ISSN 1028-334X, Doklady Earth Sciences, 2007, Vol. 412, No. 1, pp. 58–63. © Pleiades Publishing, Ltd., 2007.
Original Russian Text © I.I. Golubeva, L.V. Makhlaev, M.M. Afon'kin, 2007, published in Doklady Akademii Nauk, 2007, Vol. 412, No. 4, pp. 518–523.

GEOLOGY

Ilmenite-Bearing Metapelites of the Polar Urals and Taimyr Peninsula and Continuation of North Uralian Structures

I. I. Golubeva, L. V. Makhlaev, and M. M. Afon'kin

Presented by Academician N.P. Yushkin, January 31, 2006

Received March 9, 2006

DOI: 10.1134/S1028334X07010138

The issue of relationships between the Urals and structures of adjacent regions arose even before the authors of the first geological map of European Russia considered it. In 1896, F.N. Chernyshev suggested that the Uralian mountain range is conjugated with folded structures of Novaya Zemlya via Pai-Khoi and Vaigach to form the single Urals–Novaya Zemlya folded region, which is also recognized now by most geologists. Based on similarity between rocks from these regions [1, 2], Baklund assumed that Taimyr rather than Novaya Zemlya represents geological continuation of the Urals.

Both the Novaya Zemlya and Taimyr concepts have their adherents, and the problem remains unsolved thus far. The tectonic map of Eurasia published in 1966 demonstrates the Urals–Novaya Zemlya belt [3], while the monograph *Tectonics of the Lithospheric Plates of the USSR* considers the Taimyr version: "The folded basement of the Central Taimyr zone … resembles Late Precambrian structures of the Polar Urals (Kharbei anticlinorium and its analogues)…. Therefore, we believe that the Central Taimyr block was an element of the Precambrian basement of the Polar Urals and Pechora Lowland, i.e., Barentsia" [4, p. 75]. A similar model is used in some other works (e.g., *Paleovolcanic Atlas of Northeastern Eurasia* published in 2001). At the same time, geological maps of the Uralian series (Scale 1: 1 000 000) published in the same period were compiled in line with the Novaya Zemlya version [5].

We have worked in different years in both Taimyr and the Polar Urals. Without claiming a definitive solution of the more-than-century-old issue, we would like to present some new data, which may provide new insight. We focus attention on the presence of specific rocks, such as alumina schists with platy ilmenite porphyroblasts in the Kharbei anticlinorium of the Polar Urals and Central Taimyr anticlinorium (CTA). In the Polar Urals, they are represented by garnet–staurolite and ilmenite-bearing kyanite schists of the Parikvas'shor Formation [6]: in the CTA, by rocks of the Voskresenka Formation: ilmenite-bearing aluminous phyllites, garnet–staurolite–biotite schists, rutile-bearing garnet–cordierite–sillimanite schists, and gneisses [7]. Both the Parikvas'shor Formation and the Voskresenka Formation are Proterozoic (typical flyschoid) sequences, in which metapelites alternating rhythmically with metasiltstones and metasandstones constitute upper elements of rhythms.

Metapelites of the Voskresenka Formation are characterized by substantially higher compositional diversity. They include rocks of three (greenschist, epidote–amphibolite, and amphibolite) facies. In contrast, high-Ti metamorphites of the Parikvas'shor Formation belong to a single epidote–amphibolite facies. This is explained by the different sizes of corresponding geological blocks. The Voskresenka Formation is traced in the CTA for hundreds of kilometers: from the Lenivaya River in the west to the Taimyr Estuary in the east. Metamorphism in this block demonstrates distinct zoning with isogrades of metamorphic index minerals crossing stratigraphic boundaries. This was established by Urvantsev [8] and confirmed repeatedly in subsequent studies [7, 9]. The metamorphism grade first increases gradually from the west (phyllite zone) to the east (gneiss and migmatite zone) and then decreases further in a similar manner. The Kharbei anticlinorium (in present-day contours) is an order of magnitude smaller than the CTA, and no significant variations in the metamorphism grade are established within outcrops of the Parikvas'shor Formation. Therefore, we compare in this communication metapelites of the Polar Urals not with rocks of the whole Voskresenka Formation, but only with the isofacies rocks, i.e., metapelites of the epidote–amphibolites facies devel-

---

Institute of Geology, Komi Scientific Center, Ural Division, Russian Academy of Sciences, ul. Pervomaiskaya 54, Syktyvkar, 167982 Russia; e-mail: lev@geo.komisc.ru

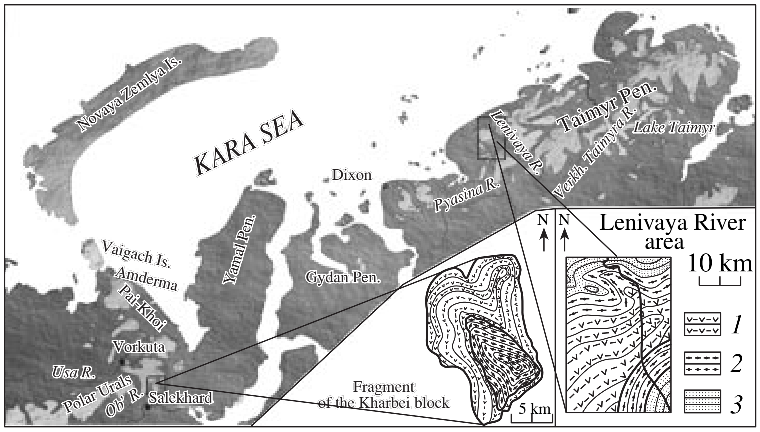

Fig. 1. Schematic location of considered areas with ilmenite-bearing metapelites in the Polar Urals and Taimyr Peninsula. (*1*) Riphean metabasites (Lapta-Yugan and Khanmekhoi formations in the Polar Urals and Trevozhnaya Formation in the Taimyr Peninsula); (*2*) Riphean flyschoid sequences with interbeds of ilmenite-bearing metapelites (Parikvas'shor Formation in the Polar Urals and Voskresenka Formation in the Taimyr Peninsula); (*3*) Lower Paleozoic flysch formation of the Taimyr Peninsula (Sterligov Formation).

oped at the western margin of the CTA at lower reaches of the Lenivaya River (Fig. 1).

Brief petrographic characteristic. High-Ti metapelites in the Parikvas'shor block of the Kharbei antioclinorium and in the Lenivaya area of the CTA are represented by rocks with a distinct porphyroblastic texture and schistose structure. Porphyroblasts are composed of garnet (1–5%), staurolite (3–20%), and ilmenite (2.5–6.0%). Garnet occurs as rounded, almost euhedral grains 2–5 mm across. Distinctly prismatic staurolite crystals are 5–12 cm long and 1–3 cm thick. One can also see staurolite prisms more than 30 cm long and garnet porphyroblasts more than 1 cm across. Alumina schists of the Parikvas'shor block contain abundant prismatic kyanite crystals that are missing from rocks of the Lenivaya River area. Ilmenite forms isometric plates with the predominant development of pinacoid facets in combination with facets of several rhombohedrons from 5 to 15 mm across and up to 1.5 mm thick. The ilmenite grains are usually homogeneous. However, they contain numerous poikilitic quartz inclusions in the primarily sand-rich interbeds. The groundmass has a granolepidoblastic texture and consists of chlorite, biotite, muscovite (50–65 vol % in total), quartz, and occasional albite.

The rocks under consideration are very similar to each other in terms of both their appearance and mineral composition. The presence of metamorphic ilmenite in the Taimyr Peninsula and Urals is the most specific feature (Fig. 2). Metapelites from the Lenivaya River basin lack kyanite, which plays a notable role in some Parikvas'shor schists. This is probably caused by specific tectonic settings in the Polar Urals. The mineral associations of these rocks correspond to either the epidote–amphibolite facies or the transitional zone of the amphibolite facies.

Petrogeochemical data. The chemical composition of schists under consideration indicates their indubitable affiliation to metapelites, although they lack real high-alumina varieties, i.e., rocks with an Al_2O_3 content of 30% or more (Tables 1, 2). In the diagnostic SAK diagram proposed by Golovenok [10], data points of rocks from the Parikvas'shor and Voskresenka formations are definitely confined to the area of metamorphites formed after hydromicas. The data points of rocks make up overlapping dispersion fields, which serve as additional evidence for their similarity (Fig. 3).

The contents of trace and rare earth elements in these schists, as well as their variations, are comparable (Tables 1). We pay special attention to the REEs, because their distribution differs from that in typical clays and metapelites. Typical spectra of the REE distribution in these rocks are summarized in [11]. They demonstrate a negative Eu anomaly and enrichment in LREE. This is evident from the distinct dextral slope of corresponding plots. A similar REE distribution was established in shales from the Riphean type section of the Urals [12]. Naturally, this "averaged" REE distribution in pelites and metapelites is virtually identical to their distribution in granites, because the majority of clays are products of continental weathering (residual or redeposited). As is known, the geochemical specificity of continental weathering crusts is determined by granitoids.

The REE spectra of ilmenite-bearing metapelites from the Polar Urals and central Taimyr are identical to each other. However, they differ from spectra of typical clays formed after granites (Fig. 4). The Eu anomaly in them is no less distinct, but it has the opposite sign. The slope is also opposite. This fact indicates moderate, although distinct enrichment of these rocks in HREE rather than LREE. In addition, the total REE content in them is substantially lower than in typical clayey sediments. We attempted to determine the mineral in metapelites responsible for the concentration of HREE. It was logical to attribute this role to ilmenite. However,

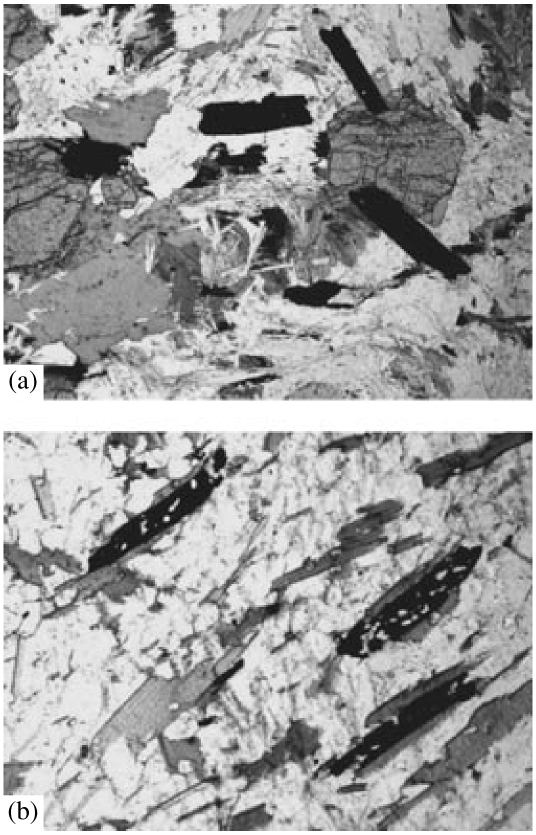

Fig. 2. Garnet–staurolite two-mica crystalline schists with platy ilmenite porphyroblasts: (a) Parikvas'shor Formation, Polar Urals, (b) Voskresenka Formation, central Taimyr Peninsula. Without nicols, magn. 10.

the REE spectrum obtained for Parikvas'shor ilmenite appeared principally different from that of the host schists. Although the REE content in ilmenite is substantially higher as compared with schists, the ilmenite is enriched in LREE rather than HREE and the Eu anomaly in the ilmenite spectra appeared to be negative rather than positive (Fig. 4c).

Ilmenite-bearing schists of the Polar Urals lack similarity with widespread metapelites in terms of REE distribution, but they appear to be very close in this respect to some igneous basic rocks. Similar REE spectra (with positive Eu anomaly and elevated contents of HREE) were obtained by different researchers for some basalts from mid-oceanic ridges and gabbroids from the gabbro–peridotite (mafic–ultramafic) layer of the oceanic crust. For comparison, we present averaged plots of the REE distribution in ilmenite-bearing metapelites of the Polar Urals and Taimyr and the REE spectrum obtained for gabbroic rocks from the ophiolitic complex of the Polar Urals (Fig. 4d). As is seen, the plots are practically identical. The similarity between spectra obtained for metapelites under consideration and those for basic rocks suggests that primary clays are products of the weathering of basic rocks. This assumption is consistent with the real geological situation: the flyschoid Voskresenka Formation in Taimyr unconformably overlies the substantially thicker Trevozhnaya Formation composed of metabasites [10, 13]. In the Polar Urals, the flyschoid Parikvas'shor Formation is also underlain by a significantly thicker metabasite sequence (Lapta-Yugan and Khanmeikhoi formations). It cannot be ruled out that the

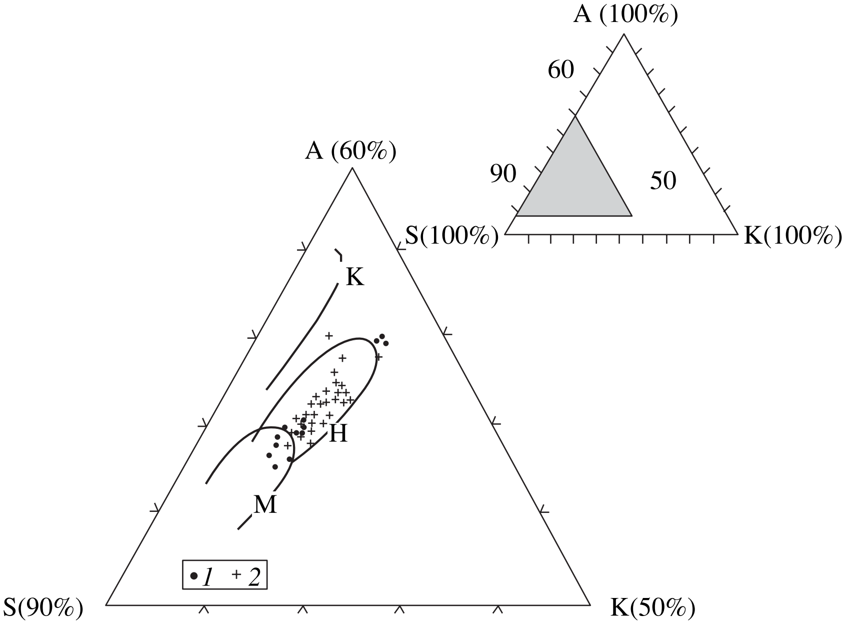

Fig. 3. Ilmenite-bearing metapelites in the SAK diagram after [10]: (S) SiO_2, (A) $Al_2O_3 + TiO_2 + Fe_2O_3 + FeO + MnO$, (K) $K_2O + Na_2O + CaO + MgO$. Fields: (K) koalinitic clay, (H) hydromicaceous clay, (M) montmorillonitic clay. (*1*) Metapelites from the Parikvas'shor Formation (Polar Urals); (*2*) metapelites from the Voskresenka Formation (Taimyr).

Table 1. Contents of oxides (wt %) and trace and rare earth elements (ppm) in ilmenite-bearing metapelites of the Polar Urals and Taimyr Peninsula

Component	Polar Urals			Taimyr			
	28/89	28/94	1065/1b	1965T	90t	88t	53t
SiO_2	42.18	48.8	58.48	46.56	56.18	54.44	56.76
TiO_2	1.44	1.43	0.98	1.25	0.97	1.13	1.14
Al_2O_3	24.53	21.16	19.41	23.5	18.57	20.72	18.61
[FeO]	11.85	14.18	8.49	10.48	9.0	7.3	9.01
MnO	0.16	0.28	0.4	0.1	0.13	0.11	0.14
MgO	5.16	4.49	3.87	4.0	3.73	3.86	3.88
CaO	1.63	2.59	0.64	1.97	1.63	3.05	2.98
Na_2O	2.24	2.37	1.3	2.8	2.3	5.01	2.66
K_2O	6.81	4.3	3.95	3.99	2.43	2.01	3.22
P_2O_5	0.11	0.15	0.14	0.18	0.2	0.08	0.15
L.O.I.	3.38	2.27	2.88	4.34	4.0	1.5	0.48
Rb	173.6	121.6	104.6	318.0	113.5	104.2	85.3
Cs	14.8	16.1	0.99	0.52	n.d.	n.d.	1.6
Sr	340	320	130	105	355	115	300
Ba	1640	230	385	355	330	655	1060
Sc	29.2	26.6	31.2	28.0	22.3	25.4	23.6
Cr	95.9	99.9	456	97	118.6	115.7	84.5
Co	20.9	32.3	21.6	27	23.1	21.4	28.2
Ni	370	n.d.	690	120	170	40	170
Se	0.7	2.21	0.33	0.96	0.72	0.96	0.57
As	0.61	1.84	1.16	0.68	0.4	n.d.	0.92
Sb	0.51	0.46	0.34	0.61	0.44	1.0	1.25
Th	8.46	7.99	14.6	8.71	7.26	10.5	8.57
U	3.57	5.94	3.84	4.82	4.4	5.74	10
Br	0.49	0.24	0.34	0.63	0.27	n.d.	0.44
La	0.15	0.23	0.19	0.43	0.32	0.3	0.19
Ce	0.47	0.5	0.5	0.9	0.76	0.79	0.48
Pr	0.05	0.09	0.08	0.10	0.11	0.12	0.07
Nd	0.52	0.43	0.43	0.4	0.51	0.6	0.38
Sm	0.22	0.15	0.16	0.11	0.17	0.2	0.14
Eu	0.24	0.49	1.74	0.77	0.45	1.64	0.94
Gd	0.49	0.34	0.34	0.23	0.28	0.42	0.27
Tb	0.1	0.07	0.07	0.04	0.05	0.08	0.05
Dy	0.74	0.51	0.48	0.33	0.34	0.6	0.34
Ho	0.21	0.15	0.14	0.09	0.08	0.17	0.09
Er	0.76	0.54	0.48	0.29	0.27	0.59	0.27
Tm	0.15	0.11	0.09	0.06	0.05	0.11	0.05
Yb	1.03	0.76	0.62	0.4	0.29	0.77	0.33
Lu	0.22	0.17	0.13	0.08	0.06	0.17	0.06

Note: Contents of petrogenic components are determined by the X-ray fluorescence method at the Institute of Geology (Komi Scientific Center, Ural Division, Russian Academy of Sciences); trace elements, by the instrumental neutron activation method at the TsLAV of the Institute of Geochemistry and Analytical Chemistry, Russian Academy of Sciences. ([FeO]) Sum total of FeO and Fe_2O_3; (n.d.) not detected.

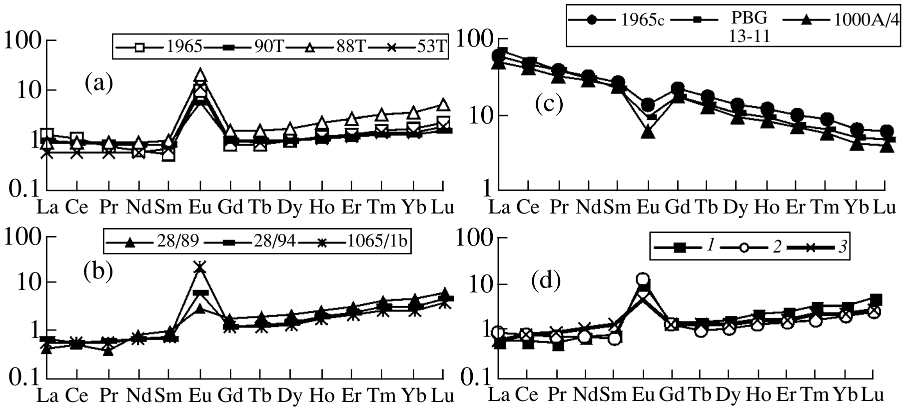

Fig. 4. The chondrite-normalized REE distribution in ilmenite-bearing metapelites of the Polar Urals and Taimyr Peninsula: (a) Voskresenka Formation (central Taimyr), (b) Parikvas'shor Formation (Polar Urals), (c) ilmenite metacrystals, (d) averaged spectra of ilmenite-bearing metapelites of Taimyr (*1*), ilmenite-bearing metapelites of the Polar Urals (*2*), and gabbro from the ophiolitic complex of the Polar Urals (*3*). In plots (a)–(c), numerals designate numbers of examined samples.

metabasite character of the parental substrate is also responsible for the elevated Ti content in corresponding clays, resulting in the formation of schists with metamorphic ilmenite during their metamorphism.

Discussion and conclusions. The obtained data indicate indisputable genetic relationships between rocks of the Parikkvas'shor and Voskresenka formations. Ilmenite-bearing metapelites from the Parikvas'shor block of the Polar Urals and Lenivaya area of the CTA demonstrate petrographic, mineralogical, and chemical similarities. The REE distribution in them is also virtually identical.

It is natural that these similarities cannot serve as an unambiguous indicator of direct relationships between structures of the Polar Urals and Taimyr Peninsula. However, the data are significant evidence in favor of such an inference. It is conceivable that the common Riphean Urals–Taimyr belt represented a fringing structure of the Barentsia (Arctida?) continent, as was assumed by Natapov in [4], and the continent was broken subsequently during initiation of the West Siberian Ocean. Other versions cannot be ruled out as well. For example, the Parikvas'shor block may be viewed as a large, although limited, fragment (terrane) that was separated from the Kara (Central Taimyr) belt of the Baikalides and accreted to the northernmost Urals. The terrane model is supported by the fact that ilmenite-bearing metapelites in the Urals are developed only in the area under consideration, while they extend for many hundreds of kilometers in Taimyr.

Table 2. Average chemical compositions of ilmenite-bearing metapelites from the Polar Urals and Taimyr Peninsula (wt %)

Component	Polar Urals (n = 16)	Taimyr (n = 29)
SiO_2	56.9	55.1
TiO_2	1.03	0.99
Al_2O_3	19.16	20.52
[FeO]	9.1	8.94
MnO	0.38	0.11
MgO	3.2	4.16
CaO	1.7	1.63
Na_2O	2.3	2.5
K_2O	2.1	3.28
P_2O_5	0.14	0.18

Note: (n) Number of analyses; ([FeO]) sum total of FeO and Fe_2O_3.

As for the more-than-century-old issue of the northern continuation of the Uralian fold belt, it is conceivable that adherents of both standpoints are right. At the pre-Phanerozoic and, probably, Early Paleozoic stages of the geological history of Eurasia, the Urals formed a single folded region together with Taimyr. The Urals–Novaya Zemlya belt was developed at the Late Paleozoic–Early Mesozoic stage.

REFERENCES

1. O. O. Baklund, *General Review of the Expedition of Kuznetsov Brothers to the Polar Urals in Summer of 1909* (St. Petersburg, 1911) [in Russian].

2. O. O. Baklund, Zapiski AN SSSR. Ser. VIII **21** (7), 1 (1929).

3. *Tectonics of Eurasia: Explanatory Notes to the Tectonic Map of Eurasia, Scale 1 : 5000000*, Ed. by. A.L. Yanshin (Nauka, Moscow, 1966) [in Russian].

4. L. P. Zonenshain, M. I. Kuz'min, and L. M. Natapov, *Tectonics of Lithospheric Plates of the USSR* (Nedra, Moscow, 1990), Part 2 [in Russian].

5. *The State Geological Map of the Russian Federation, Scale 1 : 1000000. New Series. Sheet Q-42, 43. Salekhard. Explanatory Notes* (VSEGEI, St. Petersburg, 1998) [in Russian].
6. I. I. Golubeva, in *Magmatites and Metamorphites in the North Urals and Timan* (Komi NTs, Syktyvkar, 1991), pp. 75–87 [in Russian].
7. L. V. Makhlaev and N. I. Korobova, *Precambrian Genetic Granitoid Series of the Taimyr (Metamorphism, Ultrametamorphism, and Granitization)* (Krasnoyarsk. Izd., Krasnoyarsk, 1972) [in Russian].
8. N. N. Urvantsev, Byull. Noril'sk. Kombinata, No. 1, 4 (1949).
9. A. I. Zabiyaka, *The Voskresenka Regional Metamorphic Field: The Reference Riphean Metamorphic Complex of Taimyr* (KNIIGiMS, Krasnoyarsk, 2000) [in Russian].
10. V. K. Golovenok, *Precambrian High-Alumina Formations* (Nedra, Leningrad, 1977) [in Russian].
11. S. R. Taylor and S. M. McLennan, *The Continental Crust: Its Composition and Evolution* (Blackwell, Oxford, 1985; Mir, Moscow 1988).
12. A. V. Maslov, M. T. Krupenin, Yu. L. Ronkin, et al., Litosfera, No. 1, 70 (2004).
13. *The State Geological Map of the Russian Federation, Scale 1 : 1000000. New Series. Sheet S-44–45. Ust'-Tareya. Explanatory Notes* (VSEGEI, St. Petersburg, 2000) [in Russian].