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Titanium Raw Materials of Russia

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Abstract—Russia takes the second place in the world with regard to proved reserves of titanium ores; however, no Russian deposits of titanium are involved in development. Development of 4–5 zirconium-titanium placers and 2–3 deposits of ilmenite–titanomagnetite ores will make it possible to completely satisfy the needs of the domestic industry for titanium and zirconium and to enter the global market with these products.

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INTRODUCTION

Titanium and its compounds are widely used in various industrial sectors and belong to the types of materials, which determine the level of economic development of the state and its defense capability.

Commercial exploration of titanium started only in XX, although it was discovered as early as the end of XVIII. The first titanium compound to be applied was titanium tetrachloride, which was widely used as masking smokescreens during World War I. In peacetime this titanium compound was applied for fumigation of plants during spring frosts.

The first wide-scale application of titanium as a nonmetallic raw material was in the form of pigmentary titanium dioxide, industrial production of which started in Norway in 1916. Much later, in 1951 production of metallic titanium started in the United States of America and in 1957 in the Soviet Union.

White pigmentary titanium dioxide (titanium white) is used for production of titanium white paints, papers, rubbers, plastics, ceramics etc. Titanium white paints are the best of all known white paints due to their permanence, whiteness, opacity, and other properties [1]. The demand for titanium white depends on ever-increasing volumes of housing construction and manufacturing of cars, ships, airplanes, and other products, requiring persistent, long-lasting coatings; its per capita consumption rate indirectly reflects the quality of life in the country. Major consumers of titanium dioxide are the most developed countries: the United States of America, Japan, Germany, Great Britain, and France. Global production of TiO_2 has reached 5 million tons and consumes up to 97% of titanium raw materials [2]. In recent years a great leap forward has been made by China: Chinese production of titanium dioxide has already reached 950 000 tons and in the near future it can increase to 1.5 million tons, allowing China to catch up with the United States.

The second large-scale application of titanium raw materials is the production of titanium sponge, an intermediate product in obtainment of metallic titanium and its alloys. Such qualities of the metal as low density, high heat resistance, corrosion resistance in almost any media, and extremely high mechanical and other characteristics, predetermine its indispensability and wide prospects of application in all technical fields. Until recently the rate of consumption of metallic titanium and its alloys largely served as an indicator of the country's militarization, but today it is becoming an indicator of the country's scientific and technological progress. At present, there is a search for new large-scale peaceful areas of application of titanium and its alloys and a significant increase in demand for these materials in this century is predicted.

At the same time, while the stable growth in consumption of titanium pigments does not raise any doubts and amounts to 2–3% annually according to various estimates, the production of metallic titanium and its alloys has faced two serious crises. The crisis of 1991–1995 resulted from a decrease in the number of military orders, as metallic titanium and its alloys were mostly used in products of the military-industrial and aerospace complexes. The second crisis started after the tragedy of September 11, 2001 in the United States of America, which caused a drastic decrease in aircraft production. At present, due to the growing volumes of passenger transportation and high titanium consumption in construction of new airplanes, it is predicted that the demand for intermediate titanium products in the civil aircraft industry will double already by 2015 [3]. Great future prospects of metallic titanium and its alloys are based on relative abundance of titanium in Earth's crust (it is ranked fourth among metals, going after aluminum, iron, and magnesium) and its valuable consumer properties. It is expected that titanium can replace high-tensile steels in the same way as aluminum once replaced wood in aviation. At the same time, due to difficulties in raw material processing and metal production connected with high energy and material costs, in future titanium can still remain a relatively expensive metal.

Titanium technophility index, which is the ratio of annual titanium production to its clarke, is relatively low and significantly lower than indexes of many other elements (Fe, Cu etc.). It indicates rather limited utilization of titanium so far and undoubtedly great prospects for its production and consumption in future [4].

Mineral Composition, Types, and Processing Methods of Titanium Raw Materials

Major industrial minerals of titanium are as follows: ilmenite $FeTiO_3$ (33.4–68.2% of TiO_2), rutile TiO_2 (88.6–98.2% of TiO_2), anatase (polymorphic modification of rutile), and leucoxene, an alteration of ilmenite and sphene (47–90% of TiO_2). Small amounts of titanium are obtained in complex processing of loparite concentrates. The following minerals can turn out to be potentially productive for titanium: sphene $CaTi[SiO_4][O,OH,F]$, extracted as a byproduct in Khibiny apatite deposits, titanomagnetite $(FeTi)Fe_2O_4$, and perovskite $CaTiO_3$ [5].

At present, titanium concentrates (mostly ilmenite, rutile, and leucoxene) are used as raw materials for processing industries. The best and the most expensive are rutile concentrates, containing 92–96% of TiO_2. Ilmenite concentrates contain 42–65% of TiO_2, and leucoxene concentrates 56–91%.

In order to increase the quality of titanium raw materials used for production of metallic titanium or titanium dioxide, titanium slag (75–85% of TiO_2), enriched titanium slag (91–95% of TiO_2), and synthetic rutile (87–95% of TiO_2) are produced. In processing of titanium ores these intermediate titanium products with a high content of TiO_2 are the most preferable for further production of metallic titanium, pigmentary titanium dioxide or any other marketable products. A diagram illustrating the use of various mineral concentrates of titanium is given in Fig. 1.

For production of pigmentary titanium dioxide from titanium concentrates the sulfuric-acid (sulphate) method or the chloride method are used. More than 50% of titanium dioxide produced abroad is received as a result of the chloride process. In the Soviet Union production of titanium dioxide was based exclusively on sulphuric acid digestion of domestic ilmenite concentrates and imported titanium slag. When this method is applied, the iron contained in the concentrates is not used and significant amounts of ferrous sulphate waste require utilization or burial. As compared to the sulfuric-acid method, the chloride technology is characterized by a shorter process flow and less environmental impact; it is a low-waste continuous process that can be automated. However, only intermediary products with a high content of titanium (slag or synthetic rutile) can be used as raw materials for the chloride process, i.e. it requires rather energy-intensive preliminary processing of ilmenite and leucoxene concentrates through electric smelting or hydrometallurgy. At the same time, the quality of ilmenite concentrates meets milder requirements than when the sulphuric-acid method is used for processing.

At present, the sulphate and chloride methods are applied globally at approximately the same scale. The chloride process is more environmentally safe; however, in recent years due to the improvement of the concentrates processing technology based on the sulphate method, it has become possible to establish low-waste production characterized by a drastic reduction in toxic waste generation and a wide range of produced iron-oxide pigments, which contributes to a wider application of the sulphate technology as more cost-effective and complying with environmental requirements [6]. Accordingly, there is an increased interest in high-quality ilmenite concentrates for their direct processing based on the sulphate method. Ilmenite concentrates from ilmenite and ilmenite-titanomagnetite ores of primary deposits and related

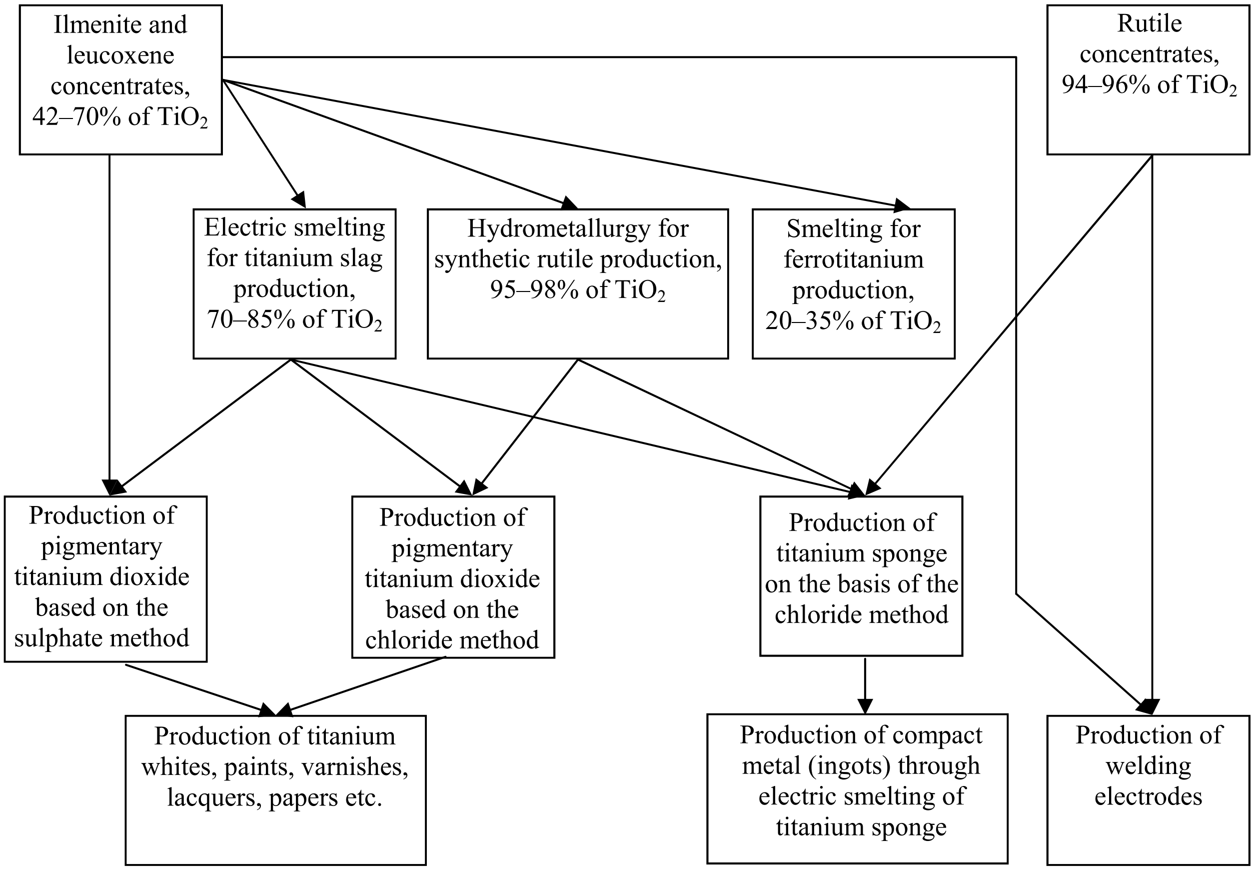

Fig. 1. Diagram of application of titanium mineral concentrates and products of their processing.

placers are the best for the purpose. Ilmenite concentrates of coastal-marine placers of distal transportation and redeposition are characterized by a high TiO_2 content (55–65%) and low concentrations of slag-forming impurities, which makes them the most suitable raw material for obtainment of titanium slag and titanium sponge to be further processed on the basis of the chloride method in order to produce metallic titanium and pigmentary dioxide.

Both the sulphuric-acid and the chloride method of processing titanium-containing concentrates do not ensure complex extraction of all the components from raw materials, a part of them is discharged into the environment in the form of sulphates or chlorides of the elements.

A similar picture is observed in metallic titanium production. Titanium metal is produced commercially all over the world by the Kroll process or the Hunter process, metallothermic reduction of highly-purified titanium tetrachloride with metallic magnesium or sodium. Titanium produced under this technology is extremely high-priced; it is about six times as expensive as ordinary stainless steel. For this reason metallic titanium has never been widely used in industry and especially in everyday life. Development of an industrial electrolytic method of low-cost titanium production would lead to a drastic increase in the demand for metallic titanium in all industrial sectors. Relevant scientific and research works are currently performed in a number of countries; several techniques have been developed, including for instance the electrolytic FFC process in the course of which metallic titanium is produced at the cathode in molten calcium chloride and the "Karelin-process" based on extraction of titanium powder from molten fluorides. However, at present none of these methods has entered the stage of industrial application yet [7].

Global Mineral-Resource Base of Titanium, Production, and Prices

Titanium reserves are mainly contained in deposits of the following three industrial groups: ancient and recent coastal-marine and alluvial (stream) placers

Table 1. Titanium dioxide resources and reserves in ilmenite and rutile as of January 1, 2008

Country's rank in the world with regard to TiO_2 reserves in ilmenite	Country	Ilmenite				Rutile			
		TiO_2 reserves		TiO_2 resources		TiO_2 reserves		TiO_2 resources	
		mln. t	%	mln. t	%	mln. t	%	mln. t	%
1	China	210	28	360	21	3	6	9.7	7
2	Australia	135	18	233	15	23.1	45	63.5	47
3	India	85	11	210	13	7.4	14	20	15
4	Republic of South Africa	63	8	220	14	8.3	16	24	18
5	Brazil	43	6	84	5	3.5	7	4	3
6	Norway	37	5	60	4				
7	Vietnam	34	5						
8	Russia	34	5	130	8	1.1	2.2	2.3	1.7
9	Canada	31	4	36	2.2				
10	Sierra Leone					2.5	5	3.6	3
11	Ukraine	30	4	45	2.8	3	6	3	2.25
12	Mozambique	11.1	1.5	60	4	0.6	1.2	0.6	0.45
13	USA	6	0.8	59	4	0.4	0.8	1.8	1.35

(55%); gabbro-anorthosites of ilmenite-titanomagnetite, ilmenite-hematite, and ilmenite-rutile primary ore deposits (25%); and anatase-rutile-perovskite deposits of carbonatite complexes weathering crusts (20%).

The majority of reserves and forecast resources are contained in primary ore deposits, but placer deposits are in the highest demand for the industry as having better technical-economic indicators. As a rule, these deposits are complex zircon-rutile-ilmenite placers. They are intensively developed abroad, and more and more new deposits become objects of commercial exploration [8].

As of January 1, 2008 the global identified resources of titanium dioxide, which is the total for 16 countries reached 2 166 billion tons, including 1 605 billion tons of ilmenite (16 countries), only 135 million tons of rutile (12 countries), and 426 million tons of other titanium minerals (leucoxene, titanomagnetite, sphene, and loparite), which are registered in Russia. Approximately 90% of the identified resources of titanium dioxide contained in ilmenite are located in the depths of nine different countries and almost 90% of the identified resources of titanium dioxide contained in rutile are concentrated on the territory of five states [2].

As of January 1, 2008 the global reserves of titanium dioxide registered in 12 different countries amounted to 968 million tons, including 747 million tons of ilmenite, only 51.5 million tons of rutile, and 170 million tons of other titanium minerals (leucoxene, titanomagnetite, sphene, and loparite), which are registered in Russia. Almost 90% of the total titanium dioxide reserves contained in ilmenite are concentrated in the depths of nine different countries. The majority (92%) of the total titanium dioxide reserves in rutile are located on the territory of six states (Table 1). After the Yugo-Vostochnaya Gremyakha deposit was included into the state register in 2009, Russia is ranked fifth among the countries possessing ilmenite reserves, following China, Australia, India, and the Republic of South Africa. At the same time, Russia is the second country in the world in terms of the total titanium reserves.

The global output of titanium concentrates and middlings in 2006 exceeded 16 million tons (including ilmenite, rutile, and leucoxene concentrates, synthetic rutile, and titanium slag). There is a continuous growth in titanium dioxide production: in 2006 the production volume reached 4 936 million tons exceeding the output of 2005 by 3.3%, and the greatest leap forward (13.8%) was made by China.

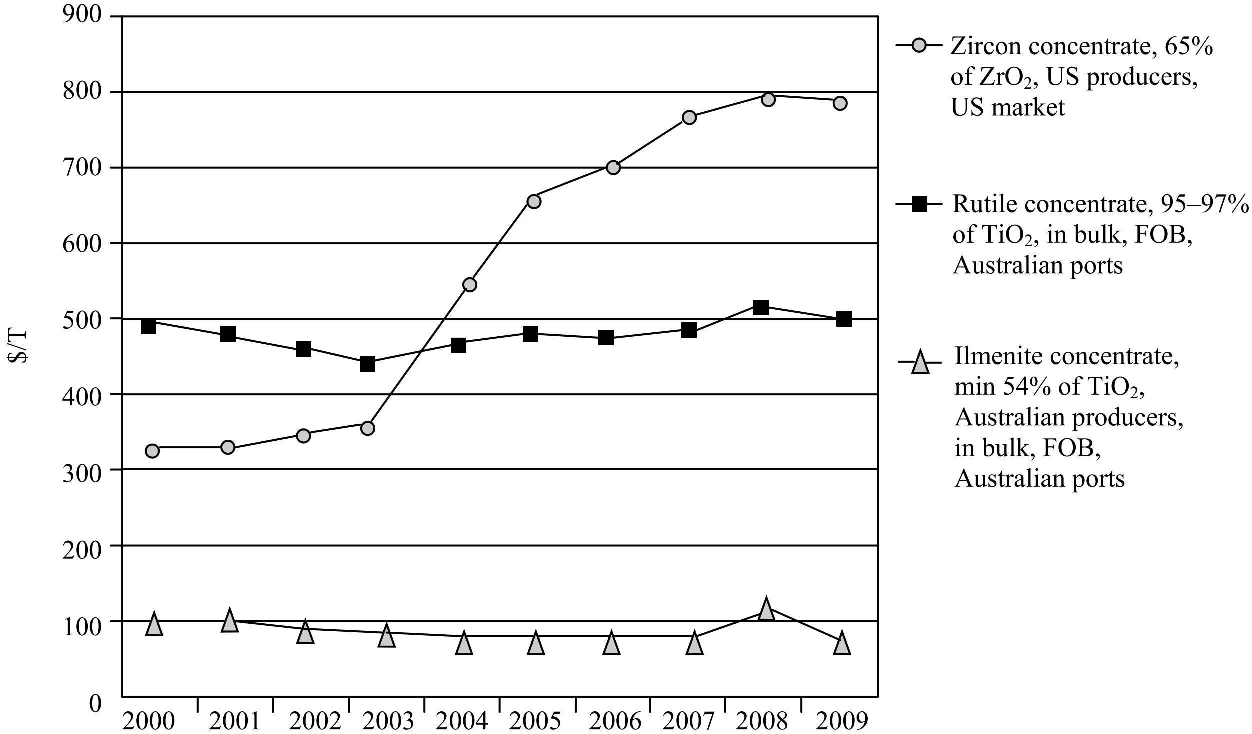

Fig. 2. Dynamics of average annual prices on ilmenite, rutile, and zircon concentrates.

A much faster growth is observed in manufacturing of titanium sponge, which is used for production of compact metallic titanium. Titanium sponge is produced in the following six countries: China, Japan, Russia, Kazakhstan, the United States, and Ukraine. In 2006 the output of titanium sponge was 20% higher than the corresponding value of 2005, and in 2007 the increase reached almost 30% with the total output of titanium sponge amounting to 170 000 tons. At present, the leading producer of titanium sponge is China, which is rapidly extending its production capacity. Russia is the third largest producer after China and Japan.

In recent years there has been a significant increase in prices for ore concentrates (especially rutile and zircon concentrates). Even during the crisis period the prices for these concentrates, unlike the majority of other mineral raw materials, remained almost unaffected (Fig. 2) with the exception of a certain decrease in prices for ilmenite concentrates.

In 2009 minor fluctuations in prices for ilmenite and rutile concentrates are observed. The price for ilmenite concentrate is approximately 90$/t, while the prices for rutile concentrate reach 550 and 750$/t for the pigment and welding grades, respectively. The price for zircon concentrate is continuously growing, at present ranging from 850 to 1 450$/t depending on ZrO_2 content. During the period of October 2008–February 2009 the prices for such marketable products as titanium dioxide, titanium sponge, and titanium slag were almost halved; however, since February 2009 there has been an intensive growth and now the prices are approaching the pre-crisis level. The price for titanium sponge varies from 4.1 to 7.0 $/kg; titanium dioxide costs from 2.5 to 3.5 $/kg; the price for ferrotitanium (70% of Ti) is approximately 4.5 $/kg; synthetic rutile costs approximately 0.5 $/kg.

Many countries are implementing projects aimed at developing the production of titanium minerals (and often zircon). The major regions of geological prospecting and exploration of placer deposits are Australia and Africa; India, China, Kazakhstan, Russia, and Ukraine are also becoming more active in this field. Primary ore deposits are explored in Canada, Chile, China, and Russia. It is expected that in the coming years there will be a significant increase in the production capacity for concentrates of heavy minerals (mostly rutile and zircon concentrates). It is ensured

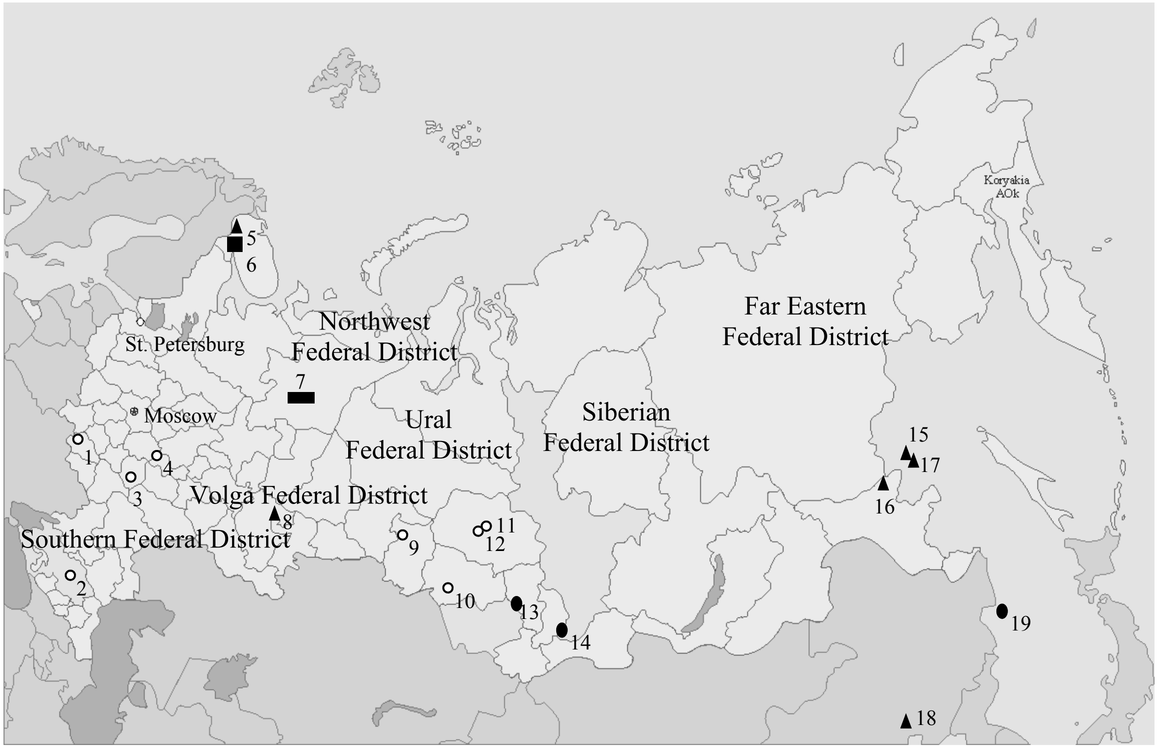

Fig. 3. Map of location of major titanium deposits on the territory of Russia. Deposits: (1) Unechskoye, (2) Beshpagirskoye, (3) Tsentral'noye, (4) Lukoyanovskoye, (5) Yugo-Vostochnaya Gremyakha, (6) Lovozerskoye, (7) Yaregskoye, (8) Medvedevskoye, (9) Tarskoye, (10) Ordynskoye, (11) Georgievskoye, (12) Tuganskoye, (13) Nikolaevskoye, (14) Tulunskoye, (15) Kuranakhskoye, (16) Chineyskoye, (17) Bol'shoy Seyim, (18) Kruchininskoye, and (19) Ariadnenskoye. Types of deposits: Primary deposits (▲) Ilmenite-titanomagnetite, (■) Loparite, and (▬) Leucoxene. Placer deposits: (○) Complex titanium and zirconium (ilmenite, rutile, and zircon) and (●) Titanium (ilmenite).

both by discovery, prospecting, and exploration of new deposits and by development and implementation of new technologies of extracting valuable minerals from placers of fine-grained materials.

Russian Mineral-Resource Base of Titanium

More than thirty primary and placer deposits of titanium have been detected, studied to some extent and prospected on the territory of Russia. The majority of the deposits are located in European Russia, in Eastern and Western Siberia, and in Primorye (Fig. 3).

As of January 1, 2009 the State Register of mineral reserves of the Russian Federation incorporated 24 titanium deposits, including 20 objects with balance reserves and 4 deposits with off-balance reserves only. Primary deposits account for 93.4% of the balance reserves under $A+B+C_1$ categories; 12 placer deposits account for the remaining 6.6%, but in absolute terms these titanium reserves are rather large.

During the Post-Soviet Era, Russian titanium reserves have increased more than 1.5-fold due to the completion of geological prospecting works at a number of deposits. At present, Russian titanium reserves reach approximately 210 million tons of TiO_2 (~20% of the global TiO_2 reserves). In this respect the mineral-resource base of titanium greatly differs from the majority of other metals, the decreased production of which in recent years has not been compensated with an increment in reserves. The number of deposits with balance titanium reserves has increased from 10 to 20. Two large-scale deposits of ilmenite-titanomagnetite ores, the Chineyskoye deposit and the Yugo-Vostochnaya Gremyakha were included into the state register in 2000 and 2009, respectively.

The analysis of the structure and quality of the Russian titanium reserves included into the register demonstrates that they are mostly represented by primary deposits with complex geographical and

Table 2. Proved titanium reserves included into the State Register of the Russian Federation as of January 1, 2009 in accordance with ore types

Commercial types of ores and deposits	Number of deposits with balance reserves	Average TiO_2 content, (%) in ore, (kg m^{-3}) in sands	TiO_2 balance reserves as of 01.01.2009	
			cat. A+B+C_1	cat. C_2
			ratio % to the Russian Federation reserves	
Primary deposits				
(1) Quartz-leucoxene oil-bearing sandstones[a] (Yaregskoye)	1	10.4%	38.5	66.7
(2) Ilmenite-bearing sandstones[a] (Tulunskoye)	1	3.3%	1.1	1.2
(3) Ilmenite-titanomagnetite ores (Medvedevskoye)	1	7.0%	12.0	3.0
(4) Apatite-ilmenite-titanomagnetite ores (Kruchininskoye)	1	8.4%	14.0	8.0
(5) Titanomagnetite ores (Podlysanskoye and Chineyskoye)	2	8.9%	20.8	9.3
(6) Loparite ores (Lovozerskoye)	1	1.3%	1.8	1.6
(7) Apatite-nepheline ores with titanomagnetite and sphene (Yukspor, Kukisvumchorr, and Partamchorr)	3	1.0%	5.6	9.6
Primary deposits, Total	10	—	93.4	99.4
Placer deposits				
(1) Zircon-rutile-ilmenite placers (Beshpagirskoye, Lukoyanovskoye, Tarskoye, Tuganskoye, Georgievskoye, Tsentral'noye, Ordynskoye, and Butkinskoye)	8	22.92 kg m^{-3}	6.5	0.6
(2) Ilmenite placers (Ariadnenskoye)	1	32.82 kg m^{-3}	–	<0.01
(3) Quartz sands with associated ilmenite, rutile, and zircon (Novozybkovskoye)	1	0.81 kg m^{-3}	0.1	<0.01
Placer deposits, Total	10	—	6.6	0.6
Total for the Russian Federation	20	—	100.0	100.0

[a] In the State Register of the Russian Federation the deposits are conditionally classified as primary deposits due to mining and processing conditions of ores. In addition, there are another four deposits containing off-balance titanium reserves in the State Register of the Russian Federation, including two primary deposits (Shubinskoye: rutile-bearing eclogites and Kopanskoye: titanomagnetite ores) and two placer deposits (Ayskoye: ilmenite-titanomagnetite sands and Nikolaevskoye: ilmenite sands).

economic, mining and geological, and technological characteristics of ores. The ores prevailing in the titanium state register are high-silica leucoxene, titanomagnetite, sphene and other ores, the commercial value of which remains questionable (Table 2). Licenses for additional appraisal and exploration of 14 deposits (~80% of A+B+C_1 reserves) have been issued, and 10 deposits are registered in the state unallocated fund of mineral resources (including the large Kruchininskoye deposit of primary ores in Chita Oblast). It is planned to develop Russian primary titanium deposits through open-cut mining (the open-pit method), with the exception of the complex titanium-rare-metal Lovozerskoye deposit which is currently developed through underground mining and the Yaregskoye deposit where the shaft-mining method will be applied. It is planned to develop placer deposits on the basis of both the open-pit method and the hydraulic borehole mining method.

As it has been described above, the major industrial type of titanium and zirconium deposits in the world in general and in Russia in particular is recent and ancient coastal-marine zircon-rutile-ilmenite placers, accounting for ~60% of titanium and ~95% of zirconium production. The second leading type includes primary deposits of ilmenite and ilmenite-titanomagnetite ores in connection with gabbroic complexes. Brief descriptions of deposits that can become high-priority mining objects are given below.

Titanium-Zirconium Placer Deposits

Two provinces of ancient coastal-marine placers have been identified in Russia and the neighboring countries. The first province confined to the East European Platform (Tsentral'noye, Lukoyanovskoye, Beshpagirskoye, and other deposits) is characterized by formations greatly varying in age: from the Middle Devonian to the Neogene Period. The second province lies within the boundaries of the West Siberian Plate and is represented by productive formations of the Paleogene (Tuganskoye, Tarskoye, Ordynskoye, and other deposits) [9, 10].

In fact all Russian placers are complex deposits of titanium, zirconium, quartz (quartz-glauconite and quartz-feldspar) sands, and kaolin. The share of non-metallic components, including mineral resources of overburden rocks (clays, sands, and sandstones) can account for 10–40% of the value of primary marketable products. Exploration of these complex titanium-zirconium placers will make it possible to produce at some of them high-titanium (chloride) ilmenite and rutile concentrates, required in the first place for the metallurgical sector, as well as to obtain zirconium concentrates. The objects that have the highest potential in this respect are the Tsentral'noye, Beshpagirskoye, Lukoyanovskoye, Tuganskoye, and Tarskoye deposits.

The Tsentral'noye (Central) deposit is located 60 km east of the city of Tambov in a well-explored area with a well-developed infrastructure. It was discovered in 1959 and prospected in 1959–1965. Sand reserves of the deposit were registered by the USSR State Committee on Reserves in 1972 as off-balance reserves (due to economic reasons). In 2007 after additional exploration of the deposit, the reserves of the Eastern section (about 30% of the deposit overall reserves) were registered by the State Committee on Reserves as balance reserves. With regard to proved reserves (~900 mln. m^3 of sands) this deposit is classified as super-large. By reserves and concentration of ore minerals, the Tsentral'noye deposit is comparable to one of the largest deposits in the world: the Australian WIM-150 which is currently being prepared for commercial development.

The deposit is a stratal coastal-marine placer of the Cenomanian age of the Mesozoic. Productive formations represented by a horizontal stratum reaching 1–15 m in thickness (6.5 m in average) can be traced at a length of 18 km, the width of the stratum varying from 2 to 18 km. The ore bed is formed by glauconite-quartz sands, containing rutile (4–8 kg m^{-3}), ilmenite (33–36 kg m^{-3}), and zircon (5–7 kg m^{-3} in average). The stratum lies almost horizontally at depths varying from 3.5 to 22 m (18 m in average). Throughout the stratum roof there is a thin (2–3 m) horizon of nodular phosphorites, which are of commercial interest for phosphorite flour production. Apart from the basic ore minerals, the sands contain glauconite (2–49 kg m^{-3}), garnet (5–9 kg m^{-3}), and kyanite (1–4.5 kg m^{-3}), which can be obtained in the concentrating process as by-products and be of commercial interest as well.

The gold content of the ore sands remains an unsolved problem (in the first instance for the Eastern section, where the expected gold content can reach approximately 200 mg m^{-3}). Gold is 90% free and consisting of very small particles: almost 80% of gold is found in sands belonging to the grain-size classes of –0.5+0.1 and –0.1+0.05 mm. It is represented by flaky, platy, and flattened cavernous grains, the majority of which are 0.05–0.35 mm in size. The gold fineness is 900–980‰. Such great reserves of ore sands make it possible to establish an ore-mining and processing enterprise with the capacity reaching 9 mln. m^3/year on their basis.

In chemical composition rutile concentrate is in compliance with the All-Union State Standard GOST 22938-78 and can be used for manufacturing of electrode coatings, as well as for direct production of titanium tetrachloride; its recovery ratio reaches 88%. Zircon concentrate is represented by zircon sand consisting of grains below 0.1 mm in size (mainly 0.063+0.044 mm); its ZrO_2 + HfO_2 content reaches 65%, including approximately 1% of HfO_2; zirconium dioxide recovery ratio is 90%. The impurity (titanium and iron) content of the concentrate is in compliance with the All-Union Standard (OST) and its radioactivity is at a level of 0.15–0.18 Th_{equiv}. Ilmenite concentrate contains 57–59% of TiO_2 and 31% of Fe_2O_3; its recovery ratio is 85%. Due to high concentrations of Cr_2O_3 (0.36%) and P_2O_5 (0.31%) it cannot be used directly for production of titanium pigments based on the sulphuric-acid method. A possible application is smelting of the concentrate for obtainment of titanium slag and chlorination of the latter to titanium tetrachloride, suitable for production of titanium sponge and (or) pigment.

The cobble sand fraction (+2 mm) and the overburden rocks can be used for obtainment of

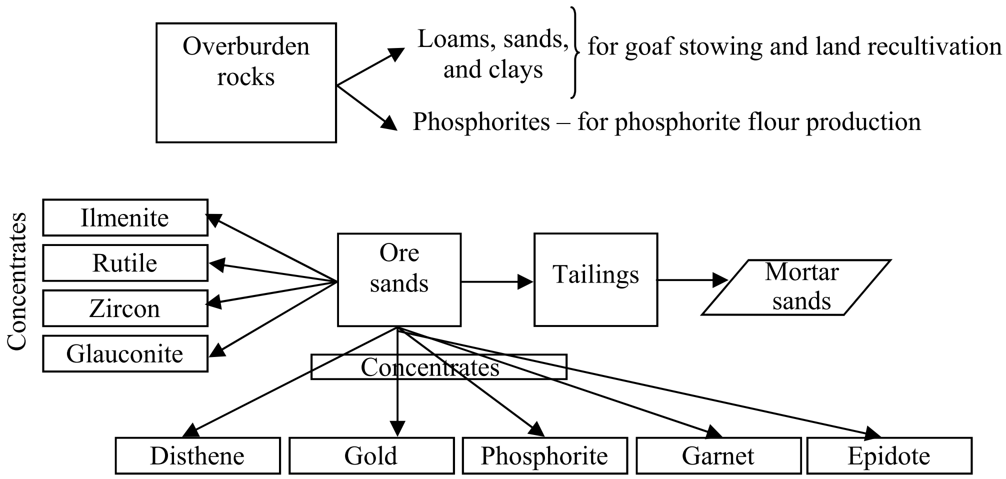

Fig. 4. Diagram of multipurpose utilization of the Tsentral'noye deposit resources.

phosphorite concentrate containing 13–17% of P_2O_5, which can be applied as phosphorite flour. Glauconite concentrate and quartz mortar sands can be received in the ore sands concentration process as by-products. Technological studies have also identified a possibility to obtain disthene, epidote, and garnet products (Fig. 4).

At present, the Eastern section of the Tsentral'noye deposit is being prepared for commercial exploration.

The Beshpagirskoye deposit is located on the territory of Stavropol Region, 40 km east of the city of Stavropol. Preliminary prospecting of the deposit based on a widely-spaced drilling grid was performed in the early 1960s. The reserves of the deposit have been neither registered nor classified as forecast resources.

In 2002 a license for geological exploration and extraction of mineral resources of the deposit was given to "Tekhnotsentr" LLC (a subsidiary of "Itera" Group of Companies), which has performed basic geological prospecting works, has explored the southern part of the deposit, and has calculated the deposit reserves. In 2006 the reserves of the Beshpagirskoye deposit were approved by the State Committee on Reserves.

The productive horizon encompasses two continuous strata of ore sands, containing titanium and zirconium minerals: the upper and the lower. The roof of the upper formation is located at a depth of 14–36 m (20 m in average), the top of the lower layer, at a depth of 30–45 m. The upper ore bed is above the groundwater level, while the lower formation is water-encroached. The thickness of the upper stratum varies from 0.3 to 12.3 m with an average value of 3.55 m. The lower formation is characterized by more continuity and minor fluctuations in thickness, which ranges from 1.2 to 2.8 m, amounting to 2.3 m in average.

The ore sands contain such valuable minerals as ilmenite, rutile, leucoxene, and zircon. The content of these minerals in the upper ore bed is as follows (kg m^{-3}): 21.4 of ilmenite, 8.7 of rutile, and 9.3 of zircon; in the lower stratum: 24.3 of ilmenite, 10.7 of rutile, and 7.9 of zircon. High concentrations of nugget gold have been also detected at this deposit.

Main marketable products include ilmenite, rutile, and zircon concentrates. Ilmenite concentrate contains 62% of TiO_2 and 27.3% of Fe_2O_3. The content of slag-forming oxides (SiO_2 and Al_2O_3) is below the standard limit. With regard to these parameters the concentrate almost matches the concentrate produced by Volnogorsky Mining and Concentrating Complex; it is almost identical to the KIM-grade concentrate (Technical Specification TU-48-286-72) of Irshanskiy Mining and Concentrating Complex but exceeds the requirements to Cr_2O_3 content. The rutile concentrate contains 94% of TiO_2 and its chemical composition is in compliance with the All-Union State Standard GOST 22938-78.

Standard zircon concentrate is in compliance with All-Union Standard OST 48-82-81. It contains 65.4% of ZrO_2+HfO_2, including approximately 1% of HfO_2, 0.39% of TiO_2, 0.07% of Fe_2O_3, and 0.085% of $Th_{equiv.}$; it can be used in any field of application. Among non-metallic products of concentration the quartz-feldspar product has the best application prospects: it can be used as molding sand, in production of dark bottle glass and construction materials (lime-sand bricks) etc.

The majority of the reserves (65%) are confined to the upper productive stratum. It is planned to develop the upper formation through open-cut mining and the lower formation, on the basis of the hydraulic borehole mining method.

Expediency of the Beshpagirskoye deposit development is substantiated by the large-scale mineral-resource base of titanium-zirconium ores that can be extracted through open-pit mining and hydraulic borehole mining not only within the boundaries of the deposit, but also in other sections of the Stavropol placer district (Poperechniy, Grachevskiy, Tuguluk-skiy, Kambulatskiy, Gofitskiy, and other sections). At present, "Kol'tsovgeologiya" OJSC is performing prospecting and appraisal works, aimed at localization of P_1- and P_2-category forecast resources of the whole placer district and at calculation of C_2-category reserves in specific areas, in which the appraisal works are completed.

The Lukoyanovskoye deposit is located in the south of Nizhny Novgorod Oblast, 180 km far from the city of Nizhny Novgorod, at the border between Lukoyanovskiy and Gaginskiy districts. The Lukoyanovskoye titanium-chromium-zirconium deposit is represented by a series of large coastal-marine placers. As a result of prospecting and exploration works a number of individual dissociated placers have been identified: Itmanovskaya, Matkovskaya, Kazanovskaya, Ulyanovskaya etc. Itmanovskaya placer, which is the largest and the richest of all has been investigated more thoroughly: the length of the placer ore bed exceeds 6 km, its average thickness is about 5 m (varying from 2 to 12.1 m). The stratum is characterized by a slightly inclined position at depths varying from 5 to 42 m (28 m in average). Itmanovskaya placer is well-explored and its reserves were approved by the Territorial Reserves Commission under the Nizhny Novgorod Geological Committee in 1995. The ore sands of the placer also contain approximately 7 kg m^{-3} of rutile, 1.7 kg m^{-3} of leucoxene, and about 90 kg m^{-3} of ilmenite-chromite-hematite aggregate. The placer is characterized by the highest zircon content among all discovered Russian placers and is comparable to the world richest zircon-containing placers (approximately 23 kg m^{-3}).

The unique feature of the placer composition is that due to similar physical properties and fineness of precipitates, ilmenite, chromite, and hematite get incorporated in one middling, and its complete separation into ilmenite, chromite, and hematite components is a difficult technological task.

Titanium concentrates are represented by the following two production types: rutile and hematite-chromite-ilmenite. The first product contains 95.2% of fine-grained rutile, its ratio of recovery from the source sands reaches 85.7%. With regard to its impurity content, the rutile concentrate is in compliance with the All-Union State Standard GOST 22938-78 and can be used in production of electrode coating materials.

Hematite-chromite-ilmenite middling contains 99.8% of the corresponding mineral aggregates. So far it has not been possible to separate them on the basis of mechanical concentration methods. The integrated mineral ratio of recovery from the source sands is 77.1%. The concentrate contains up to 50% of Fe_2O_3, 9–10% of Cr_2O_3, and 30% of TiO_2. It is a non-standard product; however, smelting tests performed by the Titanium Institute and the Institute of Metallurgy and Materials Science, Russian Academy of Sciences have demonstrated that it can be used for obtainment of titanium slag and high-chromium iron.

As a result of the concentration process a high-quality zircon concentrate containing 99.4% of fine-grained (0.01–0.10 mm) zircon is received; its ratio of recovery from the source sands reaches 89.9%. The concentrate contains 60% of zirconium dioxide and minimal percentage of iron and titanium oxides which are below the limits set by the All-Union Standard OST 48-82; its radioactivity is approximately 0.1% Th_{equiv}. It can be successfully applied for further processing into metal, dioxide, and zirconium compounds, as well as for production of parting mixtures, refractories, ceramics, glass, glazes etc.

Investigations of the gold content of the ore sands in the primary production area with the use of Knelson concentrator have detected that the gold content reaches 1 g/t and it is possible to obtain commercial gold concentrate from the ore sands. The results of the investigations form the basis for organization of thorough geological prospecting and technological works for further appraisal of gold contained in the ore sands of the deposit.

Laboratory analyses of the overburden rocks have demonstrated that their argillaceous varieties are applicable for production of common bricks and various types of expanded-clay aggregates, while sands can be used in molding mixtures and plasters. For more comprehensive utilization of the resources, the tailings have been investigated with the following results: the obtained quartz-feldspar product is suitable for production of electrical insulator porcelain, it can be used as silica filler in production of lime-sand bricks, bottle glass, and decorative facing crypto-crystalline material, sygran (synthetic granite); the epidote product is suitable for facing tile glazing and the epidote concentrate can be used in dark ceramics production. Argillaceous tailings can be used in the ferrous-metal industry for production of molding boxes, and if the quartz-feldspar product is added to the tailings, they can be used for production of ceramic bricks, ceramic mettlach tiles, and facing tiles.

At the development rate of 1.5 mln. m^3/year the placer reserves of the ore sands can provide a sufficient supply of raw materials for 20 years of operation of a mining and concentrating plant. At present, a complex of pre-project activities on the development of advanced mining and concentrating technologies is being implemented at the Itmanovskaya placer deposit. By 2014 it is planned to construct and put into operation a mining and concentrating complex with the processing capacity reaching 1 500 mln. tons of ore sands per year on the basis of this deposit [11].

The Tuganskoye deposit is located 40 km east of the city of Tomsk in a well-explored area with a well-developed infrastructure. The reserves of the deposit were last approved by the State Committee on Reserves in 1992. It is a stratal coastal-marine placer located at depths varying from 5 to 100 m. In plan the ore bodies are represented by stratal lenses, curved in parallel to the ancient coastal line. Within the placer there are five dissociated sections, including Kuskovo-Shiryaevskiy and Yuzhno-Aleksandrovskiy which are of commercial interest.

On the territory of Kuskovo-Shiryaevskiy section, which is the richest in reserves there is an ore bed of slightly-argillaceous quartz sands lying horizontally at depths varying from 10 to 98 m (34 m in average). The sands contain zircon (14 kg m^{-3} in average), rutile+leucoxene (5 kg m^{-3}), and ilmenite (32 kg m^{-3}). The average thickness of the stratum is 7.6 m. The ore bed located on the territory of Yuzhno-Aleksandrovskiy section is 5.0 m thick, it lies at a shallow depth of about 7 m. Commercial reserves of the ore sands, containing 11 kg m^{-3} of zircon, 4.65 kg m^{-3} of rutile+leucoxene, and 30 kg m^{-3} of ilmenite are quite moderate but sufficient to form the basis for establishment of a mining and concentrating enterprise with the capacity reaching 1 mln. m^3 of ore sands per year. Due to favorable mining and geological conditions this section is considered a high-priority object for commercial exploration.

As a result of concentration of the Tuganskoye deposit ore sands, it is possible to obtain a rutile-leucoxene product containing 85.2% of TiO_2 at the recovery ratio of 11.54%; ilmenite concentrate containing 54.64% of TiO_2 at the recovery ratio of 55.35%; zircon concentrate containing 65.0% of ZrO_2 at the recovery ratio of 86.2%; glassmaking quartz sands of VS-050 grade; refined kaolin of KR, KK, and KKT grades, and other products.

This deposit is the best in Russia in terms of both quantity and quality of the reserves. The deposit is recognized as prepared for exploration and the following reserves have been already approved: ore sands and associated valuable components (zircon, ilmenite, rutile+leucoxene, and monazite; ZrO_2 reserves related to zircon; TiO_2 reserves in ilmenite and TiO_2 reserves in rutile+leucoxene); reserves of associated components (Sc_2O_3 in zircon, ilmenite, and rutilee+leucoxene; HfO_2 in zircon); reserves of quartz and kaolin components (tailings). Apart from that, the overburden rocks of the Tuganskoye deposit have been also approved as raw materials (Fig. 5) for production of construction materials and for other applications: low-melting clays for brick production; high-melting clays for fabrication of ceramic tiles, sewer pipes, and bricks; silica sands for production of lime-sand bricks, stone pieces, and other small-size molded articles; molding sands (All-Union State Standard GOST 2138-84); sands for fabrication of ballast stones for construction works (All-Union State Standard GOST 8267-82), and macadam production (All-Union State Standard GOST 9128-84).

Therefore, the Tuganskoye deposit is a complex deposit of titanium, zirconium, quartz sands, kaolin, and clay. The value of nonmetallic products accounts for approximately 40% of the total marketable output of the mining and concentrating plant.

In 2008 pilot mining of commercial sands in the amount of 30 600 m^3 was performed on the territory of Yuzhno-Aleksandrovskiy section. Works on additional appraisal of Kuskovo-Shiryaevskiy section hydro-

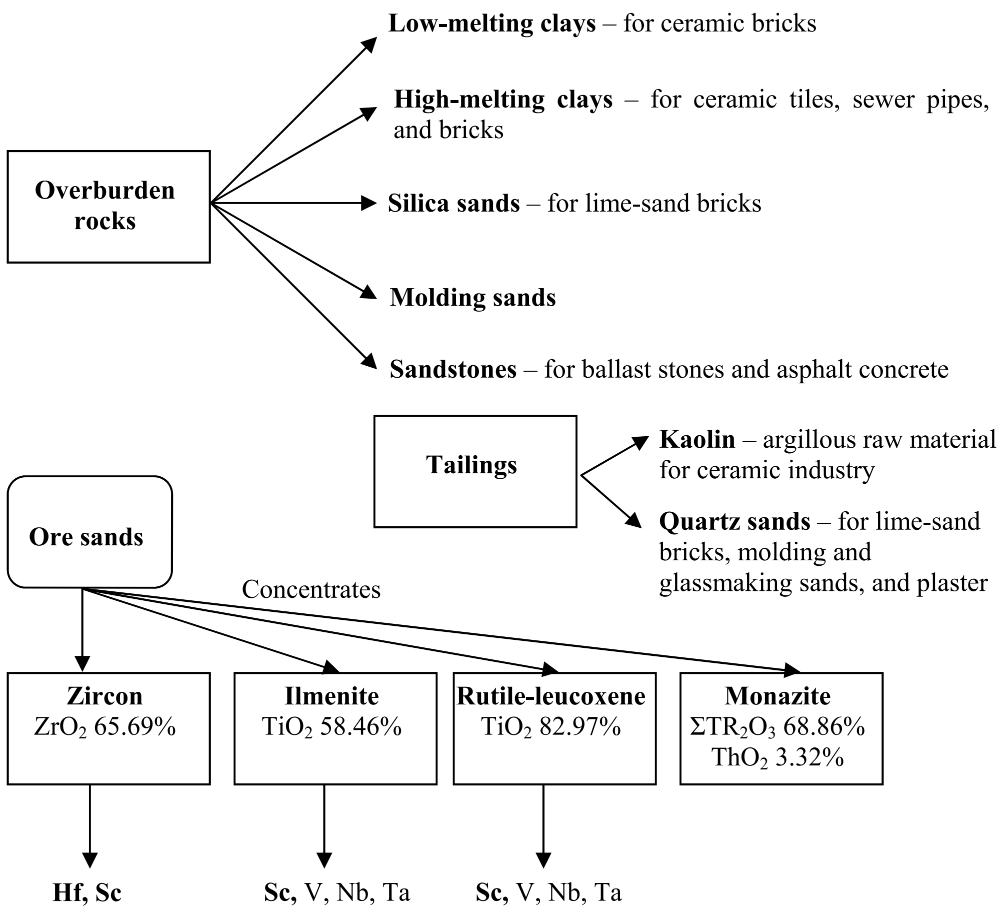

Fig. 5. Mineral resources and components of the Tuganskoye deposit. Reserves approved by the State Committee on Reserves are given in bold.

geological and engineering-geological conditions have been started. A development project on open-pit mining of silica sands and other overburden rocks of Yuzhno-Aleksandrovskiy section of the Tuganskoye deposit has been prepared and approved; the project will make it possible to prepare approximately 7 mln. tons of ore sands for production [12].

Alongside with the above-listed deposits, the following objects can also become development targets: the Tarskoye deposit in Omsk Oblast, the Ordynskoye deposit in Novosibirsk Oblast, and the Georgievskoye deposit in Tomsk Oblast. All these deposits can be developed only on the basis of the hydraulic borehole mining method due to deep-lying productive strata.

Primary Ore Deposits

Titanium can be found in almost all types of rocks forming the lithosphere, but the highest titanium content is characteristic for basic igneous rocks. The overwhelming majority of large-scale primary deposits of titanium ores of the igneous type are associated with these rocks. The majority of titanium igneous deposits are confined to the most ancient Proterozoic rocks of Earth's crust. Ore deposits and occurrences of the anorthosite belt of the Far East date back to the Archean and the Early Proterozoic. They are the most ancient titanium deposits on the territory of Russia. There is a significantly smaller number of Paleozoic titanium deposits; they are mostly represented by the Ural group of ilmenite-titanomagnetite deposits associated with gabbroic massifs. There are also Paleozoic gabbro-anorthosite massifs characterized by ilmenite-titanomagnetite mineralization in Transbaikal area. Loparite-bearing nepheline syenites also date back to the Paleozoic. No Mesozoic or Cenozoic titanium deposits of magmatic genesis have been identified in Earth's crust.

It is possible to distinguish the following three large provinces of primary titanium ore deposits by location.

Deposits of Karelian-Kola area: ilmenite-titanomagnetite (Yugo-Vostochnaya Gremyakha, Pudozhgorskoye), loparite (Lovozerskoye), and titanomagnetite-perovskite (Afrikanda).

Deposits of the Urals: ilmenite-titanomagnetite (Medvedevskoye, Kusinskoye etc.)

Deposits of Siberia and the Far East: ilmenite-titanomagnetite (Bol'shoy Seyim, Kruchininskoye, Kuranakhskoye, Chineyskoye etc.)

A separate group is formed by oil-bearing quartz-leucoxene sandstones of the Yaregskoye deposit (the Komi Republic).

Ilmenite-Titanomagnetite Ores

Exploration of primary deposits of easily concentratable ilmenite-titanomagnetite ores will make it possible to establish large-scale production of pigmentary titanium dioxide on their basis with a production output satisfying the Russian needs for titanium pigment. Primary deposits usually contain significant amounts of ore reserves and it is possible to use them as the basis for large-scale production of ilmenite concentrates and obtainment of titanomagnetite concentrates with high vanadium content [13]. Ilmenite concentrates are one of the best sources for obtainment of high-quality scandium [14]. It is also possible to receive scandium from pyroxene tailings, i.e. from refuse generated in the process of concentration of titanomagnetite ores. Several primary deposits of ilmenite-titanomagnetite ores have been detected and prospected on the territory of Russia. Two of them, the Medvedevskoye deposit in the Urals and the Kruchininskoye deposit in Transbaikal area, are well-explored and included into the State Register of Reserves of the Russian Federation. The Medvedevskoye deposit is being prepared for production and overburden mining works have been already started. The Kruchininskoye deposit is included into the state unallocated fund of mineral resources.

Such well-explored deposits as the Yugo-Vostochnaya Gremyakha deposit in Murmansk Oblast and the Kuranakhskoye deposit in Amur Oblast have better prospects, as well as the preliminarily appraised deposit of Bol'shoy Seyim. Individual sections of these deposits containing up to 30–50 mln. tons of ore are characterized by the titanium dioxide content varying from 9 to 15% (20–35% of ilmenite). All these deposits can become a reliable source of high-quality ("sulphate") ilmenite concentrates (250 000 t/year and more), which makes it possible to establish large-scale domestic production of titanium pigment, the demand for which in our country is immense.

The Yugo-Vostochnaya Gremyakha (Gremyakha-Vyrmes) deposit is located in Kola district of Murmansk Oblast, 25 km to the south of Murmashi town. The deposit under the final name of Yugo-Vostochnaya Gremyakha is classified as explored; its reserves were included into the State Register of mineral resources of the Russian Federation in 2009. With regard to proved reserves (~40 mln. tons of $B+C_1$ reserves and 10 mln. tons of C_2 reserves) the deposit is classified as large-scale. It is the second largest in Russia after the Yaregskoye deposit.

The ore body is lens-shaped, stretching from north to south. It can be traced almost continuously at a length of 2 870 m. The width of the ore body varies from 50 m at the periphery to 320 m in the center, and its average thickness reaches 129 m. The total ore-bearing area of the deposit covers 552 400 m^2.

Prospecting of the deposit has been fully completed, a technical and economic feasibility study of the deposit conditions has been compiled, and its reserves have been calculated. Mining and metallurgical plant "Noril'skiy nikel'" OJSC has received a license for the development of the deposit. A combined magnetic-gravity concentration scheme, envisaging flotation of sulphides and electrostatic aftertreatment of rough ilmenite concentrates has been accepted. There is a construction project for establishment of a mining and metallurgical plant on the basis of this deposit. By 2015 the plant production capacity will reach 340 000 tons of cast iron, 494 000 tons of titanium slag, and 9 000 tons of vanadium slag. The annual ore production will reach 3 mln. tons [15].

The Bol'shoy Seyim deposit is 25 km far from the Baikal-Amur Mainline in Tynda district of Amur Oblast. Additional geological appraisal and technological research of the deposit ores were performed in 2007–2008. The average content of the main components of the Bol'shoy Seyim deposit at TiO_2 cut-off grade of 5% is as follows: 8.0–8.4% of TiO_2 (reaching 11.7–12.0% in massive ores), 17.91% of total iron, and 1.03–1.46% of phosphorus pentoxide. Traditional technological testing of ores has demonstrated that it is possible to obtain ilmenite, titanomagnetite, and apatite concentrates with high recovery ratios of TiO_2, Fe_{total}, and P_2O_5.

High-priority exploration sections with the average content of TiO_2 varying from 10 to 17% have been selected. Geological prospecting works are to be completed in 2010 and ore production will start in December 2012. The planned capacity of the ore mine at the first stage is 2 mln. tons of ore; when the mining and concentrating plant reaches its design capacity, the ore mine will produce 6.5 mln. t/year (with TiO_2 content of 8.14%).

The Kuranakhskoye deposit is located in the north of Amur Oblast, 20 km to the south of the Baikal-Amur Mainline. It is a part of the Kularskiy ore cluster which also includes the Bol'shoy Seyim, a large preliminarily appraised deposit. In 1995 the Territorial Reserves Commission under the Amur Geological Committee approved C_1+C_2 reserves of ilmenite-titanomagnetite ores of the deposit high-priority development section in the amount of 4.4 mln. t. The average content of TiO_2 in the ores is 13.2–14.0%. As a result of further prospecting and appraisal works, as of January 1, 2004 it was calculated that the deposit possessed 23 mln. tons of ores with the average TiO_2 content of 9.6% and the iron content of 32.1%. It is one of the richest deposits of titanomagnetite ores, a source of high-quality ilmenite for production of pigmentary titanium dioxide based on the sulphate method. In 2006–2007 the Territorial Reserves Commission of Amur Oblast approved only balance reserves of iron ores, and the deposit is not included into the register of titanium reserves.

The ores are easily concentratable for production of ilmenite and titanomagnetite concentrates [6]. At present, the deposit is developed through open-cut mining. Construction of a concentrating plant 4 km far from Olekma railway station is being finalized. The annual production of the plant will include the following: 1 760 000 tons of bulk concentrate (dry magnetic separation), 900 000 tons of standard titanomagnetite concentrate (wet magnetic separation), 770 000 tons of rough ilmenite concentrate (non-magnetic product of wet magnetic separation), and 290 000 tons of standard ilmenite concentrate [16]. It is planned to export all produced concentrates to China.

Nonconventional Sources of Titanium

The ore reserves prevailing in the titanium state register are associated with non-traditional minerals, the commercial value of which remains questionable. Oil-bearing leucoxene-quartz ores of the Yaregskoye deposit in the Komi Republic account for approximately 30% of the balance titanium reserves of the Russian Federation. Titanomagnetite ores of the Chineyskoye deposit (Chita Oblast) and the Podlysanskoye deposit (Krasnoyarsk Region) account for more than 20%.

For many years these deposits have been objects of study for Russian geological institutions. There have been numerous attempts to explore these deposits; however, difficulties in technological conversion of ores have not been overcome. Therefore, great titanium reserves and resources attributable to titanomagnetite, perovskite, sphene, and high-silica leucoxene are not in demand by the industry yet [5, 9].

The Afrikanda deposit of perovskite-titanomagnetite ores is located in Murmansk Oblast. It is confined to pyroxenites and olivinites of the massif of the same name, which is a multiphase intrusive massif of the central type. The content of perovskite in the ores varies from 10 to 36% and the titanomagnetite content from 20 to 30%. In average the composition of the ore is as follows (wt %): 14–16 of TiO_2; 17–18 of Fe_2O_3; 0.17–0.25 of $(Nb,Ta)_2O_5$; and 0.47–0.64 of Th_2O_3 [5, 17].

The deposit was prospected in detail and prepared for exploration. C_2 reserves of TiO_2 were included into the State Register but later excluded in 1971. Even mining and concentrating of ores on an experimental-industrial scale were started. More than 10 different perovskite concentrate conversion schemes were proposed; the most well-developed schemes among them were the suphuric-acid, combined nitric-suphuric-acid, and pyrometallurgical (electric smelting) methods [18], as well as the chemicometallurgical and pyrometallurgical schemes of titanomagnetite concentrate conversion.

The major part of titanium in ores (60–90 relative %) is associated with perovskite. The average content of titanium dioxide in perovskite is close to 55%, rare earth elements account for 2–7%, the total of niobium and tantalum pentoxides varies from 0.6 to 2.5%, and the content of thorium is 0.1–0.8%.

One of the main reasons for exclusion of the Afrikanda deposit from the Register was the high content of radioactive thorium in the ore and technological complexity of its extraction from perovskite concentrates. The technical and economic feasibility study for perovskite processing through ammonium titanyl sulphate with an output of 100 000 tons of TiO_2 has demonstrated that the profit of the enterprise would amount to 33 million rubles in prices of 1980 [19].

The large *Zhidoyskoye deposit* of perovskite and titanomagnetite ores is located on the territory of Irkutsk Oblast, 60 km far from the city of Angarsk, and is confined to the alkaline ultrabasic rock massif of the same name. Like the Afrikanda deposit, this object is formed by perovskite-titanomagnetite ores but the Zhidoyskoye deposit ores are characterized by extremely low radioactivity. The average TiO_2 content of perovskite ores is 6–7%. As a result of the ores concentration performed in the Central Chemical Laboratory of the Irkutsk Geological Department, a concentrate containing 42% of TiO_2 and 0.55% of (Nb_2O_5+Ta_2O_5) was obtained. Perovskite is slightly radioactive (U and Th total is below 0.10%).

The Zhidoyskoye deposit forecast resources of TiO_2 are estimated at 10 mln. t. In 2000 two laboratory samples were collected at the deposit: the perovskite concentrate obtained from low-grade ores (7% of TiO_2) contains 37% of TiO_2, the concentrate from high-grade ores (10% of TiO_2), 48% of TiO_2. The deposit is not prospected and is included into the unallocated fund of mineral resources.

The Chineyskoye deposit is located in the north of Chita Oblast. It is one of the largest deposits in terms of forecast resources of iron ores and the largest deposit of vanadium reserves in the world. It is the only deposit of titanomagnetite ores in Russia which is included both in the register of iron ore reserves and the register of titanium reserves. The main ore mineral is titanomagnetite, accessory minerals are ilmenite and spinel. The content of titanomagnetite in the ores reaches 33.2% and the content of ilmenite 0.83%.

Major components of the ores which determine their commercial value are iron, titanium, and vanadium. The major part of TiO_2 is concentrated in titanomagnetite (65.8%), smaller percentages are contained in ilmenite (24.7%) and nonmetallic minerals (9.5%). The average iron content in the ores reaches 34.64%; titanium dioxide accounts for 6.76% and vanadium pentoxide – for 0.55% in average. It is possible to recover 18.8–20.0% of TiO_2 into ilmenite concentrate (40% of TiO_2) through electric separation.

Such titanomagnetite concentrates are non-conventional raw materials for the domestic metallurgical industry. There are still no industrial methods for their multipurpose utilization ensuring the extraction of all three major components (iron, titanium, and vanadium) despite the unique technological solutions developed in the Uralian Institute of Metals [20] and Baikov Institute of Metallurgy and Materials Science.

Possibilities of industrial utilization of nonstandard ilmenite concentrates containing only 40% of TiO_2 have not been identified either. It is necessary to continue technological studies aimed at increasing TiO_2 content at least to 42% and to perform relevant marketing research in parallel. The deposit is currently at a stage of preparation for development.

The largest titanium reserves in Russia are contained in oil-bearing leucoxene-quartz sandstones of *the Yaregskoye deposit* located on the territory of the Komi Republic. The deposit is represented by a metamorphosed coastal-marine placer of the Devonian, lying at a depth of 150–280 m. The ore stratum is formed by cemented oil-bearing quartz sandstones and leucoxene. The formation is 19 km long and 3–5 km wide. There are three ore horizons: upper, middle, and lower. Balance reserves of titanium are confined to the lower horizon with an average thickness of 13 m.

The lower horizon is represented by a shallow-dipping (at an angle of 15°) tectonized rock mass, formed by quartz-leucoxene sandstones with interbedded mudstones and siltstones in the lower and upper parts of the placer. Its mineral composition is as follows (%): 75–85 of quartz, 10–20 of leucoxene, 0.1–1.0 of anatase, 1–2 of siderite, up to 0.05 of zircon, ilmenite, rutile, and monazite. The main titanium-bearing mineral is leucoxene, containing 50–60% of TiO_2 and 40–50% of SiO_2 (SiO_2 content in standard titanium concentrates should not exceed 3%).

The content of titanium dioxide in the sandstones of the lower horizon reaches 10.4% with up to 20% of TiO_2 in individual parts. It is the largest and one of the richest titanium deposits in Russia. Its reserves can ensure more than 100 years of operation of a future mining and concentrating enterprise at a production and processing rate of 4 mln. tons of ore per year. Numerous programs on establishment of production and processing of titanium concentrates on the basis of the Yaregskoye deposit were approved in the Soviet Union; however, due to complicated mining, geological, and technological characteristics of the deposit, after the testing stage no further progress was made. Prospects for establishment of the Russian main titanium-mining base at this deposit are poor, which has been confirmed by a number of foreign companies familiar with this object (DuPont, BHP etc.). The major deterrent in the deposit exploration is the necessity to apply the shaft-mining method with goaf stowing for development of the productive formation and to elaborate an absolutely new industrial scheme for processing of high-silica leucoxene concentrates. The high silica content makes it impossible to obtain marketable titanium products from the concentrate on the basis of the existing technological schemes (chloride and sulphate methods etc.).

In 2004 upon an assignment of "Lukoil" OJSC, "GIREDMET" OJSC developed a technical and economic feasibility study (project design) for the construction of the first stage of Yaregskiy integrated mining and chemical plant with a separate pilot production unit. It is planned to produce and process 650 000 tons of oil-titanium ore with the total output of pigmentary titanium dioxide, which is the end product of plant, reaching 42 280 tons (including 5 200 tons obtained at the pilot production unit). It is envisaged that the ore mine will reach the production capacity of 650 000 tons in the sixth year after the start of the plant construction. Afterwards, it is possible to construct another shaft of the same capacity (650 000 tons of ore).

CONCLUSIONS

Russia, which is the second richest country in the world by proved titanium reserves until recently has not been involved in development of any solely titanium deposits. The necessity to develop Russian titanium deposits is obvious, which is specifically reflected in the two federal programs approved by the Government of the Russian federation: "Russian Titanium" (1992) and "Russian Ore" (1996). In compliance with these programs the development of the Tuganskoye, Tsentral'noye, Lukoyanovskoye, Tarskoye, and Tulunskoye deposits was to be started in 1996–2000; by 2005 all mining and concentrating plants established on the basis of the above-listed deposits would have reached their full design capacity and would jointly produce hundreds of thousands tons of ilmenite concentrates and dozens of thousands tons of zircon and rutile concentrates. The programs have never been implemented due to target financing deficiency. Minor quantities of TiO_2 (approximately 2 000 t/year) are obtained from loparite concentrates. In 2009 development of the Kuranakhskoye deposit was started, but all manufactured marketable products will be exported to China.

In 2012–2015 Russia will annually need minimum 600 000 tons of ilmenite concentrates for production of various types of titanium products, including approximately 200 000 tons of ilmenite concentrates for production of metallic titanium, alloys, master alloys, and ferroalloys and 400 000–600 000 tons for obtainment of pigmentary titanium dioxide. At present, the domestic industry is completely oriented at imported raw materials, the majority of which are supplied from Ukraine.

Despite the fact that Russia is the largest producer of metallic titanium and its alloys in the world (>20% of the global market), there is almost no production of pigmentary titanium dioxide in our country. Every year Russia spends hundreds of millions dollars on imported titanium pigments, paint materials, and high-quality paper products.

At present, in connection with the completion of prospecting works at a number of new titanium deposits and development of advanced ore production and processing technologies, provision of the Russian industry with titanium mineral raw materials should evolve in the following directions.

(1) Production of titanium sponge, metallic titanium, alloys etc. can be supplied with high-titanium (58–62%) ilmenite (chloride) concentrates due to the industrial development of placer deposits, including the Tsentral'noye and Beshpagirskoye deposits in the first place. The ore sands of these placers will also provide rutile concentrates for the electronic industry and zircon concentrates for production of ceramics, glazes, refractories etc., as well as for obtainment of zirconium, its alloys, and master alloys.

Establishment of mining and concentrating plants for obtainment of ilmenite, rutile, and zircon concentrates on the basis of buried titanium-zirconium placers must be accompanied by associated production of nonmetallic raw materials (aluminosilicates, quartz, glauconite etc.) and probably gold-containing products. Without multipurpose utilization of resources, operation of the Russian buried placers can turn out to be unprofitable [21].

(2) Large-scale production of titanium pigments (approximately 300 000 t/year) should mostly rely on primary titanium ore deposits of the Kuranakhskoye, Bol'shoy Seyim, and South-East Gremyakha. Exploration of these deposits will make it possible to produce the total of 600 000–700 000 tons of ilmenite concentrates per year. All these deposits are complex,

which means that alongside with ilmenite concentrates it will be also possible to obtain titanomagnetite concentrates with a high (commercial) content of vanadium and also apatite concentrates, at the Bol'shoy Seyim deposit [21].

(3) It is also possible to produce titanium pigments from leucoxene concentrates of the Yaregskoye deposit, which is the largest titanium object in Russia (42 000 tons of pigmentary titanium dioxide per year) after technological and production testing is completed.

(4) Further research works on obtainment of titanium products from non-conventional types of mineral raw materials remains a priority task waiting for solution.

The strategy described above will make it possible not only to fully satisfy the needs of the Russian industry for titanium, zirconium, vanadium, and scandium, but also to enter the global market with various titanium, zirconium, vanadium, and scandium products.

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