages of development of the proto-North Atlantic, have suggested the occurrence of rifting between the Baltic and Barents cratons (their Fig. 2a) in late Precambrian time. This initial rifting developed in the late Precambrian/early Palaeozoic time into a zone of oceanic spreading, the Iapetus Ocean (their Fig. 2b), which in this interpretation is located in a position intermediate to the structural units inferred by Russian geologists to occur beneath the Barents Shelf: the Timanian Baikalides and the Norwegian–Barentsian Caledonides (e.g. Atlasov 1964; Gafarov 1966).

In order to fit the model of oceanic spreading suggested by Harland & Gayer (1972) with more recent Russian structural maps of the Barents Shelf, I would suggest that the Iapetus Ocean in fact coincides with the Norwegian–Barentsian Caledonides and is independent of the Timanian fold belt. Furthermore, the deep structure of the Barents Platform is here differentiated into the Barents Craton in the north-west separated by the Norwegian–Barentsian Caledonides (Iapteus Ocean) from the *Pechora Craton* to the south-east. The Pechora Craton is a new term which I have introduced for the deep substratum of the south-eastern portion of the Barents Shelf and the Pechora Basin. I retain the term Barents Craton for the north-western portion of the Barents Shelf substratum: see also Glossary, p. 348). The Pechora Craton would be separated from the Fennoscandian Shield by the Timanian Baikalides (the Timan Aulacogen). An outline of this suggested distribution is shown in Fig. 6.

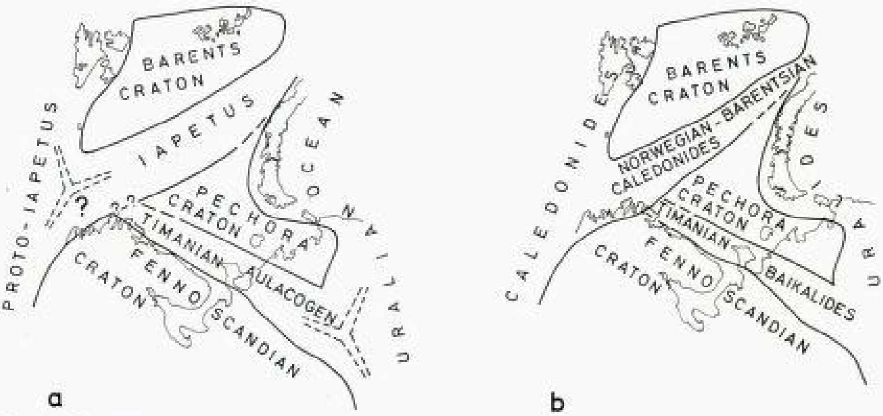

Fig. 6. Palaeogeographic (a) and structural (b) setting of the Timanian belt in the basement of the Barents Shelf (see text for detailed explanation).

To the east of the Fennoscandian, Barents and Pechora cratons there existed the Uralian Ocean, which, as with the proto-North Atlantic, persisted throughout Palaeozoic time. The opening of this basin presumably occurred sometime in the Middle/Upper Precambrian and the thick eugeosynclinal and miogeosynclinal Riphean sequences were then deposited. Analysis of the geological and geophysical information has suggested the existence of an earlier eastward-dipping subduction zone (between the Russian Plate and an inferred island arc) and of a later developing Benioff zone along which oceanic crust has been disappearing until the Russian and Siberian plates collided in Permian/Triassic time (Hamilton 1970). Although the Precambrian/Cambrian history of the Urals is somewhat uncertain and difficult to interpret in terms of plate tectonics, it would seem that the first period of converging plate movements has produced the Baikalian (? and Caledonian, see Raznitsyn 1962, 1972) pre-Uralids and the second the Hercynian Uralids of the Russian geologists (e.g. Bondarev et al. 1973).

In the above crude simplification of the suggested history of the proto-North Atlantic and Uralian oceans I have attempted to show that since ? Middle/Upper Precambrian time the Fennoscandian Shield and the Barents and Pechora cratons have been bordered by two geographically and temporally extensive oceans in which shelf deposits and thick geosynclinal sequences were accumulated. Oscillatory movements of plates underlying and bordering the two respective oceans were not synchronized, although both oceans closed at about the same time. In the light of all this the history of the Timan Aulacogen appears much shorter and simpler; it is a sedimentary basin which probably opened sometime in the Middle/Upper Precambrian and ceased to exist by the very end of the Precambrian. This narrow elongated basin probably resulted from a restricted intracontinental spreading down-warping and faulting followed by folding and upthrusting of the accumulated sediments without any subduction zone development. Rifting was probably shallow in contrast to equivalent phenomena in the Uralian and proto-North Atlantic oceans. Thus, although the initial opening of all three basins probably occurred more or less simultaneously in Precambrian times, their subsequent histories have been quite different, the Timanian basin being a zone of comparatively weak tectonic activity of short duration. Data on the suite of igneous rocks of the Timans (p. 328, Fig. 4) are not very helpful for purposes of interpretation. The variety of intrusive bodies indicates that they might have been related to periods of mantle upwelling and to phases of relaxation post-dating compressive stresses.

Aulacogens are, by definition, deep linear troughs genetically related to extensive oceanic basins or geosynclines, arranged transversely to the margins of the platforms and dying out towards the centre of a craton. Since the Timanian Aulacogen is oriented more or less perpendicular to the main trend of both the proto-North Atlantic and the Uralian basins, an important question immediately arises; did two separate genetic junctions exist, 1) the Uralian/Timanian junction and 2) the proto-North Atlantic/Timanian junction, or was there only one and, if so, where was it located? Theoretically both possibilities are equally probable; however, sedimentary facies, stratigraphy and structure of the Riphean of the Urals and the Timans are strongly suggestive of a Timan–Ural palaeogeographic interconnection, and some further suggestions may be made taking into account data on current directions in the Riphean strata of north-eastern Norway. These are indicative of a south-westerly to westerly source of supply, a fact which suggests the occurrence of a topographic high located to the W–SW at least during a part of Riphean time, with a roughly eastward longitudinal transport along a basin inclined towards the Uralian Ocean. If this is assumed as a general feature, not only restricted to north-eastern Norway, the Timanian Aulacogen would not have had a direct connection with the proto-North Atlantic Ocean. On the other hand, the great thickness of the basinal Riphean strata of Varanger Peninsula is very suggestive of a considerable north-westward extension of a palaeogeographically important sedimentary basin related to the proto-North Atlantic Ocean.

Summing up the various evidence, two alternative solutions may be offered to explain the evolution of the Timanian basin: 1) the Timan Aulacogen was genetically related only to the Uralian Ocean, and extended north-westward towards the proto-North Atlantic; or 2) two separate aulacogens developed simultaneously related to the proto-North Atlantic and to the Uralian Ocean, these merging either temporarily or permanently into one. The second idea of two independently created aulacogens seems rather difficult to imagine, and I am therefore inclined to believe in the first possibility, the development of the Timanian Aulacogen related to the Uralian Ocean. In this model, the fairly rapid sagging and NW longitudinal extension of the aulacogen is seen as resulting in a connection and eventual merging with the proto-North Atlantic Ocean.

In my attempt to combine the notion of aulacogen development with the concept of plate tectonics I have found the suggestions made by Hoffman

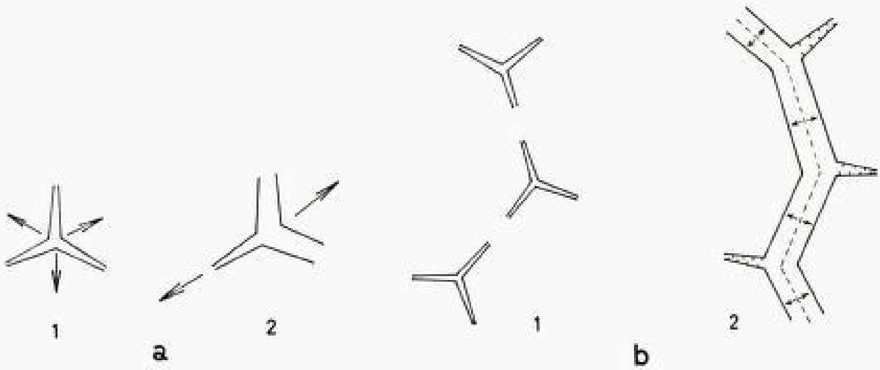

Fig. 7. Diagrammatic representation of (a) the development of an aulacogen from a triple junction and (b) the development of an ocean and associated aulacogens from a set of triple junctions.

(1972)* for the Precambrian of the NW Canadian Shield to be the most applicable in the present situation. Adapting this, I have envisaged a primary intracontinental junction between three spreading zones (the RRR type of McKenzie & Morgan 1969) at the Timanian/Uralian junction (Fig. 6). I have then assumed that the initially similar velocities of spreading could have subsequently changed with two of the three fractures becoming particularly active. As a result of this high mobility the Uralian Ocean would have developed rapidly, whereas the third branch, the Timanian Aulacogen, would have opened relatively slowly; active dilation in this third arm diminished fairly quickly and an underdeveloped abandoned basin, the aulacogen, was produced. The development of such a dynamic system is shown schematically in Fig. 7**. The early Proterozoic structure of the Siberian Platform may serve as a particularly good example of such a theoretical model. An extensive ocean with large geosynclines was developed there south of an ancient shield, and three aulacogens radiating northwards from the northern oceanic margin subdivide the shield into several cratonic blocks, the Angara and Aldan cratons being the most extensive (Salop & Scheinman 1969: Leytes et al. 1970).

The interpretations and ideas as presented in this paper by no means solve the problem of the deep structure and crustal history of the Barents Shelf and of the nature of the north-eastern continental margin of the Fennoscandian

* A modified and extended version of Hoffman's paper appeared in print after this manuscript had been submitted for publication: Hoffman, P., Dewey, J. F. & Burke, K. 1974: Aulacogens and their genetic relation to geosynclines, with a Proterozoic example from Great Slave Lake, Canada. *In* R. H. Dott Jr. & R. H. Shaver (Eds.): Modern and ancient geosynclinal sedimentation. *SEPM Spec. Publ.* No. 19, 38–55.

** The hypothesis presented for the formation of the Timanian Aulacogen has parallels in a recently published model (Burke & Dewey 1973) of plume-generated triple junction development according to which the opening of two of the three rifts, the third being an inactive failed arm, is suggested to be a general feature of intracontinental triple junction evolution. The actual number of the *Journal of Geology* (Vol. 81, No. 4) in which Burke & Dewey's (1973) paper appeared was not received by the NGU library until January 16th 1974, after the draft of my manuscript had been written and the main ideas presented at the Bergen University Oil Conference, December 15th, 1973.

Shield. The model of an aulacogen related to the Uralian Ocean and possibly also to the proto-North Atlantic, although admittedly based on relatively sparse evidence, is, however, surely one of several possible approaches which, it is hoped, will lead to our eventual understanding of this part of the earth's crust. In writing this paper I have intended to attract the attention of other students to the problems of the Late Precambrian structure of the north-eastern margin of the Fennoscandian Shield and adjacent fold belts and to initiate interest and discussion; if this is achieved a principal aim will have been fulfilled.

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Abbreviations:
AN SSSR A. Sci. USSR – Academy of Sciences of the Union of Soviet Socialist Republics.
AAPG – The American Association of Petroleum Geologists.
GSA – The Geological Society of America.
Izv(estia) – Proceedings.
MOIP – Moskovskoye Obshchestvo Ispitateley Prirody – Moscow Society of Naturalists.
GIN – Geological Institute.

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GLOSSARY

Upper Proterozoic: ca. 1600–560 m.y. (Garris et al. 1964). The term embraces Riphean and Vendian and corresponds approximately to Middle & Upper Proterozoic of the Canadian scheme (Semikhatov 1973).

Upper Precambrian = Upper Proterozoic.

Late Precambrian: corresponds to Upper Proterozoic as defined above, used rather informally.

Riphean: term introduced by Schatsky (1945) for the sedimentary Precambrian succession of the Bashkirian Urals. Embraces most of the Upper Precambrian: ca. 1600–650 m.y. Subdivided into Lower R. (1650 ± 50–1350 ± 50 m.y.), Middle R. (1350 ± 50–950 ± 50 m.y.) and Upper R. (950 ± 50–650 ± 50 m.y.) on the basis of stromatolites, onkolites and catagraphs (Garris et al. 1964).

Vendian: Term introduced by Sokolov (1952, 1958) for the youngest stratigraphic unit of the Upper Proterozoic: 650 ± 50–560 ± 50 m.y. Some beds assigned to Vendian exhibit higher ages (see e.g. Sokolov 1973). Characterized by a widespread glaciation. Equivalent to the Eocambrian of Norwegian geologists.

Varangian Ice Age: term introduced by Harland (1965a). Represented by glacigene deposits of Vendian age.

Aulacogen: term introduced by Schatsky (1964) to designate large, fault-bounded, graben-like downwarps genetically related to geosynclines. Aulacogens radiate inwards from platform margins, are characterized by gentle to moderate folding and their tectonic activity decreases with increasing distance from the platform/basin margin (Salop & Scheinmann 1969; Bogdanov et al. 1972).

Baikalian Orogeny: tectonic movements which occurred around the time of the Precambrian/Cambrian transition and which were completed in the Middle Cambrian. Initial movements are known from the Lower Riphean (Schatsky 1932, 1935, p. 154; *vide* his papers of 1958, p. 99; 1960).

Barents Platform: comprises Palaeozoic–Cenozoic sequences of the Barents Shelf overlying the Barents Craton, Pechora Craton, Norwegian–Barentsian Caledonides and the Timanian Baikalides.

Barents Craton: basement of the north-western part of the Barents Platform.

Pechora Craton: new term (Bolschemenskaya Zona of Gafarov 1966); basement of the Pechora Basin, Pechora Sea and south-eastern part of the Barents Platform.