## GEOLOGY OF MINERAL DEPOSITS

Review paper

https://doi.org/10.17073/2500-0632-2023-02-85
UDC 553.04:553.689.2

# World's barite resources as critical raw material

**G. Yu. Boyarko** ✉, **L. M. Bolsunovskaya**
*National Research Tomsk Polytechnic University, Tomsk, Russian Federation*
✉ *gub@tpu.ru*

**Abstract**
The relevance of the work is connected with the status of barite as a critical mineral raw material, as accepted in most industrialized countries.
*Purpose*: to study the dynamics of commodity flows (production, import, export, consumption) of barite throughout the countries, its world prices, sources of barite raw materials and the prospects for its production and consumption.
*Methods*: statistical, graphic, logical.
*Results*. The production of barite raw materials from 0,3 Mt/year in 1920s grew intensively and reached 8.0–9.6 Mt/year in the 2010. Initially, both the mining and processing of barite raw materials industries were located directly in the USA, Germany, Britain, Italy, and France. These countries accounted for over 90% of world production and 80–95% of world consumption. In the 1950s, a sharp increase in the consumption of barite as a weighting agent for drilling fluids began. This led to an increase in its production in large oil and gas producing countries (the USA, the USSR, Mexico, Canada), export flows (from Morocco and other countries), and cessation of exports from Germany, Britain and France. The share of international trade in barite also increased from 0,3–0,5 Mt/year in the 1950s to 4.2–6.0 Mt/year (55–70% of his income) in the 2010s. The cumulative world production of barite between 1920–2020 is expected to be 550 Mt. World barite resources in deposits prepared for exploitation are estimated at 740 Mt. The group of critical countries importing barite raw materials (imports over 50%) represents 38.8% of the GDP of the world economy (USA, European Union, Germany, Italy, Saudi Arabia, Canada, Kuwait, Norway, Oman, Algeria, Malaysia, Indonesia, UAE, Azerbaijan, Argentina). The group of countries exporting barite raw materials includes 31.0% of the GDP of the world economy (India, Morocco, China, Kazakhstan, Turkey, Iran, Laos, Mexico, Pakistan, Bulgaria. A decrease in the criticality of barite raw material supply is possible as a result in reducing consumption (Japan, France, Italy and the Czech Republic), increasing world barite production with the commissioning of new deposits, given the significant prepared resources of this raw material in Iran, Kazakhstan and Pakistan, as well as the search for new barite deposits, including chemogenic marine bottom sediments.

**Keywords**
critical minerals, barite, resources, production, world trade, consumption

**Acknowledgements**
The article was written as part of the grant from the Russian Science Foundation for 2022–2023 on the topic "Critical Mineral Products in the Russian and World Economy" (project No. 22-28-01742).

**For citation**
Boyarko G.Yu., Bolsunovskaya L.M. World's barite resources as critical raw material. *Mining Science and Technology* (*Russia*). 2023;8(4):264–277. https://doi.org/10.17073/2500-0632-2023-02-85

## ГЕОЛОГИЯ МЕСТОРОЖДЕНИЙ ПОЛЕЗНЫХ ИСКОПАЕМЫХ

Обзорная статья

# Мировые ресурсы барита – критического минерального сырья

**Г. Ю. Боярко** ✉, **Л. М. Болсуновская**
*Национальный исследовательский Томский политехнический университет, г. Томск, Российская Федерация*
✉ *gub@tpu.ru*

**Аннотация**
*Актуальность* работы обусловлена статусом барита как критического минерального сырья, принятым в большинстве промышленно развитых стран.
*Цель:* изучение динамики товарных потоков (производства, импорта, экспорта, потребления) барита по странам мира, его мировых цен, сырьевой базы барита и перспектив его добычи и потребления.
*Методы:* статистический, графический, логический.

*Результаты*. Производство баритового сырья с 0,3 млн т в 1920 г. непрерывно растет и достигло в 2010-х годах 8,0–9,6 млн т/год. Первоначально и добывающие, и перерабатывающие баритовое сырье производства располагались непосредственно в США, Германии, Британии, Италии и Франции, на которые проходилось свыше 90 % его мировой добычи и 80–95 % мирового потребления. В 1950-х годах началось резкое увеличение потребления барита в качестве утяжелителя буровых растворов, что привело к увеличению его добычи в крупных нефтегазодобывающих странах (США, СССР, Мексика, Канада), появлению экспортных потоков (из Марокко и других стран), прекращению экспорта из Германии, Британии и Франции. Доля международной торговли баритом также возросла с 0,3–0,5 млн т/год в 1950-е годы до 4,2–6,0 млн т/год (55–70 % от его мировой добычи) в 2010-е годы. Накопленная мировая добыча барита за 1920–2020 гг. составила 550 млн т, имеющиеся мировые ресурсы барита в подготовленных для эксплуатации месторождениях оцениваются в 740 млн т. Группа критичных стран-импортеров баритового сырья (импорт свыше 50 %) представляет 38,8 % ВВП мировой экономики (США, Европейский союз, Германия, Италия, Саудовская Аравия, Канада, Кувейт, Норвегия, Оман, Алжир, Малайзия, Индонезия, ОАЭ, Азербайджан, Аргентина). Группа стран-экспортеров баритового сырья включает 31,0 % ВВП мировой экономики (Индия, Марокко, Китай, Казахстан, Турция, Иран, Лаос, Мексика, Пакистан, Болгария). Снижение критичности обеспеченности баритовым сырьем возможно путем снижения его потребления (что и осуществляется в Японии, Франции, Италии и Чехии), увеличения мировой добычи барита с вводом в эксплуатацию других баритовых месторождений, учитывая значительные подготовленные ресурсы этого сырья в Иране, Казахстане и Пакистане, а также поиска новых месторождений барита, в том числе хемогенных морских донных осадков.

**Ключевые слова**
критический минеральный продукт, барит, ресурсы, добыча, мировая торговля, потребление

**Благодарности**
Статья написана в рамках выполнения гранта Российского научного фонда на 2022–2023 гг. по теме «Критические минеральные продукты в российском и мировом хозяйстве» (проект № 22-28-01742).

**Для цитирования**
Boyarko G.Yu., Bolsunovskaya L.M. World's barite resources as critical raw material. *Mining Science and Technology* (*Russia*). 2023;8(4):264–277. https://doi.org/10.17073/2500-0632-2023-02-85

## Introduction

Barite (natural barium sulfate / fixed white / barium white) is predominantly used as a weighting agent for drilling fluids (75–88% of consumption), an inert filler in paint and varnish, rubber, paper, glass, cement and construction industries, in the production of plastics, ceramics (6–16%) and as a chemical raw material for the production of barium compounds (up to 6%) [1–3].

The world leaders in barite production are China, India and Morocco, and the leaders in its consumption are the USA, China, India and Saudi Arabia. In the United States, despite significant domestic production of barite (400–700 kt/year), due to imports of up to 87% of its consumption, this commercial product is considered a critical material [3, 4]. The same is the case with barite raw materials in the European Union, which imports up to 82% of its consumption [5][1]. In China, despite its world leadership in mining, barite is also a critical (strategic) commercial product [3, 6, 7]. In Russia, the demand for barites is satisfied by its production from a single source (Tolcheinskoye deposit in the Republic of Khakassia), which is a risk factor of significant import dependence occurrence [3].

The earliest mention of mineral raw materials as a critical material was at the 1953 hearing in the U.S. Senate when discussing "Stocks and Availability of Strategic and Critical Materials for the United States in Time of War"[2]. In the late 1990s, the concept of "critical minerals" (Critical mineral raw materials) was firmly established in the economies of the leading industrialized and rapidly developing countries. This denotes a material that is practically indispensable for the latest industrial technologies, but extremely presents a supply logistics risk [7]. The main indicator of the criticality of mineral raw materials is the level of its import dependence for the national economy. In the list of US critical mineral products, a more fractional gradation of imports is proposed and is

[1] Study on the review of the list of critical raw materials: critical raw materials factsheets. European Commission, Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs. Publications Office; 2017. https://doi.org/10.2873/398823

[2] Stockpile and accessibility of strategic and critical materials to the United States in time of war. Hearings before the Special Subcommittee on Minerals, Materials, and Fuel Economics of the Committee on Interiod and Insular Affairs, United States Senate, Eighty-third Congress, first-[second] session, pursuant to S. Res. 143. A resolution to investigate the accessibility and availability of supplies of critical raw materials. Part 6. Petroleum, gas, and coal. Industrial and labor representatives; state administrative and production experts on petroleum, gas, coal, and synthetic fuels. United States. Congress. Senate. Committee on Interior and Insular Affairs. Washington, U.S. Govt. Print. Off.; 1953.

defined with thresholds of 15, 50, 70, 85, 90 and 95% of consumption[3]. A gradation of import dependence for Russia has been proposed consisting of three ranges: insignificant imports (up to 25%), significant imports (25–75%), and total imports (over 75%) [8]. The second indicator of the criticality of mineral raw materials determines the level of uncertainty of its supply from producers to consumers, and its assessment is subjective [9]. Therefore, the logistics of critical mineral raw materials for its separate types needs to be analyzed.

In China, despite its world leadership in mining, barite is also a critical (strategic) commercial product [3, 6, 7]. In Russia, the demand for barites is satisfied by its production from a single source (Tolcheinskoye deposit in the Republic of Khakassia), which is a risk factor of significant import dependence [3].

## Research methods

Data on world production and world trade of barite raw materials for 1920–2020, as well as on its world prices was analyzed, in order to examine world barite resources and its commodity markets. Sources of information: Bulletins and reviews of the US Geological Survey[4] and Britain Geological Surveys[5], databases of the Federal Customs Service of Russia[6], Federal State Statistics Service of Russia[7] and the UN International Trade Department[8], reviews of information centers[9]. Content analysis of scientific literature sources, national foreign and Russian reports and accounts, periodicals and ongoing publications devoted to existing problems in the world mineral resource base of barite was carried out. Resources, reserves, production, trade and consumption of barite raw materials are given in metric tons, while prices in US dollars per ton of barite. The indicators of the share of imports and exports of barite for individual countries and the world are determined by the ratio of their volumes to the sum of the supply of this product (production plus import). Average world barite prices are calculated based on the total volumes and value of world exports.

## Overview of world resources and commodity flows of barite raw materials

Barite is a fairly common mineral present in many geological formations (sedimentary, hydrothermal, exogenous, etc.), and forms independent monomineral deposits. It is also present as an associated component in complex (mainly polymetallic) deposits.

Commercially significant barite deposits are represented by four mineral types [3, 10]:

– bedded-sedimentary (stratiform);
– bedded-volcanic (stratiform);
– metasomatic (including carbonatites);
– residual (weathering crust/residuum).

Many more geological formations of barite deposits (carbonatite, nodular, barite-fluorite, barite-celestite, etc.) [10, 11] can also be identified. However, the bulk of barite mining is mainly carried out from the deposits of the above four types.

Barite deposits are geologically quite widespread. In terms of the location of extractive and consuming industries, they are world-wide and also developed on national territories (see Fig. 1).

Over the hundred-years from 1920 to 2020, the cumulative world production of barite amounted to 550 Mt. As at 1 January 2021. The world barite resources in deposits prepared for exploitation are estimated at 740 Mt[10] (Fig. 2), which at current demand level is enough for 70–80 years of consumption.

If in 1920 world production and consumption of barite accounted for about 0.3 Mt, by 1940 it had increased to 1.0 Mt/year. Then from 1946, progressive growth developed to a local maximum in 1981 (8.4 Mt). A fter falling consumption of drilling barite in the 1980–90s at the level of 4.4–5.7 Mt/year, resumed growth up to 9.6 Mt in 2012 (see Figs. 3, 4).

In the first half of the 20th century, the industries producing and processing of barite raw materials were located directly in the USA, Germany, Britain, Italy and France. They accounted for over 90% of its world production and 80–95% of world consumption. The use of barite was mainly for the production of paint filler (over 50% of consumption) and barium

[3] Final List of Critical Minerals 2018. Department of the Interior U.S. 83 Fed. Reg. 23295. 2018. URL: https://www.federalregister.gov/documents/2018/05/18/2018-10667/final-list-of-critical-minerals-2018

[4] US Geological Survey. URL: http://minerals.usgs.gov/minerals/pubs/commodity/tin/index.html#mcs

[5] Britain Geological Surveys. URL: http://www.bgs.ac.uk/mineralsuk/statistics/worldStatistics.html

[6] Federal Customs Service of Russia. URL: http://stat.customs.gov.ru/analysis

[7] Federal State Statistics Service of Russia. URL: https://gks.ru/emiss

[8] UNdata. A world of information. URL: https://data.un.org/Default.aspx

[9] Information And Analytical Center "Mineral". URL: http://www.mineral.ru/Center/index.html
Market Research Group "Infomine". URL: https://infomine.ru/
TrendEconomy. URL: https://trendeconomy.ru/

[10] US Geological Survey. URL: http://minerals.usgs.gov/minerals/pubs/commodity/tin/index.html#mcs
Information and Analytical Center "Mineral". URL: http://www.mineral.ru/Center/index.html

chemicals. However, over time, the national resources of barite were reduced and there was a transformation of commodity flows from producers to consumers [3].

At the end of the 1950s, there was a sharp increase in the consumption of barite as a weighting agent for drilling fluids. This led to an increase in its production in large oil and gas producing countries (USA, USSR, Mexico, Canada), new export flows (from Morocco, Mexico, Canada and others countries), import flows to other producing countries (Algeria, Venezuela, Trinidad/Tabago), as well as the formation of transit flows of barite raw materials through the Netherlands, Belgium and Singapore [3].

In the 1980s, after the end of the energy crisis of the 1970s, there was a reduction in drilling and, accordingly, the consumption of barite raw materials, primarily in the United States.

In the 1990s and at the beginning of the 21st century, the world economy began to transform, due primarily to China's industrial potential. Own extraction of barite in China itself, as well as in India, Kazakhstan, Iran, Pakistan grew sharply.

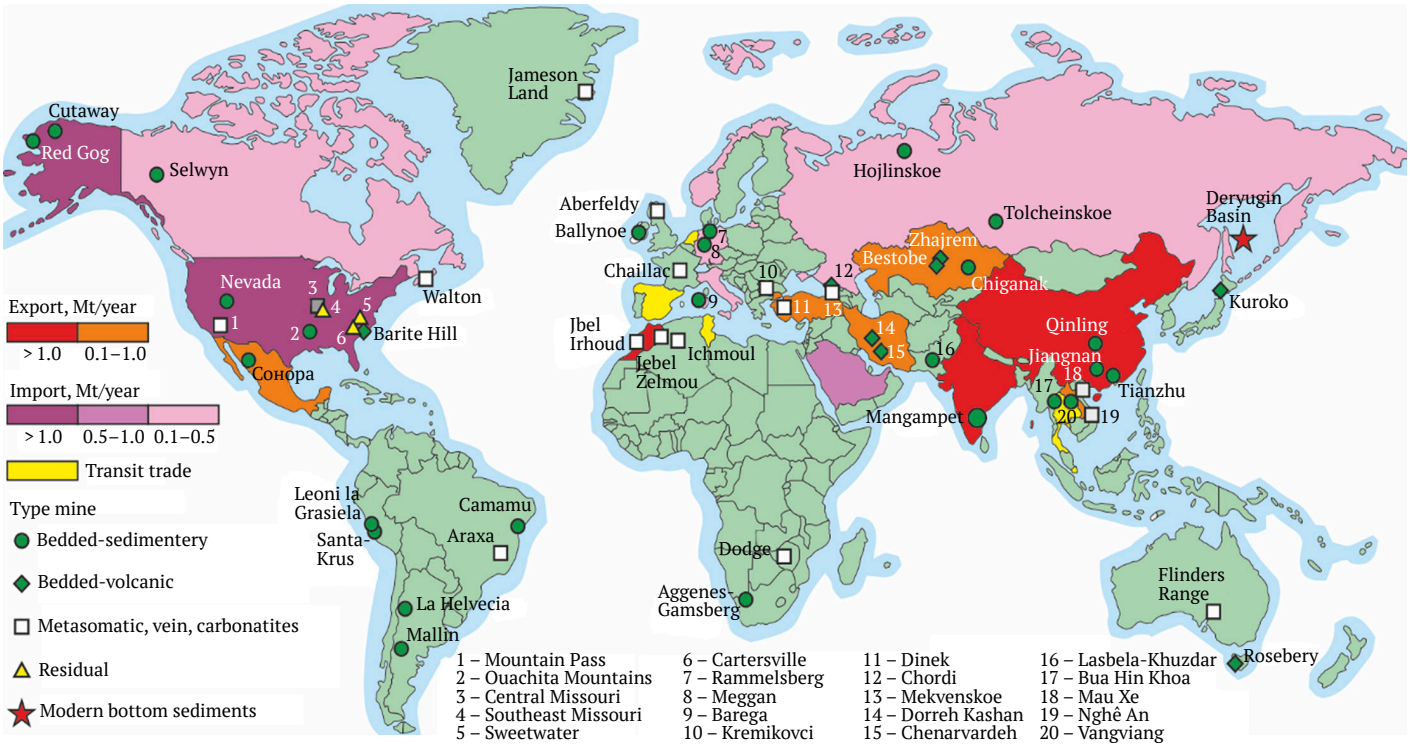


**Fig. 1.** Map of the world with the localization of barite deposits and lead countries in the international trade of barite raw materials (exporters, importers and transit countries)

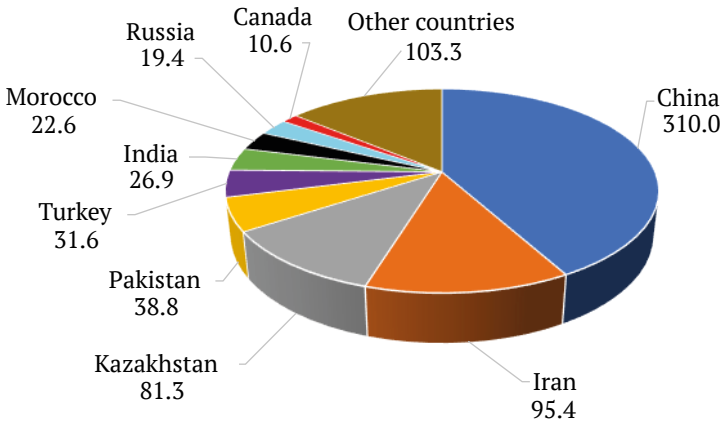


**Fig. 2.** Barite world resources in deposits prepared for exploitation (Mt)

Based on data provided in the US Geological Survey (http://minerals.usgs.gov/minerals/pubs/commodity/tin/index.html#mcs), the Information Center "Mineral" (http://www.mineral.ru/Center/index.html) and the Information Group "Infomine" (https://infomine.ru/)

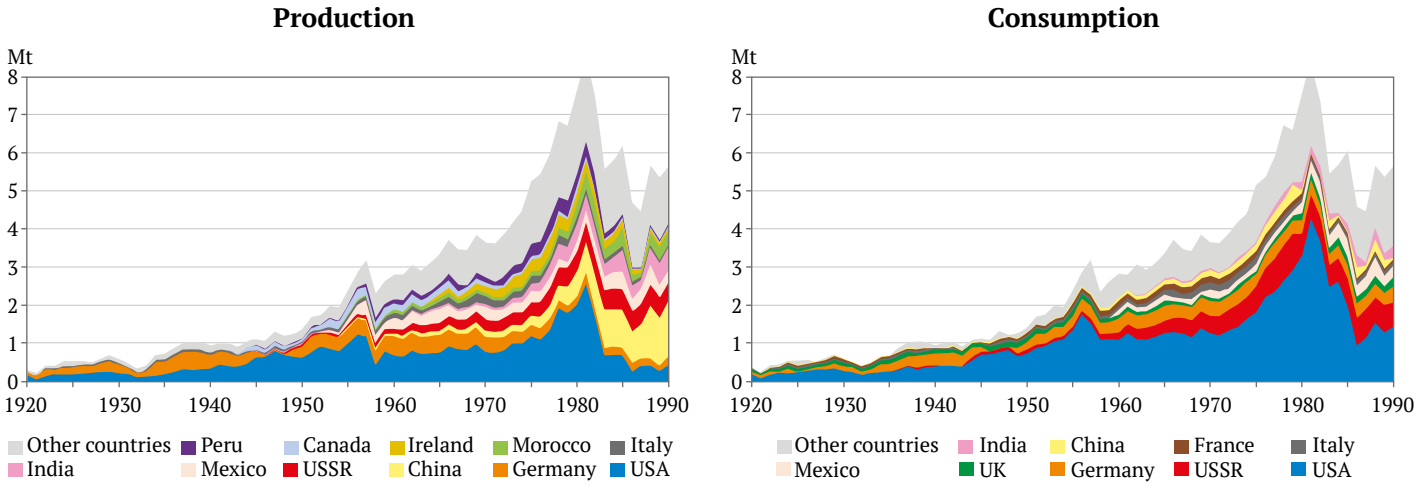


**Fig. 3.** Dynamics of world barite production and consumption for 1920–1990
Based on data provided in the US Geological Surveys (http://minerals.usgs.gov/minerals/pubs/commodity/tin/index.html#mcs) and Britain Geological Surveys (http://www.bgs.ac.uk/mineralsuk/statistics/worldStatistics.html), State Statistics Committee of the Russian Federation (http://stat.customs.gov.ru/analysis)

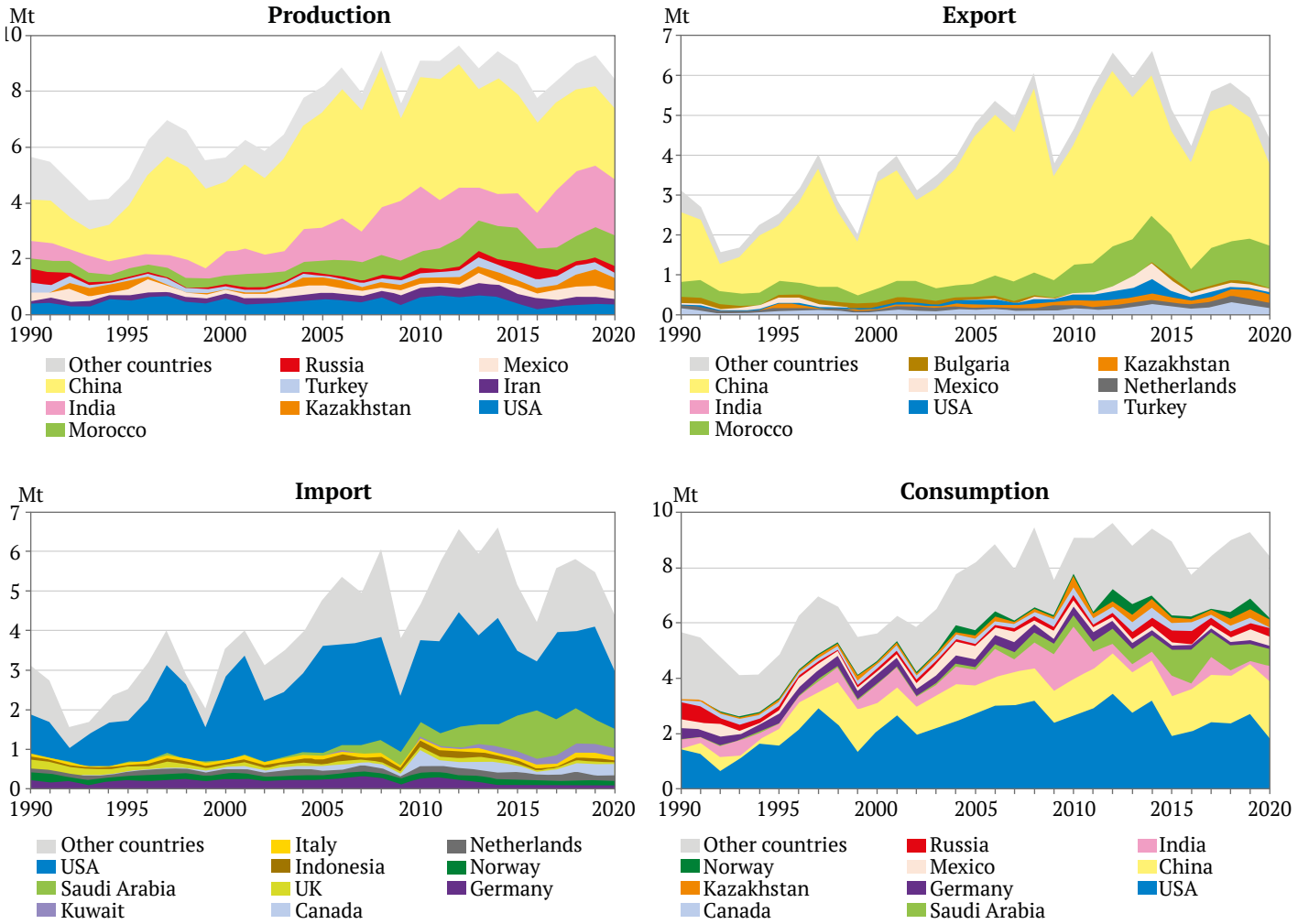


**Fig. 4.** Dynamics of world production, export, import and consumption of barite flows for 1990–2020
Based on data provided in the US Geological Surveys (http://minerals.usgs.gov/minerals/pubs/commodity/tin/index.html#mcs) and Britain Geological Surveys (http://www.bgs.ac.uk/mineralsuk/statistics/worldStatistics.html), the State Statistics Committee of the Russian Federation (https://gks.ru/emiss) and the Customs Service of the Russian Federation (http://stat.customs.gov.ru/analysis), the UN Department of International Trade (https://data.un.org/Default.aspx)

In recent years, due to the depletion of long-term developed oil fields, the volume of production drilling significantly increased. There was also an increase in the consumption of barite weighting agent (and, accordingly, imports) not only in the USA, Canada, Russia, but also in Saudi Arabia, Kazakhstan, Kuwait, Argentina, Indonesia, and the United Arab Emirates and Oman [3].

**Major barite-producing countries.** The *United States* has been the undisputed world leader in barite consumption throughout the entire study period. In 1941, it also became the leader in production, losing the last status only in 1983. The cumulative national production amounted to 63.3 Mt, the cumulative consumption – 146.6 Mt, and the remaining resources of the deposits – 7.6 Mt.

Numerous deposits of stratiform barite (Quachita/Washita Mountains, Red Dog, Cutaway basin and in Nevada), volcanogenic-sedimentary (Barite Hill), hydrothermal (Mountain Pass and in Missouri) and residual (Sweetwater, Cartersville and in Missouri) were developed in the United States type [1, 12, 13, 14]. Numerous deposits of stratiform barite (Quachita/Washita Mountains, Red Dog, Cutaway basin and in Nevada), volcanogenic-sedimentary (Barite Hill), hydrothermal (Mountain Pass and in Missouri) and residual (Sweetwater, Cartersville and in Missouri) were developed in the United States type [13]. The maximum level of production of barite raw materials in the United States was attained in 1981 (2.6 Mt), although it would fall by 1985 to a minimum of 269 kt.

In succeeding years, the level of national production of barite in the United States is 400–700 kt/year. Since 1986, the USA is a net importer of barite raw materials, importing 0.9–2.9 Mt/year (70–90% of consumption). National consumption of barite in the United States increased in the context of the rapid growth in the oil industry: from 0.7 Mt in 1946 to 1.7 Mt in 1956. In 1957–1974, it was at 1.1–1.7 Mt/year. After 1975, in connection with the development of secondary and tertiary technologies for oil production, consumption began to grow up to 4.3 Mt in 1981. This was followed by a recession of 0.9–1.5 Mt/year in 1986–1995 In the 21st century, the national consumption of barite raw materials in the USA is 1.7–3.4 Mt/year.

*China*, which mined only 25 kt of barite raw materials in 1955, intensified work on the development of the barite mining industry in the 1980s, and increased its production volumes, becoming the world leader in 1983. It then continued to increase production volumes up to a maximum of 5,0 Mt in 2008 [3]. The cumulative national production of barite in China is 108.3 Mt, the cumulative consumption is 39.1 Mt. Remaining resources amount to 310 Mt. The main volume of production of barite raw materials is related mainly to the deposits Qinling, Jiangnan and Tianzhu [12, 15–17].

Most of mined barite is exported, with China being the world leader in its international trade from 1980 to 2017. Exports of barite raw materials from China in 1980–1987 amounted to 20–36% of world trade. In 1988–2012, this increased to 45–66%. However since 2013, due to the increase in domestic consumption of barite, it has fallen to 12–39%. National consumption of barite raw materials in China increased from the level of 100–200 kt/year in 1964–1994. It then further increased to 1.5 Mt in 1998, and stabilized at the level of 1.0–1.3 Mt tons/year in 2000–2009, continuing to grow up to 2.0 Mt in 2020. The predominant use of barite in China is as a paint filler.

In the *USSR*, as in China, the mass production of barite began late, after the Second World War. It increased from 30 kt in 1946 up to a maximum of 540 kt in 1978. Later in Russia, there was a decline in industrial production of barite, accompanied by a decline in production to 50–85 kt/year in 1993–2007. However, since 2008, there has been an increase in the production up to 434 kt in 2016. The cumulative production of barite in the USSR/Russia amounted to 16.9 Mt, accumulated consumption – 24.3 Mt, residual resources – 19.4 Mt.

Barite raw materials are extracted at the Tolcheinskoye deposit in the Republic of Khakassia. Work at other previously developed deposits (Khoylinskoye, Kvartsitovaya Sopka) has ceased [3]. Barite was also imported: in the 1940–1950s – 20–70 kt/year (30–88% of consumption); in the 1960–1980s 100–400 kt/year (6–38%); in the 1990s and in the 21st century – 25–65 kt/year (10–30%). National consumption of barite in the USSR in the 1920–1940s was 5–20 kt/yea. After 1944, it began to increase from 55–78 kt/year in 1944–1957 up to 950 kt in 1979. In the 1980s, it reached the level of 550–750 kt/year. National consumption of barite in Russia in the 1990s and in the 21st century is 100–450 kt/year.

*India* also began intensifying barite production in 1975, peaking at 2.3 Mt in 2010. Most of the mined barite is exported. Since 2018, India has become the world leader in the international trade of barite raw materials (up to 37% of the market), ahead of China [3]. Cumulative production of barite in India amounted to 43.0 Mt, cumulative consumption – 20.0 Mt, residual resources – 26.9 Mt. The main volume of production of barite raw materials are extracted at the unique Mangampet deposit [12, 18]. National consumption of barite in India in the 1920–1950s was 5–20 kt/year;

in the 1960–1970s it was 30–55 kt/year. After 1977, it grew 547 kt in 1993 and up to 1.9 Mt in 2010. In the future, the consumption of barite in India is estimated to be at the level of 500–600 kt/year.

*Morocco* began developing its own barite deposits in 1958: Jbel-Irhoud and Jebel-Zelmou. These were completely focused on the export of this raw material [19, 20]. For a long time (1980–2005), the level of production and export of barite was 0.4–0.5 Mt/year, later increasing to 0.7–1.2 Mt/year and Morocco traditionally ranks third in international trade barite raw materials (10–24% of the market) [3]. Cumulative production of barite in Morocco amounted to 24.6 Mt; cumulative consumption – 2.8 Mt; and residual resources – 22.6 Mt. There is the opportunity to significantly increase the resource base of barite [21, 22].

*Mexico* quickly brought the level of barite production to 200–400 kt/year for consumption in the national oil industry. This was achieved by developing the Sonora deposit in 1953 [23]. The cumulative production of barite raw materials in Mexico is 17.4 Mt; the cumulative consumption is 12.9 Mt; and the remaining resources are 3.8 Mt. In the 1950–1970s, 100–200 kt/year were exported (mainly to the USA). However, due to the increase in national consumption of the oil industry, export volumes fell in the 1980s to the 30–65 kt/year. In 1997, the export of barite raw materials practically ceased, resuming only after 2011.

*Turkey* is fortunately located near European consumers of barite raw materials. Since 1973, the Dinek deposit has remained active[24], exporting 100–300 kt/year. 50–100 kt/year are directed to own consumption. Turkey's cumulative production is 9.2 Mt; cumulative consumption is 3.4 Mt; and the remaining resources of barite raw materials are 31.6 Mt.

**Barite-producing countries which have lost export status.** Due to the depletion of their own deposits, many exporting countries of barite raw materials have practically left the international market: Yugoslavia in 1966; Germany in 1973; Greece in 1976; Peru in 1985; Ireland in 1995; and Bulgaria in 2009 [3].

*Germany*, originally in the 1920–1930s, was the world leader in the production and consumption of barite. Production was carried out at the Rammelsberg and Meggan fields [25, 26]. By 2020, the national cumulative production of barite raw materials amounted to 23.3 Mt; cumulative consumption – 26.8 Mt; and residual resources of own deposits – 1.2 Mt. Barite production volumes increased from 100 kt/year in the 1920s to 400 kt/year in the 1930–1960s (with a fall up to 2 kt/year during the Second World War). After 1972, they began to decline down to 34 kt in 2017. At the same time, an import flow of barite raw materials emerged (from 10% of imports from consumption in the 1960s to 70% in the late 1990s). By 1979, Germany had become its net importer of 100–300 kt/year of barite. The level of consumption of barite raw materials in Germany remained for a long time at 300–400 kt/year with a fall only during the economic crisis of 2008–2009. (174 kt in 2009) and with a decrease in demand from 2014 to the present (up to 130–160 kt/year).

*Peru* began development of the Leoni la Grasiela deposit in 1951 (100–435 kt/year, the vast majority was exported). Prior to 1985 it was a significant exporter of barite (up to 13% of the world market). The cumulative production of Peru amounted to 7.1 Mt; remaining resources – 3.4 Mt. At present, the Santa-Cruz de Kokachakra field is being developed in Peru with a production level of 15–105 kt/year.

*Ireland* began started development of the Ballynoe deposit in 1955 (100–370 kt/year). Almost all of the mined barite was exported (sometimes up to 22% of the world market). Production ceased in 1994. The cumulative production of Ireland amounted to 5.7 Mt; residual resources – 1.0 Mt.

*Bulgaria* began extracting barite as an associated useful component at the Kremikovtsi iron ore deposit (100–250 kt/year), most of which was exported. In 2009, as a result of the global economic crisis, production ceased and resumed only in 2014 at the level of 40–70 kt/year. The cumulative production of Bulgaria amounted to 4.5 Mt; the remaining resources – 9.5 Mt.

**New countries extracting barite raw materials.** New countries appeared with large-scale production of barite raw materials: Kazakhstan, Iran (up to 450 kt/year) and Laos (up to 400 kt/year) [3].

In *Kazakhstan* in the 1990s, in the context of an unfavorable economic environment, production from existing developed barite deposits (Karagaily, Zhairem, Bestobe and Chugunak [27]) was only 10–50 kt/year. Since 2003, the production of barite raw materials has increased to 170–270 kt/year. By 2019 it had grown to 600 kt/year. A significant part of the mined barite (100–220 kt/year) is exported to Azerbaijan, Turkmenistan, Uzbekistan and Russia. Intensive geologic exploration is under way, in order to increase Kazakhstan's barite raw materials. Since 1992, the cumulative production of barite in Kazakhstan in a short space of time rose to 6.0 Mt; the cumulative consumption of 3.6 Mt. Remaining resources are very large – 81.3 Mt.

*Iran* with its unique deposits of Dorreh Kashan and Chenarvarde [28, 29], (15–90 kt/year), since 1991 has increased production of barite raw materials up to 150–230 kt/year. Since 2009, volumes have increased up to 300–435 thousand t/year. Part of the mined barite is exported: 50–150 kt/year. The cumulative production of barite in Iran is 10.0 Mt; the cumulative consumption is 8.5 Mt; and remaining resources are very large – 95.4 Mt.

*Laos*, which was not previously of interest in terms of minerals, discovered the Vangviang deposit [30]. Thus rapid growth in barite production began from 27 kt in 2013 to 420 kt in 2019. 60–100 kt/year are exported.

**Transit countries of barite raw materials.** Trade intermediaries have also emerged among producing countries and end-consumers of barite raw materials: the Netherlands, Spain, Tunisia, Thailand, Belgium, Hong Kong and Singapore.

The *Netherlands* is a convenient logistic point for receiving goods at the major ports of Amsterdam and Rotterdam with further transshipment to the countries of the central part of the European Union. In the absence of barite mining and the minimum volume of national consumption of 10–40 kt/year, the volume of imports and exports is 100–200 kt/year.

Until 2009, *Spain* independently mined up to 50–100 kt/year of barite with its own consumption of 50–70 kt/year. In 2010, the national production of barite raw material reduced. Consumption decreased to 20–40 kt/year, but imports increased to 50–100 kt/year and exports (30–50 kt/year).

*Tunisia* mines up to 10 kt/year of barite raw materials with a consumption of up to 5 kt/year. However, since 2008, it has been importing and exporting 30–80 kt/year of barite.

*Thailand* mines barite at the Bua Hin Khoa deposit (50–200 kt/year) with domestic consumption of 50–150 kt/year. Imports and exports of barite raw materials were previously at the level of 20–30 kt/year. However, since 2010, volumes have increased to 60–130 kt/year. This is partly the result of the transit trade of barite.

Transit flows of barite raw materials through Belgium, Singapore and Hong Kong are low – 20–40 kt/year.

**Other barite producing countries in the G20.** *Britain* in the 1920–1930s produced 40–80 kt/year of barite raw materials. Maximum production of 100–120 kt/year was reached in the 1940s, after which there is a stable production of 30–60 kt /year up to the present day. The Aberfeldy field is under development [31]. National consumption is also kept at a fairly stable level of 90–130 kt/year, requiring imports of 60–90 kt/year. Britain's cumulative production was 6.4 Mt, cumulative consumption was 12.3 Mt, and residual resources were 2.4 Mt.

*Canada*, has been developing the Selwyn and Walton deposits since 1944 (100–300 kt/year). Production has reduced to 30–50 kt/year since 1982. This level is maintaine at this level to the present day. In the 1940s–1970s, mined barite raw materials were exported (100–200 kt/year), mainly to the USA. Nevertheless, the needs for the national oil and gas industry of Canada have reoriented commodity flows. Since 1979, exports have practically ceased, and since 1999 imports of barite began to grow (100–400 kt/year). Canada's cumulative production amounted to 6.8 Mt, cumulative consumption – 6.0 Mt, and residual barite resources – 10.6 Mt.

*Italy* in the 1920–1950s, barite raw materials were at a level of 20–100 kt/year. In the 1960–1980s: 100–200 kt/year. In the 1990s, production fell to 40–70 kt/year. The Barega and Mont-Aga deposits are under development. In terms of barite raw materials import, only 20–40 kt/year were purchased. Until the 1950s, the level of national consumption of barite in Italy was 20–50 kt/year. However, in the 1960–1980s, against the backdrop of the development of the chemical industry, it increased to 100–200 kt/year, and later stabilized at the level of 90–110 kt/year. Italy's cumulative production was 7.2 Mt; cumulative consumption was 8.8 Mt; and residual resources were 2.0 Mt.

*France* in the 1920-1960s produced barite raw materials at volumes of 30–100 kt/year; in the 1970–1980s – 100–200 kt/year; in the 1990s 40–70 kt/year. In 2007, mining operations ceased. The Chaillac deposit was under development. In terms of barite raw materials import, only 20–40 kt/year were purchased. France's cumulative production was 6.4 Mt; cumulative consumption was 7.3 Mt; and residual resources were 0.8 Mt.

The *European Union* is a complex conglomerate of its members. Some of them produce barite (Bulgaria, Britain, Germany, Slovakia), other countries only consume barite raw materials (Italy, Poland, Czech Republic, Austria), while other countries are involved in transit trade (Netherlands, Spain, Belgium). As a result, despite the criticality of barite raw materials for the EU in general (68–82% of imports from demand), there is also a significant counter-export flow (up to 25%). The cumulative production of the European Union is 63.0 Mt; the cumulative consumption is 77.5 Mt; and the remaining resources are 0.8 Mt.

**Countries – net importers of barite raw materials.** *Saudi Arabia* has been a consumer of barite raw materials for a long time at the level of 10–30 kt/year. Since 2004, due to the transition to secondary and tertiary oil production technologies, it has significantly increased the volume of drilling operations and, according the consumption of barite, (up to the maximum to 1.2 Mt in 2016). The accumulated national consumption of barite raw materials in Saudi Arabia is 9.8 Mt.

*Norway* began to develop North Sea oil and gas fields. It has been importing significant volumes of barite raw materials since 1979 (100–300 kt/year) [3]. The cumulative national consumption of barite in Norway is 5.6 Mt.

Barite consumption has also increased recently in Kuwait (up to 215 kt/year), Argentina (up to 180 kt/year), Indonesia (up to 150 kt/year) and the United Arab Emirates (up to 80 kt/year) [3].

**The criticality of the world barite raw material trade.** The share of international trade in barite raw materials has been continuously growing since the 1940s (5–14%) to 55–70%, and in the 2010s (see Fig. 5).

The following groups of countries can be defined according to the ratio of the import and export shares of barite raw materials (Fig. 6):

– critical level importing countries (imports over 50%) – Algeria, Germany, USA, European Union, Malaysia, Canada, Argentina, Italy, Azerbaijan, Oman, Kuwait, Saudi Arabia, Indonesia, UAE, Norway;

– importing countries with moderate imports – Britain, Russia, Brazil;

– exporting countries with a small share of exports (up to 50%) – Bulgaria, China, Mexico, Kazakhstan;

– exporting countries with a high share of exports – Morocco, Turkey, India, Pakistan, Laos, Iran;

– countries of transit trade of barite raw materials – the Netherlands, Tunisia, Spain, Thailand.

The total gross domestic product of importing countries of critical level barite raw materials is 38.8% of the world GNP, exporting countries (both with a small and with a high share of exports) – 31.0%, countries of transit trade – 3.2%. Thus, the criticality of the international trade market in barite is very high, primarily for members of the G20 (USA, European Union, Saudi Arabia, Indonesia and Argentina).

A decrease in the criticality in the barite raw material supply is possible by reducing its consumption, increasing barite production with the commissioning of prepared barite deposits, restoring previous extractive industries and searching for new deposits.

**Reducing the consumption of barite raw materials by finding substitutes or eliminating its use.** In the paint and varnish industry, barite filler has been replaced with titanium dioxide and bleached kaolin. However, this process is very slow, and linked to the traditional conservatism of consumers accustomed to familiar commercial products. Nevertheless, Japan, with a barite consumption of 100–150 kt/year in the 1980s and 1990s, reduced its demand to 25–40 kt/year by the 2010s. Consumption of barite raw materials also decreased in France, Italy, and the Czech Republic. In South Korea, small

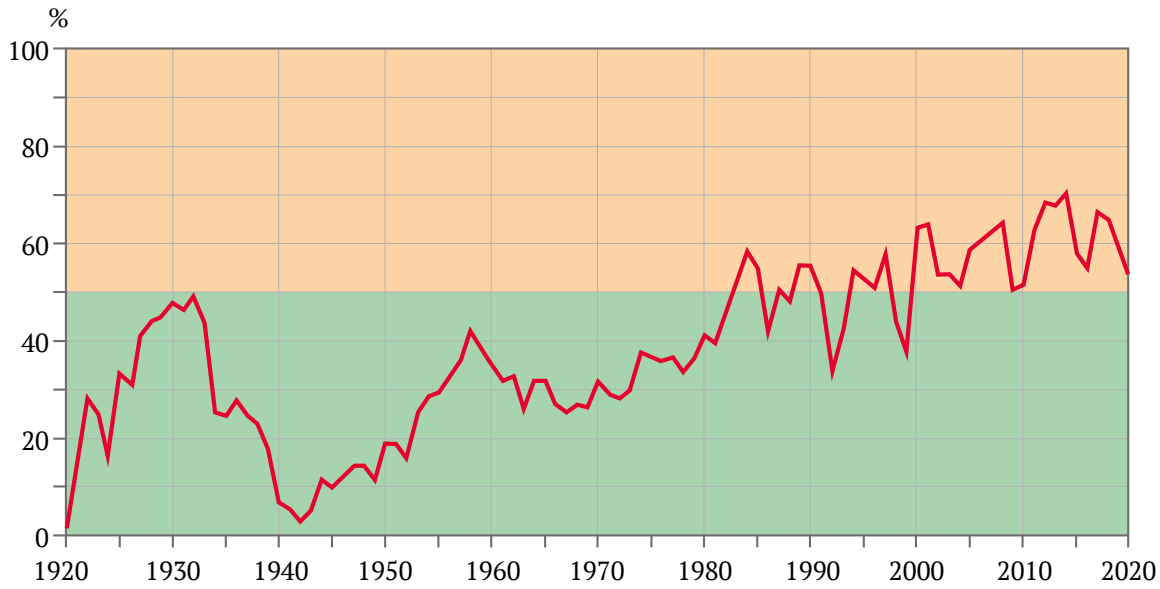


**Fig. 5.** Share of international trade volumes (export/import) on supply (production) of barite raw materials

volumes of barite was initially used (25–40 kt/year), indicating a planned limitation of its applicability. In principle, it is also possible to replace barite in the main segment of its consumption in drilling fluids with flaky hematite (in terms of physical and operational properties). However, in practice this replacement has not become widespread. Barite is used even in the new bromide-based super-heavy drilling fluids. It is used no longer as a weighting agent, but as a filler and fluid thickener.

The available world resources of barite raw materials (740 Mt) at the current level of its demand are enough for 70–80 years of consumption. Barite resources are most favorable in China, Iran and Kazakhstan. Difficulties arise from the fact that most are located outside the national territories of critical barite importing countries. Their development is problematic due to the relative cheapness of barite raw materials. Therefore projects for their development are unattractive. Problematic projects for the development of barite deposits in the harsh conditions of the Subarctic are the Hojlin group in Russia, the Jameson Land Basin in Greenland and the Cutaway Basin in Alaska.

There are also logistical problems. For example, the centers for the extraction of barite raw materials in Kazakhstan are located far from seaports, significantly increasing the transport component in the cost of shipped products. Furthermore, political sanctions against certain countries (Iran, Russia, China, etc.) are viewed as anegative signal, already leading to a decrease in export deliveries of barite from China and Iran. Nevertheless, these complex issues can be resolved with new exploration projects in the territories


**Fig. 6.** Share diagram of import and export volumes on supply volumes (mining + import) of barite raw materials in 2020 for countries with commodity flows of barite over 50 kt

of new countries (for example, discoveries of barite deposits in Laos).

A fundamentally new source of barite raw materials can be modern chemogenic barite sediments found at the bottom of the Deryugin Basin in the Sea of Okhotsk (see Fig. 1) [32]. They are found in an area of up to 16 km$^2$ at relatively shallow depths of 1470–1480 m. They are in the form of travertine-like accumulations, concretions, and crusts. The resources of barite sediments in this field are up to 10 million tons of $BaSO_4$. This corresponds to an average concentration of barite formations up to 600 kg/m$^2$ [33, 34]. Similar recent marine barite sediments have also been found in other areas of the seabed of the World Ocean [35]. In addition to their chemogenic formation, a biogenic genesis of modern marine barite has also been proposed [36]. Previously, barites from bottom sediments of the seas were not even considered as a potentially useful resource. By analogy with projects for the development of deposits of deep-sea iron-manganese nodules, the development of underwater barite sediments is technically and economically feasible. In addition, the emergence of a new chemogenic type of barite deposits requires a rethinking of geological forecasts for searching of similar deposits in ancient bathyal and abyssal sedimentary formations.

## Conclusions

The production of barite raw materials is continuously growing and reached 8.0–9.6 Mt/year in the 2010s. The share of barite international trade is also increased to 4.2–6.0 Mt/year or 55–70% of world production. Cumulative world production of barite for 1920–2020 amounted to 550 Mt; the available world resources of barite in deposits prepared for exploitation are estimated at 740 Mt.

Signs of the criticality in commodity flows of barite raw materials for the national economies of countries are a high share of imports from supply (over 50%) with significant import volumes (over 50 kt/year) and the excess of accumulated national consumption over national production.

The group of critical countries importing barite raw materials (imports over 50%) represents 38.8% of the GDP of the world economy. Imports in 2020 were as follows: USA (1.5 Mt, 68% of demand); the European Union (512 kt, 75%), including Germany (91 kt, 70%) and Italy (96 kt, 97%); Saudi Arabia (500 kt, 100%); Canada (290 kt, 88 %); Kuwait (208 kt, 100%); Norway (118 kt, 100%); Oman (95 kt, 100%); Algeria (75 kt, 65%); Malaysia (70 kt, 82%); Indonesia (62 kt, 100%); UAE (91 kt, 100%); Azerbaijan (59 kt, 100%); Argentina (51 kt, 88%).

The group of countries exporting barite raw materials includes 31.0% of the GDP of the world economy. Exports in 2020 were as follows: India (1.46 Mt, 73% of production); Morocco (1.07 Mt, 97%); China (541 kt, 21%); Kazakhstan (217 kt, 48%); Turkey (181 kt, 87%); Iran (162 kt, 54%); Laos (100 kt, 56%); Mexico (101 kt, 35%); and Pakistan (91 kt, 63%).

Barite raw materials are virtually impossible to replace in the production of drilling fluids, its main segment. There is a movement towards an increase in world consumption of weighted drilling fluids due to systemic changes in the development of oil and gas fields. This is due to a general increase in the depth of drilling to open oil and gas deposits from 1–2 km to 3–5 km and intensive involvement in the development of hard-to-recover reserves of shale oil and gas. This requires 5–8 times more production wells, in accordance with the technological drilling scheme.

The world demand for barite will only increase in the near future in view of growing consumption due to systemic changes in the development of oil and gas fields. This is associated with a general increase in drilling depth and intensive involvement in the development of hard-to-recover shale oil and gas reserves. Accordingly, there has been a growth in the consumption and import of critical barite raw materials to oil and gas producing countries: USA, Saudi Arabia, Kuwait, Indonesia, England, Canada and Norway.

The world barite raw material base has enabled an increase in production, both in traditional producing countries (Morocco, Mexico) and in new leading barite export countries (India, China). The state of barite mining in Russia although critical (the only mining enterprise), can be resolved by future commissioning of new deposits and the formation of controlled barite import flows from friendly countries (Kazakhstan, India, China, Iran).

A decrease in the criticality of barite raw material supply can be attained by reducing consumption in varnish and paint use (Japan, France, Italy and the Czech Republic), as well as by increasing world production of barite with the commissioning of new deposits, given the significant prepared resources of this raw material in Iran, Kazakhstan and Pakistan. There are potential new barite deposits in geologically poorly studied territories (Mongolia, Laos, Myanmar, Western Sahara, the shelf of the Moroccan coast, etc.), as well as searching for a new chemogenic type of barite deposits on the bottom of the seas and in ancient bathyal and abyssal sedimentary formations.

## References

1. Bearden S.D. Barite: World sources and the US market. *Mining Engineering*. 1997;49(11):87–88.

2. Bonel K.A. *Mineral profile: Barites*. British Geological Survey; 2005. 28 p.

3. Boyarko G.Yu., Khatkov V.Yu. Current state of production and consumption of barite raw materials in Russia. *Bulletin of the Tomsk Polytechnic University. Geo Assets Engineering*. 2021;332(10):180–191. (In Russ.) https://doi.org/10.18799/24131830/2021/10/3403

4. Schulz K.J., DeYoung J.H., Seal R.R., Bradley D.C. (eds.) *Critical mineral resources of the United States – economic and environmental geology and prospects for future supply*. United States Geological Survey; 2017. 862 p. https://doi.org/10.3133/pp1802

5. Chen J.B., Huo W.M., Feng D.D. Analysis of strategic (critical) mineral resources situation in China and the U.S. and the EU. *Natural Resources. Economy of China*. 2020;33(8):9–17. (In Chinese)

6. Jiang Y., Wang T., Long T. Research on listing barite as a strategic mineral resource. *Acta Geoscientica Sinica*. 2021;42(2):297–302. (In Chinese) https://doi.org/10.3975/cagsb.2020.110204

7. Eremin N.I. Critical metals. *Geologiya Rudnyh Mestorozhdenij*. 2016;58(6):595–596. (In Russ.) https://doi.org/10.7868/S0016777016060034

8. Khatkov V.Y. Trade flows of import-dependent mineral products. *Mineral Recourses of Russia. Economics and Management*. 2017;(5):66–71. (In Russ.)

9. Singh R.K., Kumar A., Garza-Reyes J.A., de S´a M.M. Managing operations for circular economy in the mining sector: An analysis of barriers intensity. *Resources Policy*. 2020;69(4):101752. https://doi.org/10.1016/j.resourpol.2020.101752

10. Kasymov M.A. Formation types of barite deposits. *Proceedings of the Kyrgyz State Technical University named after I. Razzakov*. 2014;(33):108–112. (In Russ.)

11. Akhmanov G.G., Vasiliev N.G. *Mineral raw materials. Barite*. Handbook. Moscow: Geoinformmark; 1997. 39 p. (In Russ.)

12. Clark S.H.B., Poole F.G., Wang Z. Comparison of some sediment-hosted, stratiform barite deposits in China, the United States, and India. *Ore Geology Reviews*. 2004;24(1–2):85–101. https://doi.org/10.1016/j.oregeorev.2003.08.009

13. Howard K.W., Hanor J.S. Compositional zoning in the Fancy Hill stratiform barite deposit, Ouachita Mountains, Arkansas, and evidence for the lack of associated massive sulfides (USA). *Economic Geology*. 1987;82(5):1377–1385. https://doi.org/10.2113/gsecongeo.82.5.1377

14. Koski R.A., Hein J.R. Stratiform barite deposits in the Roberts Mountains allochthon, Nevada: a review of potential analogs in modern sea-floor environments. *Chapter H of Contributions to industrial-minerals research. United States Geological Survey Bulletin*. 2003;2209-H.

15. Wang F.-L., Huang Y., Fu Y. et al. A study of the enrichment mechanism of early Cambrian barite in Eastern Guizhou: Constraint from sulfur isotope. *Acta Geoscientica Sinica*. 2020;41(5):686–698. https://doi.org/10.3975/cagsb.2020.081701 (In Chinese)

16. Zhou X., Li R., Tang D., Huang K.-J. et al. Cold seep activity in the early Cambrian: Evidence from the world-class shale-hosted Tianzhu barite deposit, South China. *Sedimentary Geology*. 2022;439:106220. https://doi.org/10.1016/j.sedgeo.2022.106220

17. Li Y., Zou H., Said N., Liu H. A new classification of barite deposits in China. *Ore and Energy Resource Geology*. 2023;14(3). https://doi.org/10.1016/j.oreoa.2023.100019

18. George B.G., Shalini N., Pandian M.S. et al. Strontium and Sulphur isotopic constraints on the formation of the Mangampeta barite deposit, Cuddapah basin. *Current Science*. 2013;105(4):499–504.

19. Rajlich P., Legierski J., Šmejkal V. Stable isotope study of base metal deposits from the Eastern High Atlas, Morocco. *Mineralium Deposita*. 1983;18(2):161–171. https://doi.org/10.1007/BF00206206

20. Jaillard L. The barite massive orebody at Tarhwacht, Western High Atlas, Morocco, hosted by an albitite of sedimentary origin. *Comptes Rendus – Academie des Sciences, Serie II*. 1987;304(14):847–853.

21. Jébrak M., el Wartiti M., Marcoux E., Zaharoui M. The Bouznika Cambrian barite deposit (Morocco), an early mineralization on the Iapetus margin. *Journal of African Earth Sciences*. 2011;60(3):53–62. https://doi.org/10.1016/j.jafrearsci.2011.02.001

22. Ibrahim D., Ahmed B., Habiba A. et al. Contribution of geophysics to the study of barite mineralization in the paleozoic formations of Asdaf Tinejdad (Eastern Anti Atlas Morocco). *Economic and Environmental Geology*. 2020;53(3):259–269. https://doi.org/10.9719/EEG.2020.53.3.259

23. González-Sánchez F., González-Partida E., Canet C. et al. Geological setting and genesis of stratabound barite deposits at Múzquiz, Coahuila in northeastern Mexico. *Ore Geology Reviews*. 2017;81(3):1184–1192. https://doi.org/10.1016/j.oregeorev.2015.10.008

24. Elmas N., Kumral M., Suner F., Tasdelen S. Stratiform barite deposits hosted in metamorphic assemblages of Dinek and surrounding regions, Isparta, Turkey. *Journal of Asian Earth Sciences*. 2012;48(4):150–159. https://doi.org/10.1016/j.jseaes.2011.11.013

25. Kekeliya S.A., Tvalchrelidze A.G., Yaroshevich V.Z. The geological and physicochemical conditions of formation of massive-sulfide-barite-base-metal deposits. *International Geology Review*. 1984;26(12):1437–1444. https://doi.org/10.1080/00206818409466664

26. Large D., Walcher E. The Rammelsberg massive sulphide Cu-Zn-Pb-Ba-Deposit, Germany: an example of sediment-hosted, massive sulphide mineralization. *Mineralium Deposita*. 1999;34(5/6):522–538. https://doi.org/10.1007/s001260050218

27. Tolmacheva T., Ryazantsev A., Degtyarev K., Nikitina O. Hydrothermal barite deposits in Upper Cambrian-Lower Ordovician siliceous successions of southern Kazakhstan. *Doklady Earth Sciences*. 2014;458(1):1077–1081. https://doi.org/10.1134/S1028334X14090347

28. Jamali H., Zohouri F.S., Tabatabaei Manesh S.M. Exhalative deposits in eocene volcano-sedimentary rocks in the middle part of the Urumieh-Dokhtar magmatic belt: Detailed evidence from Nabar deposit, west of Kashan, Urumieh – Dokhtar Magmatic Belt. *Journal of African Earth Sciences*. 2019;154(5):120–135. https://doi.org/10.1016/j.jafrearsci.2019.03.011

29. Derakhshi M.G., Mohammad R.H., Moayyed M., Maghfouri S. Metallogenesis of Precambrian SEDEX-type Barite-(Pb-Cu-Zn) deposits in the Mishu mountain, NW Iran: Constrains on the geochemistry and tectonic evolution of mineralization. *Ore Geology Reviews*. 2019;107:310–335. https://doi.org/10.1016/j.oregeorev.2019.02.024

30. Ma Z., Ravelo A.C., Liu Z. et al. Export production fluctuations in the eastern equatorial Pacific during the Pliocene-Pleistocene: Reconstruction using barite accumulation rates. *Paleoceanography*. 2015;30(11):1455–1469. https://doi.org/10.1002/2015PA002860

31. Moles N.R. *Geology, geochemistry and petrology of the Foss stratiform barite-base metal deposit and adjacent Dalradian metasediments, near Aberfeldy, Scotland*. [Dissertation.] University of Edinburgh; 1985. URL: http://hdl.handle.net/1842/11180

32. Baranov B., Aloisi V., Degrachev A. Giant barite deposit mapped and the Derugin Basin (Okhotsk Sea). In: *Minerals of the Ocean – integrated strategies – 2*. 25–30 April, 2004. Saint Petersburg, Russia.

33. Astakhov A.S., Ivin V.V., Karnaukh V.N., et al. Barite mineralization in the Deryugin Basin of the Okhotsk Sea: Active processes and formation conditions. *Russian Geology and Geophysics*. 2017;58(2):200–214. https://doi.org/10.1016/j.rgg.2017.01.002

34. Andreev S.I., Kazakova V.E., Ivanova A.M., Smirnov A.N. Geology and minerals of the Far Eastern seas of Russia. In: *70 years in the Arctic, Antarctic and oceans. Collection of scientific papers*. St. Petersburg: All-Russian Research Institute of Geology and Mineral Resources of the World Ocean named after Academician I.S. Gramberg; 2018. Pp. 444–454.

35. Gwiazda P.X., Paull C.K., Caress D., Preston C.M., Johnson's S.B., Lundsten E.M., Anderson K. The Extent of Fault-Associated Modern Authigenic Barite Deposits Offshore Northern Baja California Revealed by High-Resolution Mapping. *Frontiers in Marine Science*. 2019;6:460. https://doi.org/10.3389/fmars.2019.00460

36. Gonzalez-Muñoz M.T., Martinez-Ruiz F., Morcillo F., et al. Precipitation of barite by marine bacteria: A possible mechanism for marine barite formation. *Geology*. 2012;40(8):675–678. https://doi.org/10.1130/G33006.1

## Information about the authors

**Grigory Yu. Boyarko** – Dr. Sci. (Econ.), Cand. Sci. (Geol. and Min.), Professor, National Research Tomsk Polytechnic University, Tomsk, Russian Federation; ORCID 0000-0002-0715-7807, Scopus ID 56350674500; e-mail gub@tpu.ru

**Liudmila M. Bolsunovskaya** – Cand. Sci. (Philolog.), Assistant Professor, National Research Tomsk Polytechnic University, Tomsk, Russian Federation; ORCID 0000-0002-1499-8970, Scopus ID 56350747600; e-mail bolsunovskl@tpu.ru

**Received** 24.02.2023
**Revised** 20.03.2022
**Accepted** 21.03.2022