The Tomtor ore massif is located in northernmost Yakutia, 250 km from the Arctic Ocean coast. It was discovered in late 1950s by Leningrad geologists S. A. Gulin and E. N. Erlikh. It is worth noting that Sergei Gulin figured Sergei Gurin, the protagonist in the widely popular O. Kuvaev's novel Territory, describing the life of Soviet geologists in that epoch.

The main feature of the massif is a giant field of compound ores. At present, the State Register of Reserves accounts ten elements, but the hallmarks of Tomtor are niobium, yttrium, scandium, and lanthanides, present in great abundance and highly concentrated.

The main minerals of Tomtor ores are niobium pyrochlore and rare-earth phosphates. Usually, their concentrations are no greater than 1–5 %, whereas in Tomtor they are major components. They constitute 10 to 80 % of the rocks! Actually, the rocks are niobium–REE concentrate. The production of such concentrate from common ores demands giant concentrating mills, and in Tomtor, it is given by Nature itself.
Unfortunately, although the unique ore deposit has attracted attention since its discovery, its remoteness from industrial regions by thousands of kilometers hampered its development. Even now, fifty years after the discovery, the present and future of the giant rare element deposit are obscure.

Does Russia need Tomtor in the light of dramatic changes in the raw-material base and the structure of global economy?

The term rare elements is loose. It has been conventionally used since the times when most of them were rare not even with respect to their industrial use rather than abundance in the Earth’s bowels. This “fashionable” group was visited by over 50 elements, including those currently

The daily routine of a prospecting geologist is no picnic. It is hard labor far away from lived-in areas, facing wilderness, often hostile.

On the other hand, just in these unexplored lands the pristine beauty opens up

The rare-element epoch

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The global rare element market is characterized by a profound bias. The lion’s share (up to 90%) of the niobium market accrues to Brazil, whereas China produces the vast majority of rare elements and supplies them to the whole world at low prices. A rare-earth crisis happened in 2010, and China had to shrink their export dramatically to meet its domestic demand. The subsequent multiple increase in rare element prices showed to all advanced countries that with the monopolized market it was a shortsighted policy to rely upon imported materials, as it is still done in Russia.

Russia ranks second to China in proven rare earth reserves and certainly first in resources. It has the largest deposits of niobium and rare earths (Tomtor and Chuktukon) and tantalum (Katugin). Most of the reserves of these elements are enlisted in the State Register as associated components of complex ores (mainly apatite). As a result, over 80,000 tons of rare earth oxides are deducted from the balance annually, whereas no more than 15,000—25,000 tons are extracted in the form of commercial products. Thus, the amount of rare earth elements falling to waste is twenty times as large as the demand of Russian industry. However, Russia has no production facilities for converting such waste, and the construction of new ones is economically unsound in the modern context

The appearance of new fields of application altered the pattern of rare element consumption. The materials in shortest supply are neodymium, praseodymium, terbium, and dysprosium, which are utilized in the production of electric cars. Experts predict that the demand for some of these elements will not be met in the years immediately ahead.

(Pokhilenko, Tolstov, 2012)
utilized as major structural materials in things of daily use: titanium, molybdenum, tin, etc.

Presently, rare elements include 35 members: 17 rare-earth elements (scandium, yttrium, lanthanum, and lanthanides) and rare metals (tantalum, niobium, lithium, beryllium, zirconium, etc.)

Experts indicate that nowadays the consumption of rare metals is a more important index of industrial development of a country than cast iron or steel. It is not an overstatement to say that all aerospace, nuclear, ultra-high-temperature, ultramagnetic, ultralight, ultrahard, and ultrastrong engineering materials are manufactured on the base of rare elements or with their use. At present, many rare element deposits are often associated with carbonatites, as in Tomtor. Carbonatites are deep-seated rocks in which carbonates constitute more than one-half. These rocks form in close relation with ultramafic alkalai rocks by magma differentiation in deep-seated magma chambers. The chambers are usually associated with magma-conducting faults located at depths 1—10 km and overlain by Earth’s crust strata, hampering magma rise. Magma differentiation, giving rise to carbonatites, requires specific conditions. The chamber must not be too deep; otherwise, pressure hampers carbonatite formation. Neither must it be too close to the surface, to prevent their fast cooling. Then carbonatite and ultramafic magma intrude to subsurface strata and form veins. Generally such carbonatite bodies are no more than 1 km in diameter, but the diameter of the unique central body of Tomtor is about 6 km.

Carbonatite massifs occur in the most permeable areas, which are sites of branching, junction, or cross of differently directed faults. Carbonatites have the largest ore contents of all assemblages of ultramafic alkali rocks. The products of subsurface alteration (weathering) of carbonatites are even richer. Just they contain commercial types of ores with a large set of raw materials: niobium, phosphorus, iron, and rare-earth elements.

The bubbles are gaseous–liquid inclusions in pyroxene, a typical mineral of ultramafic alkali rocks and carbonatites. They can be seen only at large magnifications. Controllable heating of a rock allows reconstruction of its formation conditions. The homogenization temperature, at which such inclusions in the mineral become homogeneous, is taken to be the formation temperature of the mineral. That is how it was found that bubbles formed in pyroxene only at large depths and high (> 1000 °C) temperatures.
The consumption of rare elements per capita varies from country to country. In advanced countries, this index is several times (or by an order of magnitude for some rare metals) less than in Japan. For the majority of less developed countries, including Russia, this index per one ton of steel or per capita is an index of the economic maturity of a country. The consumption of rare elements is manifold and even by orders of magnitude. The consumption of rare earths, including zirconium, was one-ninth as in Japan, and so on. The lion’s share was one-eighth as large as in Italy and one-seventh as in West Germany. The Soviet rare-metal industry disintegrated, and its enterprises fell into different countries: Kazakhstan, Russia, and Estonia. Apparently, the broken economic links cannot be restored as they were.

Presently, limited amounts of rare-earth ores are mined only at the Lovozero enterprise (Murmansk oblast). The ore is converted to loparite concentrate, which is processed at the Solikamsk magnesium plant, Perm Krai. Both enterprises are privately owned, and their capital goods are worn out to a significant extent. Thus, a decrease in production is expected.

The demand for rare metals in Russia is almost entirely met by import. The shortage of rare earths in Russia has been increasing since 2012. Presently, it is about 300 tons/year. This fact may retard the development of Russian high-tech industry in the decade to come.

The production of rare elements can be increased at the Lovozero enterprise, but it would concern only light lanthanides, whose liquidity is poor. A fundamental change of the situation demands operation of new unique enterprises able to meet market needs.

Russia has enormous mineral reserves of rare elements, gravitating mainly to northern and eastern regions: the Kola, Maimecha–Kotun, East Sayan, Sete-Daban, and Udzhra carbonatite provinces are the base of the ore potential of Tomtor. Further, the situation worsened, especially in the last quarter of the 20th century. The Soviet rare-metal industry disintegrated, and its enterprises fell into different countries: Kazakhstan, Russia, and Estonia. Apparently, the broken economic links cannot be restored as they were.

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Even in comparison to these deposits, Tomtor is a true leader. It is known to be among the greatest in the world. However, the mineral treasure of Tomtor became needless in the perestroika epoch.

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Even in comparison to these deposits, Tomtor is a true leader. It is known
that natural concentrations of rare elements are broadly variable, usually within few parts per million (scandium), per 10^5 or per 10^4 (tantalum), or per thousand (niobium, cerium, and lanthanum). Commercially significant concentrations are several times higher. The contents of rare element oxides in Tomtor ores astonish: 1—24 % niobium, 0.1—3.5 % yttrium, 0.01—0.15 % scandium, and 1—39 % other rare-earth metals.

Compare these figures with the famous Aracha field in Brazil, where about 90% of the global niobium production is mined. The contents of niobium oxide in its ores range within 1.0—2.5 % with next to no secondary rare earths. Ores of another large rare-earth mining district, Bayan-Obo in China, contain up to 10% rare metals, but no niobium. The assessment of Tomtor reserves done in 1999 in accordance with the standards of the State Reserves Commission shows that the boundary value of niobium oxide content, at which the ore is considered commercial, is 3.5%, above the mean concentration in Aracha. The reserves of such commercial ores in the Burannyi sector alone are 42,700,000 tons.

Thus, Tomtor is now the first rare-metal giant in the world in the resources and concentrations of niobium and rare earths. Its development would support the required increase in the production of the whole range of rare-earth products and highly liquid secondary products: aluminum and titanium oxides.

The nascence of Tomtor

How did the unique rare-earth ores of Tomtor arise? There are three major hypotheses of their origin: deposition in lakes (sedimentary origin), transformation of effused lava flows (effusive–sedimentary origin), and concentration of insoluble heavy rare elements in stepwise subtraction of rock-forming elements in the course of successive oxidation and reduction.

According to the last hypothesis, put forward by Lapin and Tolstov (1991, 1993), the main ore formation stages included weathering of initially ore-bearing carbonatites followed by redeposition and structural–compositional alteration of parent rocks under nonequilibrium conditions of the water/rock system (epigenetic transformation). At the last stage of genesis, the ores were buried under sediments, which protected them from erosion.

At last, the following scenario emerges. Tomtor itself was forming as a deep magma chamber for long, about 200 Ma (within 600 to 350 Ma BP). Probably, it included two or three independent steps. The resulting intricately built massif appeared on the day surface no earlier than the Devonian, when primitive fish appeared in seas.

At that time, the climate in what is now Arctic Yakutia was similar to tropical Africa. Under those temperatures, rocks experienced deep transformation, particularly influencing ore-bearing compound carbonatites of heterogeneous nature. Natural rock weathering and metamorphism in Tomtor worked as a concentration mill, producing ore concentrate from poor ores occurring in ordinary rare-metal deposits.

Left: niobium pentoxide content in ores of the Burannyi sector, Tomtor. Below: the main niobium mineral pyrochlore at a large magnification.
neous composition. As a result, a 300-m thick iron-phos-
phate cap formed above the massif. Iron oxides, hematite
and limonite, hued it brownish-rusty. Thewn soluble carbonates rocks were washed out during karstifica-
tion, and the initial mass of carbonates decreased by
50 to 90%. In this way, ore components rich in niobium
and rare earth accumulated.
Large depressions formed in central areas of the massif
experimenting karstification at the Carboniferous/Perma-
ian boundary. In addition, tectonic movements were caused
by repeating earthquakes occurring in the Carboniferous.
All these processes redistributed the loose matter. Rocks
were eroded from elevated areas and deposited in depressions.
That was how three local sectors arose: Northern, Burannyi,
and Southern. They were extraordinarily enriched in ore
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