Geological Structure, Mineralogy, and Genesis of the Zhelannoe Quartz Deposit (Pripolyarnyi Urals, Russia)

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Geological Structure, Mineralogy, and Genesis of the Zhelannoe Quartz Deposit (Pripolyarnyi Urals, Russia)

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Abstract—The Zhelannoe vein quartz and rock crystal deposit are unique in their geological structure, scale and high quality of ore mineralization and mineral product. The economic ores of the deposit are enclosed in monomineralic quartzite–sandstones of Early Ordovician age. At the base of giant quartz veins, almost monomineralic sericitic rock bodies (sericitoliths) containing large amounts of rutile, zircon, and REE minerals occur. The origin of sericitoliths is not metasomatic according to some geological and mineralogical evidence. A model of synchronous deposition of the sericitoliths and vein quartz is proposed based on detailed geological, mineralogical, and geochemical study of the deposit. The model implies a liquation of the hydrothermal solution and consequent sedimentation of some of mineral substance in tectonic cavities. The consequent crystal formation was not accompanied by additional introduction of hydrothermal solution, but was caused by decreasing pressure in reopened cavities and by reactions between minerals and undersaturated solution that was residual after deposition of the vein quartz and sericitoliths. The economic concentration of rutile, zircon, and REE minerals and the high concentrations of Cr, W, Th, and Nb are determined for the first time in the sericitoliths.

INTRODUCTION

The Zhelannoe deposit is the largest among all mined vein quartz and rock crystal deposits in Russia. The high quality of the mined minerals and giant complex veins are specific features of the deposit. The first quartz crystals were found there in 1948 by A.N. Maiorov and his team, but systematic prospecting and exploration for piezooptical quartz and rock quartz started in 1966. The study of the vein quartz began in 1978. The following geologists performed various special investigations of the deposit: B.A. Goldin, V.V. Bukanov, V.A. Smirnova, B.N. Sharonov, D.V. Nikitin, A.V. Kozlov, and S.K. Kuznetsov. They constructed plans of the spatial distribution of quartz occurrences, carefully studied quartz crystals and other minerals of the crystal-bearing cavities, and began to study the constituents of the vein quartz.

The problem of quartz vein and rock crystal genesis is always a heated discussion between geologists. G.G. Lemlein and I.I. Shafranovskii were the first to pay attention to the similarity between crystal-bearing quartz veins at the Pripolyarnyi Urals and Alpine veins based on special mineralogical and crystallomorphological studies. The geologists noted, however, significant genetic differences between them as well. Karyakin and Smirnova (1967) concluded that quartz veins and crystal-bearing cavities are consequent stages of the same hydrothermal process, the formation of crystal-bearing cavities followed quartz vein deposition after a break. They further proposed that the magma chamber was a source for quartz veins, but the host rocks was the source for crystal pockets. Ermakov (1956) proposed to separate the crystal-bearing or so-called barren veins into a special hydrothermal–metamorphic group. Nevertheless, the genesis of the quartz–crystal mineralization is not clear yet. Its relation to the magmatic complexes at the Pripolyarnyi Urals is debated. The age of the known magmatic rocks in the region is probably Precambrian, but the age of quartz veins corresponds to the P–T boundary.

The detailed exploration of the Zhelannoe deposit allowed some thick bodies of sericite rocks (sericitoliths) that occur at the base of quartz veins to be studied. Such rocks were not found earlier at other quartz deposits. These rocks contain to 15–20 wt % of accessory minerals (rutile, zircon, monazite, xenotime, tourmaline, and hematite). Accessories in quartz veins and host quartzite–sandstones are absent or scarce. The sericitoliths are related to zones of vein-enclosing fissures and do not show any features of metasomatic genesis. Detailed study of these rocks provided new insight into genetic features of the deposit and the Pripolyarnyi Urals rock crystal province as a whole.

The author has been collecting data on geology of the deposit during its exploration from 1982 to 1994. These data were included in the geological report of 1988. The chief geologist of the exploration party, N.A. Pozhidaev, performed most of the structural study. Some special mineralogical and geochemical studies were continued from 1966 to 2000 with the support of the Institute of Mineralogy, Ural Division of the Russian Academy of Sciences.

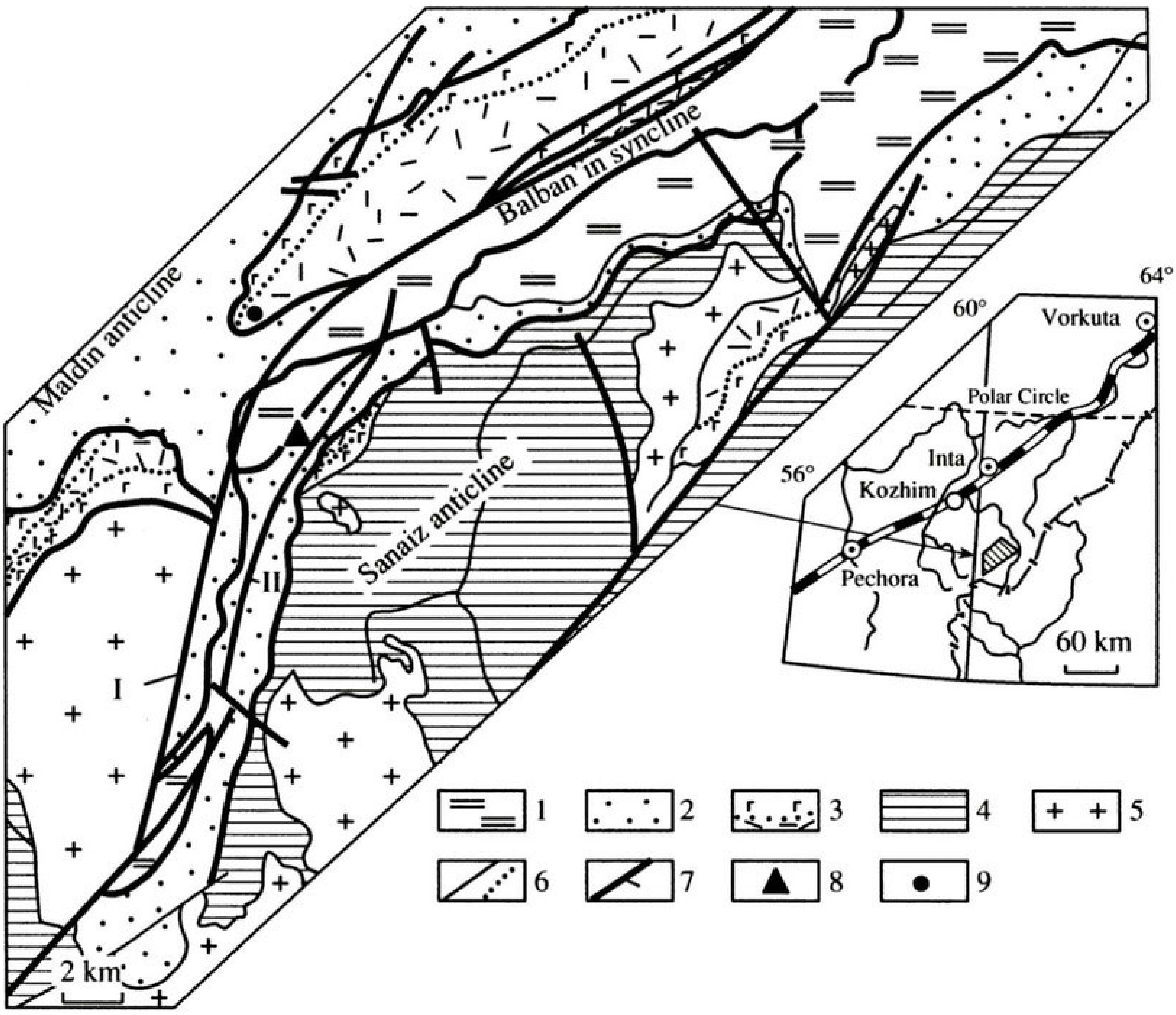

Fig. 1. Geological map of the Zhelannoe deposit district. 1—Shchugor (O_{2-3}scg) and Khydei (O_{1-2}hd) suites (limestones, calcareous sandstones, and aleurolitic schists); 2—Tel'pos suite (O_1tl) (conglomerates, gritstones, and quartzite–sandstones); 3—Sablegorsk suite (R_3sb) (acid and basic volcanic rocks); 4—Moroin, Khobein, and Puivin suites of the Upper Proterozoic complex (R_3mr–pv) (phyllitic schists, marbles, quartzites, and chlorite–muscovite–albite–quartz schists); 5—granites and granodiorites (γR_3–V); 6—geological boundaries between stratigraphic units and inside them; 7—regional faults (I—Maldin reverse fault; II—Zhelanin reverse fault); 8—Zhelannoe deposit of vein quartz and rock crystal; 9—Chudnoe gold–palladium occurrence.

GEOLOGICAL SETTING OF THE DISTRICT

The Pripolyar rock crystal province is located in the central Ural rise that is complicated by the big transverse Lyapinsk megaanticline. The Zhelannoe deposit occurs in the northwestern part of this megaanticline and is hosted by Early Ordovician sequences that overlie the Proterozoic basement (Fig. 1). Layers of coarse-grained sediments from conglomerates to aleurolitic sandstones (Tel'pos suite, O_1tl) compose the base of the folded sequences. They are conformably overlapped by alternating layers of sandstones, aleurolitic sandstones, and aleurolites of the Khydei suite (O_{1-2}hd) (Repina, 1993), which is metamorphosed to the greenschist facies at 400–500°C and 5–8 kbar (Pystin, 1994). The age of intrusive rocks, according to the predominant opinion, is Riphean (Pystin, 1994) or Vendian–Cambrian (Makhlaev, 1996), and they are emplaced exclusively in Proterozoic rocks.

The geological structure of the region is defined by the Paleozoic folds. The Sanaiz and Maldin anticlines are separated by the Balbanin syncline. These folds are large and long. They change strike from South–North to North-East in the ore deposit area and plunge 10°–20° to the NE. The anticlines were formed by the uplift of Paleozoic basement blocks due to a Paleozoic collision. Layers of Paleozoic rock envelop the raised basement blocks. The longlived large faults bounding these blocks strike NE (310°) and dip to the NW at 50°–80°. The faults pinch out upward in the greenschist sequence (Khydei suite). The Maldin reverse fault (overthrust) is the main ancient fault in the region. Vertical displacement along the fault exceeds 800 m. The large Zhelannin fault, which accompanies the Maldin fault (Repina, 1998), occurs only in rocks of the Tel'pos suite, and contains quartz veins throughout it. Alumophosphatic and REE mineralization is common in these veins.

GEOLOGY OF THE DEPOSIT

The Zhelannoe quartz crystal deposit is situated on the western steep limb of the Salaiz anticline, 4 km from the Maldin fault. Economic ores are hosted by monomineral quartzite–sandstones (Tel'pos suite, O_1tl_4) that are around 450 m thick (Fig. 2). They dip 65°–80° and strike to NW 310°. The overlying greenschists (Khydei suite, $O_{1-2}hd$) exposed to the west of the deposit are complexly folded. The underlying coarse-grained sediments form a large flexure-like fold. The Zhelanin reverse fault is 25 km length and is related to the lower steep limb of the flexure. It marks the boundary between micaceous coarse-grained sandstones with lenses of small pebble conglomerates (O_1tl_3) and monomineralic quartzite–sandstones. The surface of the sandstones was eroded during sedimentation and so its boundary with the quartzites is very irregular. Occurrence of lenses of small pebble conglomerate along the boundary is evidence of this erosion. The detachment fault along this irregular boundary is the structure that hosts the quartz mineralization of the Vostochnaya crystal-bearing zone and controls the ore mineralization of the whole deposit.

The Zhelannoe deposit occurs where the host Paleozoic sequence sharply changes strike from meridional to northeasterly. A series of crosscutting, steeply dipping faults of northwestern (310°) strike was formed here. Compression induced by the Maldin tectonic block from the NW on a massif of the Baikalides in the SE, and occurrence of the crosscutting faults caused the formation of several tectonic blocks in the central part of the monomineralic quartzite–sandstone bed (Zapadnaya zone). All of these blocks is saturated with quartz mineralization and is thus called the quartz–vein or crystal-bearing unit (knot, bundle) according to the predominance of either quartz or rock crystal economic mineralization, respectively. The deposit contains two ore zones: the Vostochnaya crystal-bearing zone and the Zapadnaya zone, which contains quartz veins and crystal-bearing pockets. These zones differ from one another in structural features and morphological type of mineralization. The zones strike conformably with host rocks and are observed between altitudes of 1200 and 800 m. Their total length reaches 4 km.

The Vostochnaya crystal-bearing zone occurs at the base of the quartzite–sandstones horizon (O_1tl_4) and is related to the Zhelanin fault that strikes 310° and dips NW 70°–85° (Figs. 2 and 3). The fault follows the irregular plane of the lithological boundary and is represented by a shear, brecciation, and micaceous alteration zone in the underlying rocks. Fractures accompanying the fault occur in the overlying brittle quartzite–sandstones. Fractures and ore mineralization do not penetrate into the underlying finely sheared pebble sandstones. The Vostochnaya zone is 30 m thick, 1300 m long, and explored for 90 m along dip. Quartzite–sandstones near the zone are white and loose due to strong leaching. Mineralization concentrates in several vein knots and is separated by blocks of unaltered rocks. The vein knots are traced 350 m along strike. The knots consist of vein "floors" separated from each other by rocks with poor mineralization. The vein floors, in turn, consist of numerous quartz veins and veinlets with crystal pockets and mineralized fractures. Branching veins are enclosed in gentle detachment fractures at sharp bends in the lithological contacts. The southeastern part of the veins joins with the fault surface, and the northwestern part gently pinches out. Vein thickness does not exceed 5–7 m.

The Zapadnaya quartz vein–crystal-bearing zone has a length 2500 m, a thickness of 200 m and plunges NE at 15° (Figs. 2 and 4). The quartz vein knots, elongated in the northwestern direction, are 100–200 m long and 70–200 m thick. In cross section, the knots have trapezoid-like morphology. Relaxation inside stressed blocks caused formation of steep, rather short reverse faults dipping to NW 310° at 80°–70°. Some gently dipping (15°–30°) reverse faults are associated with the steeply dipping ones. Several gentle faults can occur within the same steep fault and form vein floors. The amplitude of the vertical shift of blocks within the same floor is 20–70 m. Relaxation occurred repeatedly throughout a prolonged compression, the intensity of which decreased with time, but the deformation pattern was preserved. The vertical transverse faults, bounding blocks, are 1.5–2 km and form a system of open fractures. The fractures are accompanied with hydrothermally leached rocks. Such fractures were conduits for hydrothermal solutions.

More than 20 large quartz veins occur in the Zapadnaya zone. The veins consist of a combination of lenselike and platelike bodies (Figs. 5 and 6). The lenselike bodies strike NE and plunge in the same direction and dip to NW 300°–315° at 20°–30°. They are 100–150 m long, 20–90 m thick and extend for 65 m in the vertical direction. The steep platelike veins occur in the northwestern pinching out of the zone and in the upper parts of the lenselike bodies. They are 100–150 m long and tens of meters thick. Platelike and lenselike bodies formed simultaneously. Their morphology relates to the order of opening of fractures around the vein-containing fault.

The main component of the quartz veins at the Zhelannoe deposit is milky-white vein quartz with relic crystal-bearing vugs. Lenselike sericitolith bodies occur along the footwall of all large quartz veins. Both quartz and sericitoliths are necessary components of the veins. Tectonic and hydrothermal processes were manifold in blocks that underwent prolonged tension. These processes formed late crystal-bearing pockets. Small crystal-bearing vugs occur everywhere and they are necessary vein components as well. Big pockets occur; however, they are rather rare and are concentrated in the lower parts of the veins near the boundary with the sericitoliths.

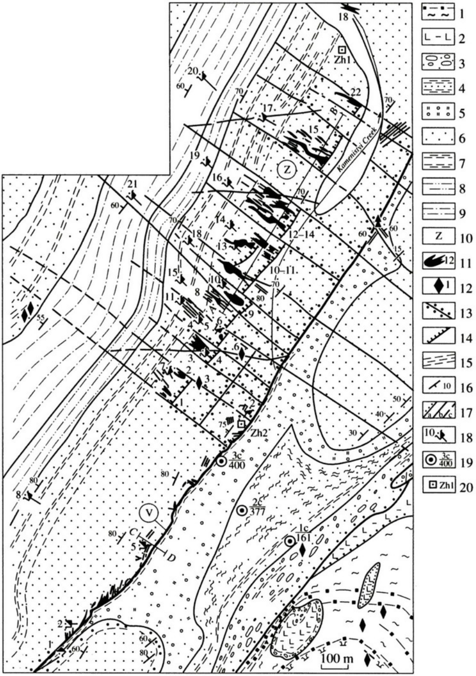

Fig. 2. Geological map of the Zhelannoe deposit. (Compiled by S.A. Repina, 1988.) 1—Moroin formation (R_3mr) (phyllitic schists with marble lenses); 2—Sablegorsk suite (R_3sb_1) (basaltic porphyrites); 3–9—Tel'pos suite: 3—conglomerates (O_1tl_1); 4—alternating sandstones and apoaleurolitic schists (O_1tl_2); 5—coarse-grained sandstones and conglomerates (O_1tl_3); 6—monomineral quartzite–sandstones (O_1tl_4); 7—pelitic layers; 8—aleurolithic sandstones ($O_{1-2}hd_1$); 9—aleurolites ($O_{1-2}hd_2$); 10—Zapadnaya quartz vein and crystal-bearing (Z) and Vostochnaya crystal-bearing (V) zones; 11—quartz vein knots; 12—crystal-bearing pockets; 13—faults accompanied with hydrothermal leaching; 14—reverse-trust faults, enclosing quartz veins; 15—zones of intensive fracturing; 16—bedding strike and dip; 17—geological boundaries: a—of stratigraphic unconformity; b—of lithological horizons and stratigraphic units; c—inside stratigraphic units and lithological horizons; 18—adit mouths; 19—structural boreholes: numerator—hole number, denominator—depth of the hole; 20—samples of quartzite–sandstones.

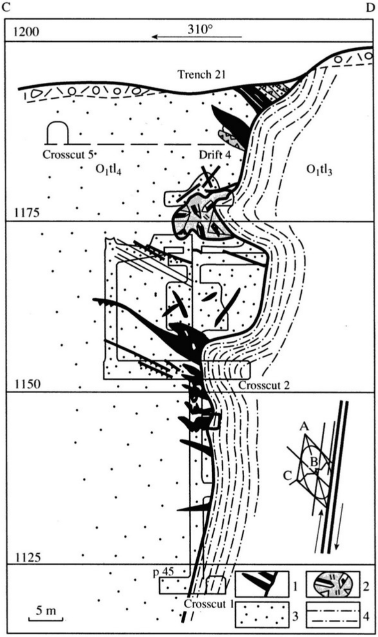

Fig. 3. Cross section through the Vostochnaya crystal-bearing zone of the Zhelannoe deposit along the line C–D (see Fig. 2). Compiled by S.A. Repina. 1—quartz veins; 2—crystal-bearing pockets; 3—monomineral quartzite–sandstones; 4—quartz-sericite gritty sandstones and small-pebble conglomerates that are sheared along the lithological boundary.

HOST ROCKS

The underground workings cross the productive quartzite–sandstones horizon all over its thickness. The horizon is divided into three parts. The quartzite–sandstones of the lower part are coarse-grained and show distinct oblique lamination strengthened with enrichment of some bands with thin-grained opaque minerals. The rocks of the central part are medium- to coarse-grained, massive, and homogeneous. In the upper part, thin (from threadlike to 10–15 cm thick) layers of metaaleurolites and metapelites occur. The amount of thin-grained rock layers increases upsection from 1 over 5–10 m to 3–5 over 1 m. The thickness of the unit with interlayered rocks is 150–200 m; this unit does not contain large quartz veins.

The quartzite–sandstones are bluish gray massive rocks composed of quartz (92–97 vol %), sericite (1–7 vol %), and rolled grains of hematite, zircon, tourmaline, rutile, leucoxene, ilmenite, garnet, apatite, epidote, and chlorite (0.3–2 vol %). The texture of the

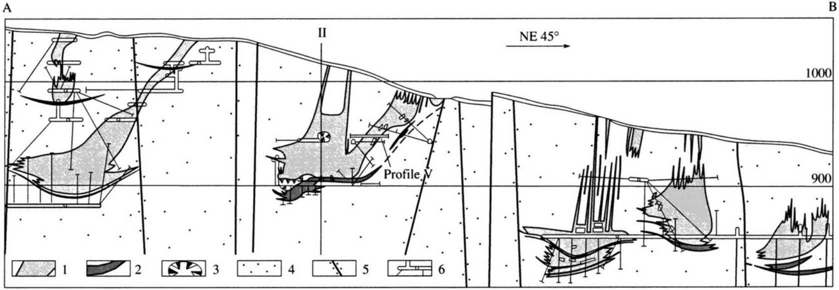

Fig. 4. Part of the longitudinal section through the Zapadnaya crystal-bearing zone of the Zhelannoe deposit along the line A–B (see Fig. 2). Compiled by S.A. Repina and N.A. Pozhidaev. 1—Quartz veins; 2—sericitoliths; 3—crystal-bearing pockets; 4—monomineral quartzite–sandstones of the Tel'pos formation (O_1tl_4); 5—fault zones accompanied with the hydrothermal rock leaching; 6—underground workings.

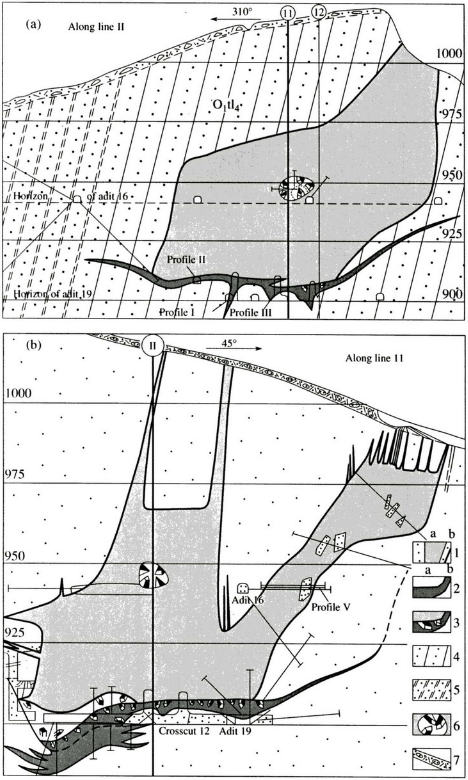

Fig. 5. The (a) longitudinal and (b) cross sections through the quartz vein–crystal-bearing knot 12–14 at the Zapadnaya zone of the Zhelannoe deposit. Compiled by N.A. Pozhidaev, 1988. 1—Quartz veins: a—in scale of the section; b—out of scale; 2—sericitoliths; 3—crystal-bearing pockets along the boundary between the quartz veins and sericitoliths; 4—quartzite-sandstones; 5—metapelite layers; 6—intravein crystal-bearing pockets; 7—loose alluvium.

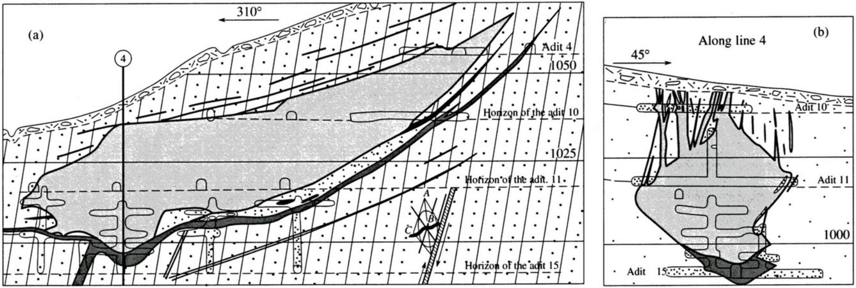

Fig. 6. (a) Longitudinal and (b) transverse sections through the quartz vein knot 5 at the Zapadnaya zone of the Zhelannoe deposit. Compiled by N.A. Pozhidaev, 1988. For explanation, see Fig. 5.

rocks is blastopsammitic and varies from thin- to coarse-grained.

The metaaleurolites show blastoaleuropelitic texture and consist of quartz, chlorite, sericite, and accessories (albite, hematite, tourmaline, rutile, zircon, and epidote). For their chemical composition, see Table 1. The rocks has lenselike, banded, and schistose textures. The metapelites are altered to a yellow claylike substance in the tectonic fractures and faults.

Unaltered quartzite–sandstones and metapelitic rocks are quite common throughout the area of the deposit, at the quartz vein contacts, and as xenoliths inside veins. The quartzite–sandstones underwent hydrothermal alteration only near fissures (no more than 1–2 m from it). Some wider alteration to 10–15 m from the vein occurs in the fault zones and around large crystal-bearing pockets. The alteration of the quartzite–sandstones began with cataclasis and bleaching of rocks. More intensive deformations and silica leaching formed poorly cemented quartz grain aggregates. Such rocks, similar in some cases even to quartz sand, occur immediately within the faults. Strongly altered quartzite–sandstones are white, sandlike, exhibit occasional metasomatic micas, but are free of opaque minerals. Some newly formed crystals of zircon, rutile, and tourmaline occur in vugs. The mass balance for hydrothermal rock alteration is estimated (Table 2) with the atomic–volumetric techniques according to data from silicate analyses (Table 1). The alteration was accompanied with a loss of 40 wt % of the substance. The most significant was the loss of Si, Fe, Mg, and Na. The V, Cr, Nb, Y, Zn, Zr, Co, Mn, Be, and W are added (Fig. 7). The content of Ti, Ca, and Al only slightly increased.

STRUCTURE AND MINERAL COMPOSITION OF QUARTZ VEINS

The vein quartz and the quartz of rock crystal pockets are related to the same geological body. There are no sharp boundaries but some differ from one another. The vein quartz composes aggregates of tightly intergrowing grains, while quartz in pockets forms crystals grown in an open space. Vein quartz aggregates are milky white, and the pocket quartz is transparent, colored or colorless, and, at last, vein quartz forms monomineralic (99.999%) aggregates, whereas pocket quartz contains a lot of mineral inclusions.

The quartz veins at the Zhelannoe deposit fill tectonic open spaces. This is evidenced by rectilinear and sharp vein boundaries, the complementarity of the opposite vein walls in every section, and occurrence of sharp angled rock xenoliths near the footwall of the veins. The veins consist of parallel–columnar aggregates of very coarse-grained quartz with zones of geometric selection in the base of crystals. Host rocks, as a rule, are not altered and preserve their initial layering and blastopsammitic texture. Vein quartz is milky white with transparent spots. At the contact with host rocks and xenoliths the rim of gray quartz to 0.5 m thickness. The quartz at the contact with sericitoliths is dark gray and smoky with transparent spots. Mineral admixtures in vein quartz are not visible.

Ontogenesis (the genesis of quartz aggregate morphology) in platelike veins was studied (Fig. 8). Three zones are distinguished in a vein parallel to its contacts. The lower zone related to the footwall contains sharp angled xenoliths of the brecciated host rocks that are oriented along bedding. The xenoliths float in quartz as a result of repeated vein fracturing, displacement of rock fragments, and mineral sedimentation in the openings. Quartz grains are small there. At the base of the central zone, the geometrical selection is distinctly manifested, but changes upward into parallel–columnar aggregates. Quartz crystals exceed 5 m in length (up to 8 m). The crystals are oriented vertically at an angle to the vein contact. Crystal growth was interrupted by the reopening of fractures, and consequently smaller quartz crystals began to grow on the planes of large crystals. These aggregates compose the upper zone along the hanging wall with crystals oriented opposite each other.

Exfoliation of quartz bands along growth surfaces with intervals from 0.5 to 7 cm is typical for vein quartz. Commonly, these surfaces are rhombohedra planes. They are smooth, slightly rough, and covered with thin, hardly visible micaceous and earthy films. Some slits and solution cavities occur on these surfaces, according to microscopic study. The earthy substance consists of thin-grained mica clusters covering the rhombohedra plane as a thin film (Fig. 9). Thin needlelike radiated tourmaline aggregates, rutile crystals, and rounded rosy grains of newly formed zircon occur in these clusters. Muscovite commonly forms tiny (to 0.02 mm) hexagonal tablelike plates in microvugs. The thin tourmaline needles grew into quartz. The crystal morphology and mineral composition of films are the same as of sericitoliths. There are no inclusions inside the zones in the exfoliation fissures. The vein quartz in giant vein bodies and in smaller veins is a rather homogeneous material of high fineness: mineral impurity content does not exceed 0.0005 wt %, and the content of admixture elements is (in ppm): Cu—0.04–0.3; Ti—1–1.25; Ca—1.4–7; Mg—0.6–2.5; Mn—0.05–0.6; Al—6–13; Fe—0.8–7.2; Na—2.5–35; K—4.2–7.8. All crystal-bearing pockets in the deposit are spatially and genetically related to the quartz veins. The crystal mineralization of the Zapadnaya and Vostochnaya zones significantly differ from each other.

Crystal-bearing pockets in the Vostochnaya crystal-bearing zone are slitlike, isomorphic in the plane of the slit, and relate to the footwall of the vein or to separate mineralized fractures. The rock crystals are long, prismatic, and obelisklike, and form druses on walls of open slits. Crystals are not large, up to 0.4 m long. They are either colorless or yellow (citrine) and found in vugs containing sericitoliths. Colorless crystals turn yellow (citrine or smoky citrine) after radiation. Quartz

Table 1. Chemical compositions of host rocks at the Zhelannoe deposit (wt %)

Components	Metaaleuropelites	Unaltered quartzite–sandstones		Hydrothermally altered quartzite–sandstones			
	17/98	Zh1/98	Zh2/98	16/14–3	16/14–2	16/8–6	24/96
SiO_2	52.34	95.63	94.83	97.84	97.24	96.60	94.12
TiO_2	2.02	0.21	0.18	0.08	0.16	0.42	0.63
Al_2O_3	20.10	1.28	1.41	0.40	0.91	1.21	2.45
Fe_2O_3	10.03	0.81	2.01	0.25	0.10	0.13	0.12
FeO	0.83	0.13	0.22	<0.10	<0.10	<0.10	<0.10
MnO	0.04	n.d.	n.d.	Traces	n.d.	n.d.	0.002
MgO	2.68	0.15	0.12	0.14	0.15	0.15	0.11
CaO	0.61	0.33	0.30	0.74	0.66	0.69	0.82
Na_2O	0.80	0.38	0.10	0.05	0.06	0.07	0.28
K_2O	6.30	0.48	0.48	0.05	0.34	0.36	0.75
H_2O^-	0.12	0.09	0.05	0.14	0.16	0.14	0.16
L.a.i.	4.04	0.26	0.34	0.12	0.16	0.22	0.49
P_2O_5	0.07	<0.05	<0.05	<0.05	<0.05	<0.05	0.06
TR_2O_3	0.025	0.005	0.00	n.a.	n.a.	n.a.	0.011
Total	99.98	99.75	100.04	99.81	99.94	99.99	100.0

Note: n.d.—not detected; n.a.—not analyzed. Samples: 17/98—metaaleuropelites from the adit 17; quartzite–sandstones unaltered: Zh1/98—from the upper part of the horizon O_1tl_4; Zh2/98—from the bottom of the same horizon; quartzite–sandstones altered: 16/14–3—slightly: 16/14–2—moderately (adit 16, crosscut 14); and 16/8–6—strongly (adit 16, crosscut 8); 24/96—quartz from the conformable fracture (adit 11a, crosscut 1m).

Table 2. Mass balance upon hydrothermal alteration of the quartzite–sandstones at the Zhelannoe deposit

Elements	Content, g/100 cm^3					Input (+) or loss (–) Zh2/98 – Zh24/98	
	Zh2/98	16/14–3	16/14–2	16/8–6	24/96	g/100 cm^3	%
Si	11.86	11.98	11.71	11.31	7.00	–4.86	–41.0
Ti	0.03	0.02	0.02	0.06	0.06	+0.03	+100.0
Al	0.18	0.05	0.13	0.16	0.21	+0.03	+16.7
Fe^{3+}	0.15	0.05	0.02	0.02	0.05	–0.10	–66.7
Fe^{2+}	0.03	0.02	0.02	0.02	0.01	–0.02	–66.7
Mg	0.02	0.02	0.02	0.02	0.01	–0.01	–50.0
Ca	0.06	0.14	0.12	0.12	0.09	+0.03	+50.0
Na	0.08	0.01	0.01	0.01	0.03	–0.05	–62.5
K	0.10	0.01	0.07	0.08	0.10	0.00	0.0
H	0.01	0.01	0.01	0.01	0.01	0.00	0.0
P	0.01	0.01	0.01	0.01	0.01	0.00	0.0
O	13.97	13.88	12.14	13.66	8.42	–5.55	–60.3
Total	26.5	26.2	25.8	25.1	16.0	–10.5	–39.6
ρ, g/cm^3	2.65	2.62	2.58	2.51	1.6		

Note: Zh—rock density. Rock samples the same as in the Table 1.

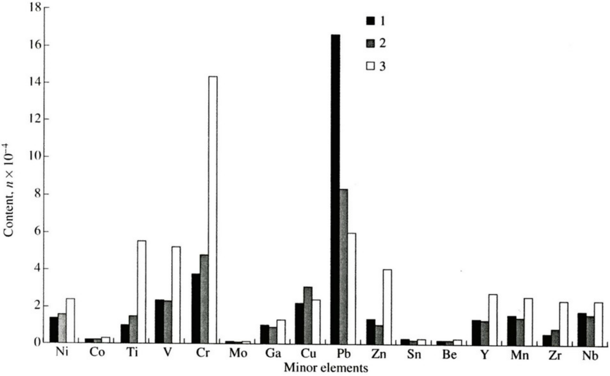

Fig. 7. Diagram of the minor element contents in the quartzite–sandstones hydrothermally altered to various degrees (135 analyzed samples). 1–3—quartzite–sandstones: 1—unaltered; 2—moderately altered; 3—strongly altered.

crystals were studied by Bukanov (1974) and Kuznetsov (1998).

Crystal-bearing pockets in the Zapadnaya zone are less common but larger. Two types of pockets are distinguished inside the veins and at the location where they pinch out. The pockets inside veins are residual and overprinted. Residual veins are rare. One of them had a volume of 600 m^3 and was mined in the latter part of the 80s. The rock crystals in such vugs are short, prismatic, pseudohexagonal, colorless, have a length of a few meters along the crystallographic axis, and a weight of a few tons. Small inclusions of high fineness gold, tetradimite, wolframite, emplectite, and chalcopyrite were found in crystals from these vugs (Popova *et al.*, 1993). Overprinted pockets are small, occur everywhere, and contain rather small colorless crystals; more rarely smoky crystals occur.

The crystal-bearing pockets at the lower pinching out of veins occur along the contact with sericitoliths. They form a series of irregularly distributed lenselike cavities along the lower vein content and occupy an area of 15000 m^2. Such cavity assemblages relate to gently lying detachment fractures, that were formed by repeated reverse faulting within the footwall vein contact. The cavities are lenselike or wedgelike and are from 0.5 to 10 m thick. The vertical zonation occurs in cavities related to some intervals in which the vein is thickest. In the upper part of cavities, quartz crystals grow on the vein quartz grains and angular rock fragments are concentrated downward. The crystals are colorless or slightly smoky. In the middle part of the cavity, numerous broken smoky quartz crystals are irregularly distributed in the loose sericitoliths cemented with ice. Crystals are pseudohexagonal, prismatic, and to 1 m long. Their length is 1–3 times greater than their width. Crystals commonly contain trapped sericitolith fragments. The smoky color of quartz crystals is induced by radiation and occurs only in crystals floating in sericitolith. The white muscovitic powder on the upper planes of the quartz crystals is typical for smoky quartz at the Zhelannoe deposit.

STRUCTURE AND MINERAL COMPOSITION OF SERICITOLITHS

Sericitoliths are dense and thin crystalline rocks, consist of mica, and clearly differ from the host quartzite–sandstones in composition and appearance. They form lenses distributed along quartz veins and contain big crystal-bearing pockets in some places. These pockets have been mined for more than ten years. These rocks were defined as near-pocket metasomatic rocks according to the results of the study of the pocket mineral composition in the Vostochnaya zone (Bukanov *et al.*, 1972; Bukanova, 1975). The sericitoliths have not been studied in detail yet, except for accessory min-

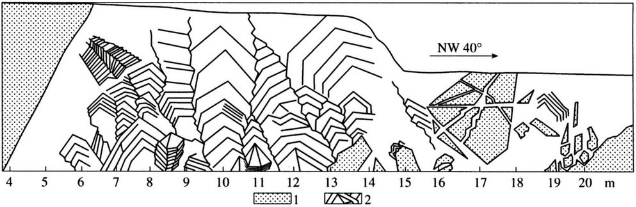

Fig. 8. Structure of the platelike quartz vein along profile V (see Fig. 5). 1—Monomineral quartzite–sandstones; 2—exfoliation fissures containing thin sericitolithic bands on the free growth surfaces of the milky-white quartz crystals.

erals, and they were not mentioned in the exploration reports. The rocks were distinguished in 1982–1983 as individual geological objects spatially and genetically related to quartz veins, which commonly contain no crystal-bearing pockets. At that time, the rocks were named sericitoliths without any preliminary studies. The chief geologist of the exploration, N.A. Pozhidaev, was the first to note the importance of sericitoliths and mapped them together with all large quartz veins. N.A. Pozhidaev revised the structure of the deposit taking in account the sericitoliths' distribution.

In plan view, lenses of sericitoliths vary in thickness from 1.5 to 15 m. They occur near every quartz vein in the Zapadnaya zone of the Zhelannoe deposit (Figs. 4, 5, and 6). They cut lie horizontally across the host rock layering. Their lower contact is commonly complicated with wedges of sericitoliths in the host rocks. Sericitoliths were either pressed in fractures or initially deposited in them. At the upper contact, sericitoliths commonly join the quartz vein, but their marginal parts are separated from the vein and change into a net of thin branching veinlets extending a few tens of meters. The contacts with host rocks are sharp, which was confirmed by chemical analyses (Table 3). The quartzite–sandstones preserve their structure and composition along the contact. In contrary, the sericitolith boundary with quartz vein is tortuous and complicated by deep coves. Xenoliths of milky-white quartz, quartzite–sandstones or metapelites, and recrystallized smoky quartz located close to the crystal-bearing pockets occur in sericitoliths near their upper contact. The sericitoliths are uniform and the primary structures are overprinted by schistosity. The internal structure of the sericitolith bodies was studied with mineralogical and geochemical methods along profiles across the body (Repina, 1999).

Sericitoliths are greenish gray thin-grained rocks that consist mainly of mica. The light fraction composes 77 to 89 wt % of the rock and consists of thin-grained muscovite. Some fragments of quartz and quartzites occur along the body contacts that are commonly tectonic. Away from the contact, quartz is absent in sericitoliths. Quartz does not form any regular intergrowths with sericitolith minerals, and so it is not a rock-forming one. The heavy fraction contains tourmaline (0.3–12 wt %), hematite (2–10 wt %), rutile (3–9 wt %), zircon (to 0.6–2 wt %), and monazite (to 0.6 wt %) (Fig. 10). The rocks have a rather high content of admixtures: Cr, Ba, Sr, Rb, Nb, Th, and in some samples, W, Au, Ga, and Be. The mineral and chemical composition of sericitoliths is uniform not only inside the same body, but in various quartz–vein knots of the Zapadnaya and Vostochnaya zones as well (Table 3). Sericitoliths show a rather high radiation level, up to 300 microroentgen per hour.

Layers with various mineral composition occur in sericitolith bodies, according to analytical studies. The lower part has the highest of hematite (7–10 wt %) and monazite (0.3–0.7 wt %) contents. Their content decreases upward: hematite to 3–6 wt % and monazite to 0.05–0.1 wt %, respectively. The tourmaline content is 0.3 wt % near the lower contact and increases upward to 3–7 wt % (up to 12 wt %). Note that variation trends of the hematite and tourmaline concentration are oppositely directed. The content of zircon increases upward from 0.6 to 1–2 wt % and rutile content increases to 1–3 wt %. The sericitoliths in the central part of the bodies are better crystallized, where crystals are rather large and commonly have regular morphology.

Sericitoliths are hydrothermally altered near the crystal-bearing knots and are converted into a loose cream-white micaceous aggregate. Hydrothermal alteration resulted in the dissolution of hematite, the redeposition of monazite, the partial dissolution of zircon and rutile, the recrystallization of tourmaline, the formation of fuxite, and the partial replacement of muscovite by kaolinite. The most remarkable feature of the rock's hydrothermal alteration is the redistribution and mobi-

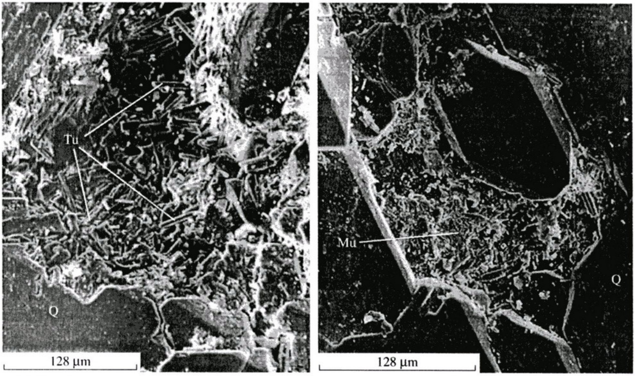

Fig. 9. Microphotographs of quartz grains. Microcavities at the growth surfaces of the quartz crystal (Q) contain needlelike crystals of tourmaline and thin flakes of muscovite (Mu).

lization of REE and gold from the lower part of sericitolith and their removal towards the crystal-bearing pockets. Near the pockets, some monazite, xenotime, and gold crystals are formed, but at some distance from the pocket, the rock appears to be unaltered. However, this element redistribution does not change the total content of these elements in the sericitolith body.

The unaltered sericitolith consists of dense aggregates of irregularly oriented white muscovite leaflets 0.015 to 0.05 mm in diameter and rare rhomb-shaped muscovite plates reach 0.3 mm in diameter. Muscovite preserves its composition and parameters of the crystal lattice. Muscovite belongs to the $2M_1$ polytype modification and has a rather high Fe_2O_3 content up to 3–5 wt % (Table 4). The terms muscovite and sericite are synonyms for the high-temperature nonhydrated thin-grained white micas (Omelyanenko *et al.*, 1982). The thin-grained muscovitic rocks contain regular disseminations of accessory minerals that are separated in the heavy fraction.

Minerals in the heavy fraction (hematite, tourmaline, rutile, zircon, and monazite) occupy around 20% of the rock volume. The dimension of the mineral grains does not exceed 0.2–0.6 mm, except for tourmaline (to 0.4–1.5 mm) and hematite (to a few centimeters) (Fig. 11). The hematite content decreases in altered sericitoliths to zero, and the heavy fraction decreases to 11–13 vol %, respectively. Well crystallized xenotime and clinozoisite occur in the heavy fraction of altered sericitoliths. Grain dimensions are the same as in unaltered rocks except for monazite and tourmaline, the dimensions of which increases to 2–5 mm.

Hematite is the most abundant mineral among the accessories, and its content reaches 10 vol %. It forms granular masses and sharp-angled plates from 0.01 to 0.5 mm in size. They are evenly distributed throughout the rock, so they appear to be gray. The TiO_2 content in hematite varies from 1.6 to 4.5 wt %, Cr_2O_3 reaches 0.7 wt %, and Nb_2O_5 0.5 wt %. The dusty hematite inclusions occur in all sericitolith minerals, but its bigger grains intergrow with tourmaline, rutile, and muscovite. The hydrothermal solutions dissolved hematite around the crystal-bearing pockets. The planes of schistosity in such rocks contain brown limonite coatings. The loose, strongly altered sericitoliths contain no hematite, but the vein quartz free of opaque minerals underwent ferruginization along fissures.

Accessory titanium minerals, namely granular aggregates of rutile and very rare anatase and titanite, are common as well (5–9 vol % to 10 vol % in altered sericitoliths). The most abundant of them is yellowish-orange rutile, while subordinate brown rutile is well crystallized, has polysynthetic articulated twins, and forms needlelike intergrowths and granular aggregates (Fig. 12). The dimensions of the minerals do not exceed

0.3–0.4 mm in the Zapadnaya zone and 0.7 mm in the Vostochnaya zone. The rutile composition corresponds to the stoichiometric composition and shows an admixture of Nb_2O_5 to 0.4 wt %. The content of spherical rutile crystals in the rock is rather low, but they are disseminated elsewhere and are garish due to their dark cherry color and metallic luster. The spherical morphology was formed with step by step planar growth related possibly to crystallization from the supersaturated solutions. The cherry-colored rutile contains a rather high content of Nb_2O_5 (to 1.8 wt %), FeO (1.5 wt %), and an admixture of Cr_2O_3 and WO_3 to 0.12 wt %. All of the rutile crystals, even those with signs of dissolution, are newly formed.

The highest tourmaline content in the sericitoliths is 12 vol %, the lowest is 0.3 vol %, and the common one is 3–6 vol %. Tourmaline forms long prismatic needlelike black crystals 0.4–2 mm long in unaltered sericitoliths and short prismatic crystals 3–5 mm length in altered ones. Tourmaline relates to the sherl–dravite series with a small Cr_2O_3 admixture up to 0.1–0.5 wt %. More than half of the tourmaline crystals exhibit sharply contoured cores of dravite–uvite composition (Fig. 11). Such zonal tourmalines were not found in the host quartzite–sandstones. The tourmaline cores are colorless, have rather high Ca and Mg contents, and the lowest Na contents. The same element distribution is found in vein quartz crystallized at the early hydrothermal stage. It is possible that colorless tourmalines were formed at this stage as well, but later underwent dissolution and preserved grains were overgrown by later dark colored tourmaline. In many cases, predominantly along contacts, sericitoliths are tectonically displaced and tourmaline in them are broken.

A high zircon content (0.6–2.3%) is typical for sericitoliths. Most of the zircon crystals are rounded, their diameter varies from 0.1 to 0.6 mm, and only one-tenth of the crystals studied are well formed. Several varieties are distinguished among zircon crystals; three of which are subordinate (malakones, dark crimson, and smoky rounded zircons). These three types of zircons are related primarily to the quartzite–sandstones, but later in the processes of vug formation, crushing, abrasion, and partial dissolution of the rock, they were separated and concentrated in the basal layer. The crystals were partly regenerated then, but preserved their rounded morphology. Most of the rounded zircons are colorless or slightly colored. Some of them are detrital, but commonly they have a hydrothermal origin, and their rounded morphology is caused by repeated cycles of dissolution and regeneration. Such cycles are common for grains of other minerals in sericitoliths as well. The newly formed rounded zircon grains show thin oscillatory zonation with alternating zones of various Hf contents. The inner zone of the rounded grains, which is comparable to newly formed zircon grains, has well-developed crystallographic morphology and contains abundant conduits, cavities, and inclusions. These grains were possibly crystallized in a viscose medium. Some zircon grains near the crystal pockets are bigger (to 0.6 mm), but are commonly smaller due to strong dissolution. Hematite and rare rutile inclusions are common in zircon, and, in some places, intergrowths with tourmaline occur. In sericitolith veinlets near the pockets, the zircon grains are crushed due to the ductile sericitolith displacements.

The monazite content in the sericitolith strongly varies from 0.002 to 0.6 wt %. The highest content occurs in unaltered sericitoliths along their lower boundary and in the altered ones along their upper boundary near crystal pockets. The monazite grains are isometric, vary in diameter from 0.15 to 0.5 mm, are lemon-yellow colored, translucent, and contain a lot of hematite and rutile inclusions. The monazite crystals in the loose sericitoliths near pockets are short, columnar, honey-yellow colored, translucent and contain no inclusions. Inside the pockets, zircon crystals reach 2.5–5 mm in size, are cream colored, and are related to the second generation. They were formed as a result of redeposition of the first generation grains. Large crystals of the second generation tend to split and form sheaflike aggregates. The monazite grains inside the pockets contain an admixture of CaO (1.5–3.4), SO_3 (1.5), and WO_3 (0.16 wt %) (Table 5), while ThO_2 content varies from 1.5 to 9 wt %. The same admixtures occur in the monazite grains of the first generation in unaltered rocks. The monazite composition under discussion differs from that of common monazite in the lower light REE content and enrichment with heavy and intermediate REE.

Xenotime occurs only in sericitoliths near the crystal pockets and is less common than monazite, although its content in some places can reach 603 ppm (Kuznetsov, 1988). An admixture of yttrium and heavy REE is distinguished in all samples. Xenotime forms pale yellow dipyramid–prismatic crystals and isometric grains 0.25–0.7 mm in diameter, and its crystals tend to split. A specific feature of the studied mineral is an admixture of WO_3 up to 2–3 wt %. The xenotime was formed at the stage of crystal formation and hydrothermal alteration of sericitoliths due to mobilization and redistribution of the yttrium group elements.

Sericitoliths in the pockets contain, except for the above mentioned minerals, muscovitic and kaolinitic pseudomorphs after needlelike clinozoisite crystals and isometric gold grains up to 0.2 mm in size.

Most of the minerals in the sericitoliths were formed by the hydrothermal process, form crystals, needlelike and radiating intergrowths, and are divided into a few assemblages. The two mineral generations are quite clear: the first generation is simultaneous with sericitolith formation, and the second one includes minerals deposited together with formation of the crystal pockets due to regeneration, dissolution, and redeposition processes (Fig. 13). Hematite, tourmaline, zircon, rutile, monazite, and muscovite are related to the first generation. Regenerated and newly formed tourmaline

Table 3. Contents of petrogenic (wt %) and minor (ppm, Au—in ppb) elements in quartzite–sandstones and sericitoliths at the Zhelannoe deposit

Components	Unaltered rocks								Hydrothermally altered rocks			
	Quartzite–sandstones		Sericitoliths									
	19/22	19/21	19/14	19/15	19/16	19/17	18/4	2/1	19/28	19/27	19/26	19/32
	1	2	3	4	5	6	7	8	9	10	11	12
SiO_2	95.04	97.84	39.04	41.07	40.21	38.71	38.35	39.69	41.02	41.27	41.09	42.28
TiO_2	0.57	0.12	6.75	6.70	7.80	8.70	8.00	4.10	8.20	8.60	7.75	6.80
Al_2O_3	1.67	0.51	27.98	29.87	28.56	28.12	27.70	27.57	30.10	29.90	30.11	30.83
Fe_2O_3	0.94	0.41	11.34	5.95	7.40	8.39	10.58	12.16	3.36	3.46	3.60	3.33
FeO	0.10	0.10	0.22	0.12	0.18	0.14	0.10	0.49	0.19	0.12	0.22	0.13
MnO	0.05	0.05	0.01	0.01	0.01	0.01	0.01	0.01	0.1	0.1	0.1	0.014
MgO	0.15	0.12	0.70	0.88	0.95	1.05	0.83	1.23	0.83	0.83	0.80	0.78
CaO	0.46	0.42	0.56	0.50	0.53	0.57	0.44	0.46	0.46	0.51	0.49	0.72
Na_2O	0.08	0.05	0.80	0.80	0.78	1.17	0.52	0.67	1.01	0.81	0.78	0.56
K_2O	0.50	0.34	8.95	9.35	8.60	8.40	8.50	8.25	9.25	9.20	9.18	8.71
H_2O	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
L.a.i.	0.10	0.10	2.38	4.34	4.14	4.02	3.60	2.26	4.76	4.54	4.75	4.60
P_2O_5	0.05	0.05	0.12	0.05	0.08	0.05	0.09	0.13	0.05	0.05	0.07	0.12
H/n.s.	–	–	0.42	0.12	0.44	0.26	0.74	0.16	0.42	0.34	0.48	0.60
TR_2O_3	0.006	0.010	0.32	0.02	0.17	0.032	0.17	0.21	0.01	0.01	0.32	0.39
Total	99.81	100.22	99.69	99.88	99.17	99.55	99.53	99.21	99.77	99.75	99.76	99.96
La	9.6	10.0	603.1	39.9	396.5	47.3	373.7	442	14.4	12.3	232.7	1202.1
Ce	17.0	16.6	937.2	67.9	637.6	90.5	635	669.1	20.2	19.6	378	1869.7
Nd	9	8	556	35	396	46	372	385	7	17	215	1167
Sm	1.66	1.74	114.8	8.63	78.92	10.94	75.92	77.82	4.79	4.75	46	221.42
Eu	0.39	0.39	20.6	1.64	14.16	2.55	13.81	13.69	1.09	0.91	8.61	41.74
Tb	0.34	0.47	9.28	0.85	3.41	2.25	4.05	4.46	1.33	0.54	3.47	11.55
Yb	1.1	1.5	29.2	10.2	16.2	21.1	18.8	10.1	18.6	17.7	17.9	25.6
Lu	0.17	0.22	4.35	1.76	2.81	3.41	3.55	1.53	3.24	3.05	2.88	3.09
Sc	1.3	1.2	33.5	31.0	32.7	33.4	34.5	21.0	38.0	38.7	37.5	33.1
Cr	23.9	19.9	561	586	598	595	705.8	157.9	679.7	629.3	567.4	907.2
Co	0.8	0.6	6.7	10.5	13.6	17.6	10.3	19.3	13.0	11.4	12.6	8.0
As	0.1	0.8	3.1	1.3	2.1	1.9	2.2	2	1.9	1.9	2.1	3.5
Se	0.35	0.3	14.3	23.8	19.9	14.4	34.2	10.1	29.4	29.5	22.8	32.3
Rb	16	1.7	306	314	353	347	321	290	432	397	347	333
Sr	17	16	215	141	211	204	217	134	701	208	207	233
Sb	0.2	0.2	11	9.9	9.7	13.3	15.2	10.6	14.7	15.0	10.9	19.7
Cs	0.6	0.6	9.1	10.1	12.8	10.1	10.3	6.5	9.6	11.6	12.5	7.0
Ba	27	29	630	684	755	889	798	1881	842	545	559	205
Zr	266	180	7448	6063	9398	10100	10284	2468	7410	75.64	7173	8440
Hf	7.6	6.7	207.1	162.8	266.6	308.2	288.4	83	283.0	280.3	228.8	257.6
Nb	10	10	100	200	100	300	100	100	200	300	100	30
Ta	0.29	0.30	10.9	10.5	13.4	14.5	16.18	5.49	15.69	15.77	14.12	16.77
W	0.4	0.4	9.1	74.2	6.4	6.0	6.6	167	111.1	6.1	6.5	9.9
Th	6.2	3.6	147.3	98.1	175.6	125	147.5	91.6	96.8	114.3	89.4	283.2
U	0.5	0.6	19.9	12.2	22.9	21.4	21.6	8.9	17.2	20.4	15.9	17.8
Au	1	8	219	5	102	7	8	115	7	7	7	280
Y	10	10	50	10	10	20	10	50	10	20	30	50
B	20	–	500	2000	2000	1000	1000	2500	2500	2500	2000	2000

Note: Samples: 1–6—profile 1 (adit 19, crosscut 11): 1 and 2—host rocks; 3–6—samples from the bottom to the roof of the sericitolith body; 7—central part of the sericitolith body in the IV profile (adit 18, crosscut 6); 8—sericitolith from the dump of the adit 2, Vostochnaya zone; 9–11—profile III (adit 19, crosscut 6) from the bottom (9) to the roof (11) of the sericitolith body in the crystal-bearing pocket; 12—profile VI, upper part of the sericitolith body in the crystal-bearing pocket (adit 19, crosscut 5).

n.s.—nonsoluble zirconium compounds. TR_2O_3 content was estimated by T.V. Semenova and L.F. Bazhenova, chemical laboratory of the Inst. of Mineralogy, Ural. Otdel. Russ. Acad. Sci.; minor elements were analyzed by A.L. Kerzin, neutron activation method, Inst. Geol. Ore Deposits, Petrography, Mineral., and Geochem. Russ. Acad. Sci.; Nb, Y, and B were estimated with semiquantitative spectral method in the same Institute and in the Inst. Geol., Karel. Sci. Center.

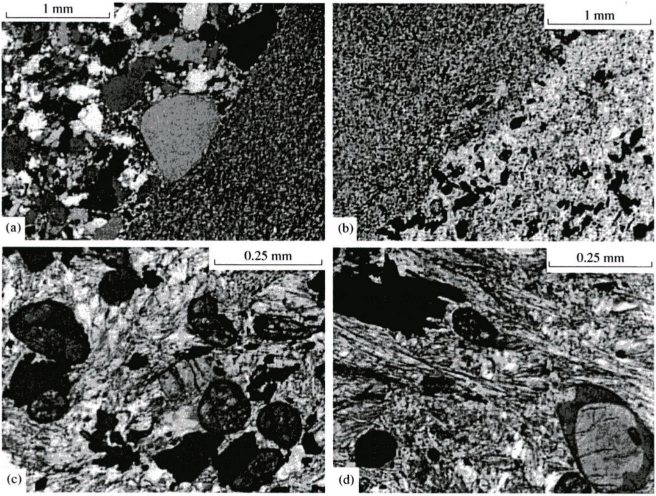

Fig. 10. Microphotographs of host quartzite–sandstones and sericitoliths: a—contact of quartzite–sandstone (left) with metapelite (right); b—contact of metapelite (left) with sericitolith (right); c—fractured rounded zircon crystals and hematite plates in muscovite; d—transverse section of a zonal tourmaline crystal (the low right corner) and intergrowth of needlelike rutile crystals (upper left corner).

and zircon, newly formed monazite, xenotime, clinozoisite, fuxite, and rare gold grains are related to the second generation.

So minerals of sericitoliths contain an admixture of Cr, Nb, W, Th, and F, and are relatively high in Fe and Ti contents. The appearance of sericitoliths is similar to that of metapelite layers, but the former compose bodies that crosscut the host rock layers, contain macroscopically distinguishable tourmaline, are coarser grained, and contain 10 to 20 times more accessory minerals. Sericitoliths do not contain any quartz, garnet, apatite, epidote, albite, and chlorite, which are common minerals in the quartzite–sandstones, but instead contains monazite and xenotime, which are absent in the host rocks. So the sericitoliths differs from the host metapelites both in petrogenic and minor elements compositions (Table 1, Fig. 14), although fragments of metapelites occur in sericitoliths.

THE GENETIC MODEL OF THE QUARTZ MINERALIZATION FORMATION

The Pripolyar crystal-bearing province was a passive continental margin with linear-block tectonic structure without magmatic events at the stage of Paleozoic collision. Rocks underwent strong acid metasomatism that formed quartz-sericite, pyrophyllite, and diaspore metasomatic rocks along deeply rooted faults (Yudovich and Ketris, 1997). These metasomatic processes were accompanied with the release of K from rocks. These solutions possibly became alkaline K-containing ones after penetrating carbonate rocks. They dissolved silica and other components from fault zones in the heterogeneous stratigraphic sequences. Fracture opening caused a decrease in pressure and the suction of solutions. The solutions accumulated in open cavities were differentiated by mechanical admixtures, density, and chemical composition, which resulted in their liquation into two immiscible liquids. High fineness quartz crystallized from one of them, but the other liquid, the dense highly mineralized substance, traveled downward and crystallized as sericitoliths. Quartz veins formed at ~400°C and pH 7.2–8.0 (Kuznetsov, 1988).

The tectonic cavities at the Zhelannoe deposit formed during a long period of compression. Relaxation along earlier formed faults occurred repeatedly and was accompanied with decreasing tension, but the general deformation pattern was preserved. The width of the open space at the first stage of deformation reached 20–70 m. At least three times the cavity opening and quartz deposition are estimated. Thin sericitolith bands occur in the quartz crystals and are evidence of almost simultaneous deposition of both of them in the same cavity. On the other hand, sericitoliths are related to the bottom of quartz veins, which proves gravity sedimentation as a mechanism of sericitolith formation. This viscous substance was layered according to the accessory mineral distribution: heavy minerals (hematite, monazite, and gold) concentrated along the lower sericitoliths boundary and relatively light tourmaline concentrated along the upper boundary.

Significant variations in the solution concentration, pH, and T occurred during the stage of the cavities filling with quartz. This is confirmed by repeated solution–crystallization cycles not only in quartz grains, but in accessory minerals of sericitoliths as well. The viscous substance was removed upward in the cavity periodically and carried crystals of zircon, rutile, and tourmaline. The latter were deposited in the quartz crystal planes. Tension cracks that appeared at the cavity openings caused exfoliation along growth planes in quartz crystals containing sericitolith bands. Physicochemical properties of the quartz-depositing solution varied in time, so the alkalinity decreased in general, which was accompanied by crystallization of sericite and hematite. The highly mineralized substance at the cavity bottom was crystallized into homogeneous thin-grained sericitolith. The mean K–Ar age of the sericite from the sericitolith is 246 ± 8 Ma. The general variations in crystal formation at the Pripolyarnyi Urals is 240–280 Ma according to data received for minerals from the crystal pockets (Bukanov, 1974; Kuznetsov, 1998). This is the age of quartz vein formation as well, because they formed simultaneously with sericitoliths.

Solution liquation into two immiscible liquids is common in the process of quartz synthesis (Rumyantsev, 1999). One of them is truly (light) a solution containing 1.5–3 wt % SiO_2; 4–9 wt % Na_2CO_3; and 90–94 wt % H_2O. Quartz was deposited from it. The other liquid is heavy and contains more than 40 wt % SiO_2; more than 13 wt % Na_2O; and correspondingly around 47 wt % H_2O (the so-called heavy phase). The

Table 4. Chemical compositions of main minerals in sericitoliths (wt %)

Components	1	2	3	4	5	6	7	8	9	10
SiO_2	44.84	45.92	37.72	36.03	–	0.02	0.07	–	32.38	32.42
TiO_2	0.45	0.16	0.26	0.43	4.55	1.6	98.99	95.88	–	–
Al_2O_3	32.77	33.57	29.14	30.14	0.04	0.02	–	–	–	–
Cr_2O_3	0.12	1.18	–	0.48	0.02	0.70	0.11	0.03	–	–
FeO	4.21	3.20	0.17	9.49	1.53	1.46	0.74	1.48	0.01	0.01
Fe_2O_3	–	–	–	–	93.93	96.89	–	–	–	–
MgO	0.60	0.78	13.98	7.26	0.04	–	–	–	–	–
CaO	0.03	0.02	4.48	0.24	–	–	–	–	–	–
Nb_2O_5	–	–	–	–	–	–	0.06	1.84	–	–
Ta_2O_5	–	–	–	–	–	–	–	0.19	–	–
ZrO_2	–	–	–	–	–	–	–	–	66.61	65.61
HfO_2	–	–	–	–	–	–	–	–	0.61	1.67
Na_2O	0.44	0.32	0.48	2.54	–	–	–	–	–	–
K_2O	11.09	10.60	0.04	0.01	–	–	–	–	–	–
H_2O	4.78	–	–	–	–	–	–	–	–	–
ThO_2	–	–	–	–	–	–	–	–	0.09	0.27
F	0.20	0.20	1.04	0.18	–	–	–	–	–	–
Total	99.53	95.95	87.31	86.80	100.11	100.69	99.97	99.42	99.70	100.02

Note: H_2O and B in tourmaline are not determined. Samples: 1—muscovite; 2—fuxite; 3—colorless tourmaline (the core of the grain); 4—dark colored tourmaline; 5 and 6—hematite; 7—orange rutile; 8—cherry-red rutile; 9—zircon crystal; 10—rounded colorless zircon grain. Here and in the Table 5 analyst—E.I. Churin (Inst. Mineral., Ural. Branch, Russ. Acad. Sci.), JXA-733 microprobe.

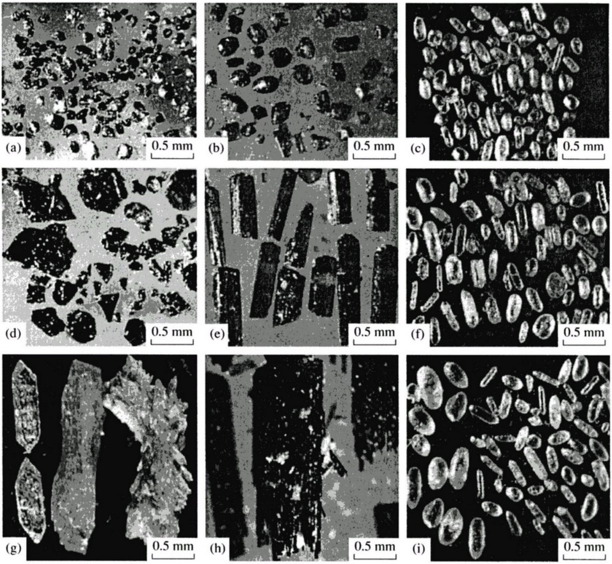

Fig. 11. Photographs of the common accessory minerals in sericitoliths and quartzite–sandstones. In quartzite–sandstones: a—hematite; b—tourmaline; c—zircon. In unaltered sericitoliths: d—hematite; e—tourmaline; f—zircon. In sericitoliths hydrothermally altered near crystal-bearing pockets: g—monazite; h—tourmaline; i—zircon.

chemical composition of sericitoliths is similar to that of the heavy phase (wt %): 39–41 SiO_2 and 8–9 K_2O.

After the filling of the cavities with quartz, vertical movements along vein-forming fractures were repeated. These movements are related to the second stage of tectono-hydrothermal activity and crystal pocket formation. The formation of new and the reactivization of already existing faults and accompanying fractures occurred at the lower contact of the quartz veins with host quartzite–sandstones. A thin band of sericitoliths related to this contact separates veins from the rock. The plastic sericitolith was emplaced into fractures under pressure in the fault zone and formed thin branching veinlets. The lenselike xenoliths of quartzite–sandstones, metapelites, and vein quartz occur everywhere along the upper sericitoliths boundary. Small lenselike cavities were formed in some places at the contact between sericitoliths and the quartz vein. The amplitude of the reverse fault was around some meters.

The rock crystal was deposited under decreasing pressure in the reopened cavities from the exhausted strongly undersaturated hydrothermal solutions that remained in rocks near fractures. The solutions were chloride–bicarbonate–sodium according to analyses of the aqueous extracts from the quartz crystals. The crystal-forming solutions had temperatures around 310° or less (Kuznetsov, 1998) and pH 7–7.5. They induced dissolution and redeposition of the host rock components and deposition of quartz crystals with accompanying minerals in open cavities. The quartzite–sandstones and sericitoliths became porous and loose near

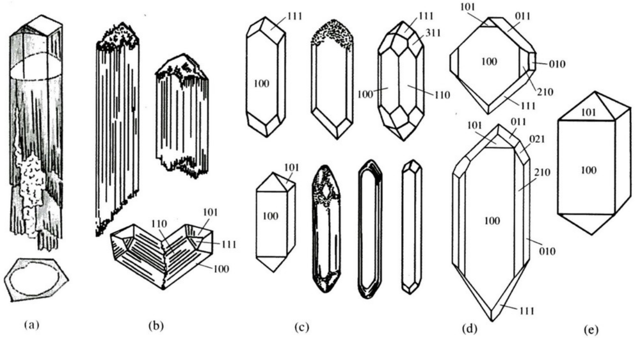

Fig. 12. Sketches of various mineral crystals in sericitolith: a—jacketlike crystal of the dark tourmaline with colorless core-seeding and its transverse section (the cavity is filled with muscovite); b—rutile crystals and their intergrowths (end planes are often absent); c—various zircon crystals with solution prints at the planes and crystal heads; d—monazite crystals in unaltered sericitoliths (uppermost crystal) and in hydrothermally altered sericitoliths near crystal-bearing pockets (the lower one); e—xenotime crystal.

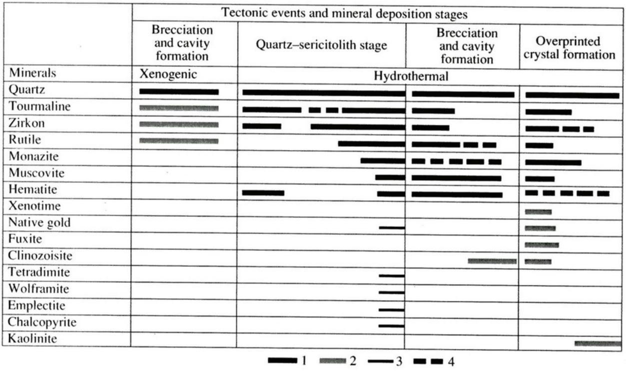

Fig. 13. Time sequence of mineral deposition in quartz veins. 1–3—mineral abundance: 1—common; 2—subordinate; 3—rare; 4—mineral dissolution.

the crystal pockets and minerals of the second generation appeared in sericitoliths, whereas the vein quartz was recrystallized. The concentration of hydrothermal solutions was variable in the process of cavity filling, which is evident from numerous dissolution surfaces in the quartz crystals. The formation of crystal pockets was accompanied with repeated tectonic activization, exfoliation in the pocket walls, and crushing of the crystals. The latter fell and mixed with a loose sericitolith substance, where they underwent natural gamma radiation and became smoke-colored.

The hydrothermal minerals and metasomatically altered rocks near the crystal pockets contain no additional components as compared with the host rocks. The concentration of petrogenic and minor components in the altered and host rocks are similar. The most remarkable processes were the dissolution of hematite; the mobilization and redistribution of REE and gold from the lower part of sericitolith bodies upward; and the deposition of monazite, xenotime, and gold in the upper part of the body.

The milky-white vein quartz containing crystal pockets is the main component of the quartz veins at the Zhelannoe deposit. Quartz was formed together with sericitoliths in the same cavities in the lower part of the vein. Then the latest crystal pockets were formed according to mechanisms of Alpine type veins formation due to consequent tectonic and hydrothermal activization. Small pockets are disseminated throughout the veins, but large ones relate to the veins that underwent long tectonic tension and are concentrated at the contact between vein quartz and sericitoliths.

Sericitolithic bodies are unusual in their association with high fineness quartz veins hosted by monomineral quartzite–sandstones. For a long time their genesis remained unclear. First, they were regarded as metasomatic rocks around crystal pockets, then as the result of near-fracture metasomatism. Recently, it was proposed that they are a restite formed after silica leaching and cavity formation. Some authors suggest that sericitolith bodies are metapelite layers that were tectonically removed from cavities. However, none of these versions has been conclusively proved.

According to geological observations, the sericitoliths were formed before the crystal pocket formation. No signs of their metasomatic origin were found. The quartz cavities containing crystals are also not a result of metasomatic leaching, but formed due to tectonic movements. On the other hand, sericitoliths differ from both quartzite–sandstones (with various accessory assemblages) and metapelite layers (with various mineral and chemical composition, structure, and mode of layering). The mean volume ratio of the vein quartz to sericitoliths (94 : 6%) is similar to the volume ratio of quartz to other accessory minerals in quartzite–sandstones. However, sericitoliths have high contents of Hf, Th, W, Nb, Ta, Cr, Au, Bi, Te, B, Ba, Sr, Y, and REE, that are not common in host rocks. The same elements are found in metasomatic pyrophillites and diaspore rocks, and in fuxite veinlets with REE and Au–Pd mineralization related to the zone of the Maldin fault

Table 5. Chemical compositions of rare elements minerals from sericitoliths (wt %)

Components	1	2	3	4	5
CaO	0.66	0.81	1.10	2.17	–
WO_3	–	–	0.02	0.16	2.35
ThO_2	1.71	4.48	8.71	1.84	0.11
Y_2O_3	0.23	0.36	–	0.16	42.43
P_2O_5	28.26	29.37	29.27	29.80	36.61
La_2O_3	13.33	13.56	11.96	14.61	0.08
Ce_2O_3	26.64	26.41	24.65	26.63	0.06
Pr_2O_3	3.36	3.62	3.84	3.66	0.10
Nd_2O_3	15.21	12.58	13.53	11.15	0.05
Eu_2O_3	1.5	0.95	1.43	1.22	0.21
Gd_2O_3	4.18	2.91	3.76	3.43	2.97
Tb_2O_3	–	–	–	–	0.74
Dy_2O_3	0.37	0.27	0.19	0.07	6.51
Ho_2O_3	1.31	1.28	1.28	1.38	2.67
Er_2O_3	0.42	0.30	0.36	–	4.33
SO_3	0.11	0.23	0.03	1.51	–
F	0.39	0.21	0.22	0.11	–
Total	97.67	97.34	100.35	97.9	99.26

Note: Samples: 1 and 2—monazite from unaltered sericitolith; 3 and 4—monazite from hydrothermally altered sericitolith near the crystal pocket; 5—xenotime. The Sm_2O_3 content is not determined, so the total sum is rather low.

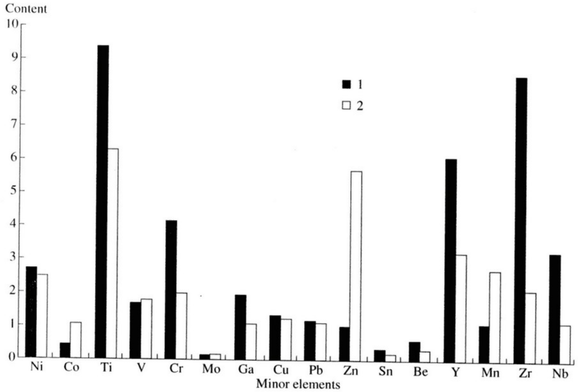

Fig. 14. Diagram of the minor element contents in sericitoliths (1) and metapelitic layers (2) at the Zhelannoe deposit (58 analyzed samples). The content of Ni, Co, Mo, Ga, Cu, Pb, Zn, Sn, Be, Y, Nb is in $n \times 10^{-3}$ wt %, the content of V, Cr, Mn, and Zr is in $n \times 10^{-2}$ wt %, and of Ti—in $n \times 10^{-1}$ wt %.

(Yudovich *et al.*, 1998; Tarbaev *et al.*, 1996). All the above listed data suggest that the alkaline solutions with typical associations of minor elements were produced by hydrothermal processes in the deep-rooted fault zones that are active for a long time.

Some thick sericitoliths bodies contain economical amounts of rutile, zircon, monazite and xenotime. So the Zhelannoe deposit may be classified as a new type of deposits of the high fineness vein quartz with accompanying rare metal and REE mineralization.

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REFERENCES

Bukanov, V.V., *Gornyi khrustal' Pripolyarnogo Urala* (The Rock Crystal of the Pripolyarnyi Urals), Leningrad: Nedra, 1974.

Bukanov, V.V., Bukanova, V.A., and Vasilevskii, N.D., Typomorphism of the Accessory Minerals in Metasomatic Rocks around Crystal-bearing Pockets, *Annual Issue of the Geol. Inst. Komi Branch of the Acad. Sci. USSR*, 1972, pp. 152–158.

Bukanov, V.V., Metasomatic Rocks Accompanying Crystal-bearing pockets at the Pripolyarnyi Urals, *Metasomatizm i rudoobrazovanie* (Metasomatism and Ore Formation), Moscow: Nedra, 1975, pp. 214–219.

Ermakov, N.P., Concerning Quartz Veins and Rock Crystal Deposits Origin, *Sov. Geol.*, 1956, no. 12, pp. 62–74.

Karyakin, A.E. and Smirnova, V.A., *Struktura khrustalenosnykh polei* (Structure of the Crystal-bearing Ore Fields), Moscow: Nauka, 1967.

Kuznetsov, S.K., *Zhil'nyi kvarts Pripolyarnogo Urala* (Vein Quartz of the Pripolyar Urals), S.-Peterburg: Nauka, 1998.

Kuznetsov, S.K., Bukanov, V.V., and Yukhtanov, P.P., *Topomineralogicheskie zakonomernosti khrustaleobrazovaniya (Pripolyarnoural'skaya subprovintsiya)* (Topomineralogical Features of Crystal Deposition (Pripolyar Subprovince)), Leningrad: Nauka, 1988.

Makhlaev, L.V., *Granitoidy severa Tsentral'no–Ural'skogo podnyatiya (Polyarnyi i Pripolyarnyi Ural)* (Granitic Rocks of the Central-Ural Rise (Polyarnyi and Pripolyarnyi Urals)), Ekaterinburg: Ural. Otdel. Ross. Akad. Nauk, 1996.

Omel'yanenko, B.I., Volovikova, I.M., Dritz, V.A., Zvyagin, B.B., *et al.*, On the Term Sericite, *Izv. Akad. Nauk, Ser. Geol.*, 1982, no. 5, pp. 69–87.

Popov, V.I., Popova, V.A., and Gur'yanov, V.Yu., Gold, Tetradimite, Emplectite, Chalcopyrite, and Wolframite in the Crystal-bearing Quartz Veins at the Zhelannoe Deposit (Pripolyarnyi Urals), *Ural'skii mineralogicheskii sbornik* (Urals

Mineralogical Papers), Miass: Inst. Mineral. Ural. Otdel. Ross. Akad. Nauk, 1993, no. 2, pp. 58–61.

Pystin, A.M., *Polimetamorficheskie kompleksy zapadnogo sklona Urala* (Polymetamorphic Complexes of the Western Slope of the Urals), S.-Peterburg: Nauka, 1994.

Repina, S.A., Lithological Mapping of the Ordovician Sequences at the Kozhim Region, *Tezisy dokladov region. Soveshch. Geologiya i metallogeniya Pripolyarnogo Urala* (Abstracts, Regional Conference on Geology and Metallogeny of the Pripolyar Urals), Syktyvkar: Inst. Geol., Karel. Nauch. Tsentr Ural. Otdel. Ross. Akad. Nauk, 1993.

Repina, S.A., Comparative Study of Hydrothermal Rocks at the Gold and Quartz Deposits at the Pripolyarnyi Urals, *Metallogeniya drevnikh i sovremennykh okeanov–98. Rudy i genesis mestorozhdenii* (Metallogeny of Ancient and Modern Oceans–98. Ores and Their Genesis), Miass: Inst. Mineral. Ural. Otdel. Ross. Akad. Nauk, 1998, pp. 188–194.

Repina, S.A., The Structure and Composition of the Sericitoliths Bodies at the Zhelannoe Quartz Deposit (Pripolyar Urals), *Metallogeniya drevnikh i sovremennykh okeanov–99. Rudonosnost' gidrotermal'nykh sistem* (Metallogeny of Ancient and Modern Oceans–99. Ore-Bearing Hydrothermal Systems), Miass: Inst. Mineral. Ural. Otdel. Ross. Akad. Nauk, 1999, pp. 161–170.

Rumyantsev, V.N., Immiscibility in Alkaline Silicate Solutions under High Pressure and Temperature (to the Problem of Structure of the Hydrothermal Quartz-depositing Systems), *Zap. Vseross. Mineral. O–va*, 1999, no. 1, pp. 125–129.

Tarbaev, M.B., Kuznetsov, S.K., and Moralev, G.V., New Gold–Palladium Type of Mineralization in the Kozhim Region in the Circumpolar Urals, Russia, *Geol. Rudn. Mestorozhd.*, 1996, vol. 38, no. 1, pp. 11–25.

Yudovich, Ya.E. and Ketris, M.P., Geochemistry of Metamorphic Rocks in the Zone of Interformational Contact at the Al'kesvozh Creek, Pripolyar Urals, *Petrologiya i mineralogiya severa Urala i Timana* (Petrology and Mineralogy on Northern Urals and Timan), Syktyvkar, 1997, vol. 95, pp. 80–130.

Yudovich, Ya.E., Efanova, T.I., Shvetsov, I.V., *et al.*, *Zona mezhformatsionnogo kontakta v kare oz. Grubependity* (The Zone of Interformational Contact near the Grubependity Lake), Syktyvkar: Geoprint, 1998.