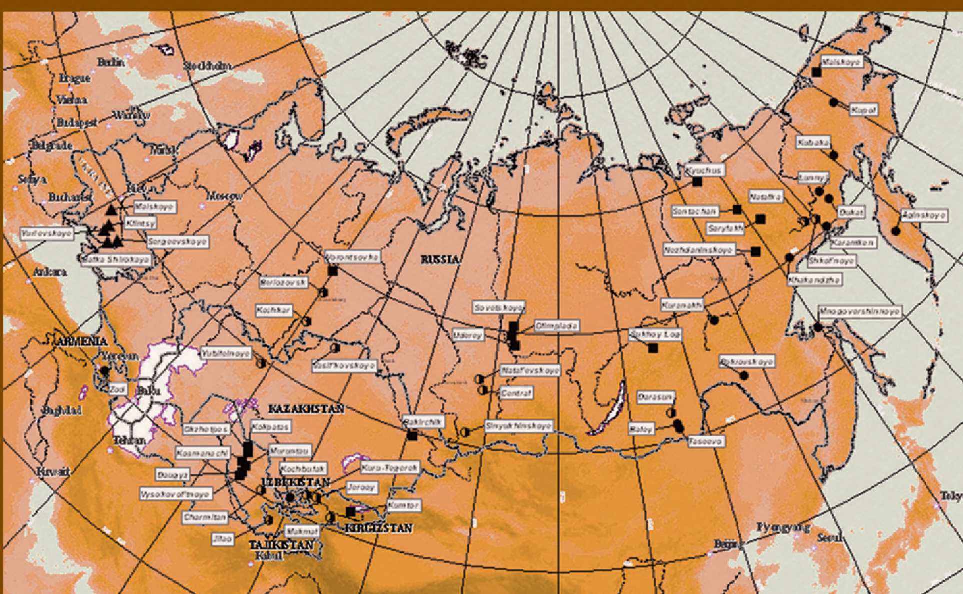
Gold Deposits Of The CIS

Gregory Levitan



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INTRODUCTION

The Commonwealth of Independent States (CIS), which was formed in December 1991 upon the dissolution of the former Soviet Union (FSU), includes the former republics of Azerbaijan, Armenia, Belarus (Byelorussia), Georgia, Kazakhstan, Kyrgyzstan, Moldova, Russia, Tajikistan, Turkmenistan, Uzbekistan, and Ukraine. The FSU was for many decades, until the end of the 1980s, the second-largest gold producer in the world after South Africa. Peak gold production in the FSU of about 290 t was reached in 1979, with a subsequent decline to about 220-230 t by the early 1990s. The significant increase in gold production in the United States and Australia during the same period moved the FSU, and later the CIS, from second to fourth place among world gold producers. However, since 1991 an increase in foreign and domestic funds for development of new gold mines has led to a sharp increase in CIS gold production: by 2004 it was up to about 321 t, once again making the CIS the second-largest gold producer in the world (Fig. 1) after South Africa. At the same time, gold reserves of the CIS are now estimated to be the largest in the world. State-funded gold exploration in the FSU from the 1950s through the 1980s led to the discovery of approximately three hundred significant deposits, including giant gold deposits such as Muruntau (of about 3,000 t, Uzbekistan); Sukhoi Log (1,952.9 t); and the world-class deposits of Nezhdaninskoye (560 t, Russia), Kumtor (458 t, Kyrgyzstan), and Bakirchik and Vasil'kovskoye (409 and 381 t, respectively, Kazakhstan), as well as many smaller deposits. These discoveries revealed new types of gold deposits such as sediment-hosted, veinlet-disseminated gold-quartz (carbonate)-sulfide mineralization as at Sukhoi Log, and the gold (arsenic)-sulfide mineralization of the Bakyrchik and Nezhdaninskoye deposits. These specific types may be practically unknown in other parts of the world. Most of the deposits found and thoroughly explored from the late 1950s to the late 1980s, except a very few (Muruntau, Amantaytau,

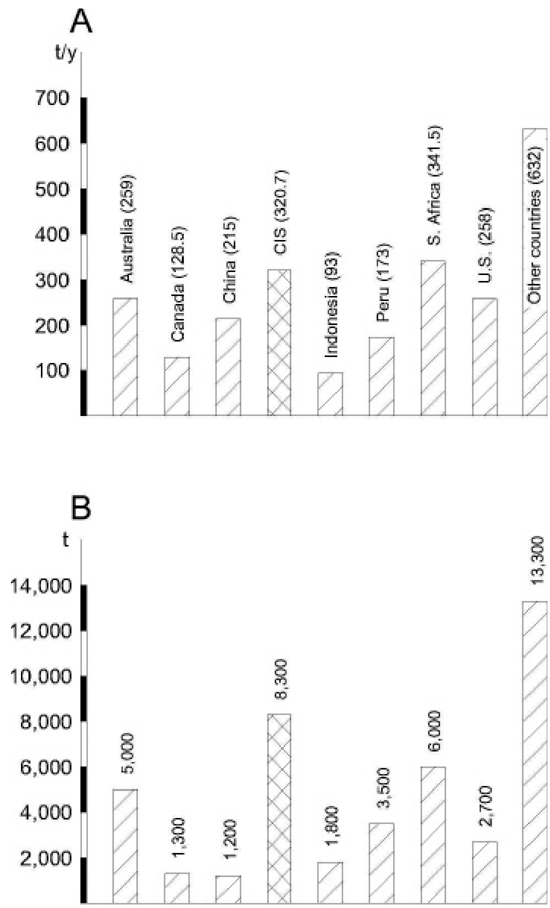

Figure 1. World gold production in 2004 (A) and reserves (B) (after *USGS Mineral Commodity Summaries* 2006 and *Minerals Yearbook* 2004 with additional information from IAC "Mineral"—www.mineral.ru).

Kumtor, Zun-Khalba, Kubaka, Julietta, and a few smaller), still await development. Success of gold mining in the FSU and in many of the current CIS countries has been and still can be adversely affected by laws classifying data on gold reserves and resources as "state" secrets.

The first brief description of gold deposits of the USSR in English was done by M. B. Borodaevskaya and I. S. Rozhkov (TsNIGRI). It was published in 1977 by Pitman Publishing Ltd. and is found in volume 3 of *Ore Deposits of the USSR* (Academician V. I. Smirnov, editor). This description includes the geological setting and mineralogy of the Muruntau deposit and fifteen other small- and medium-sized gold and gold-silver deposits. However, because of Soviet secrecy laws regarding all gold-related information, the size and grade of ore bodies and their resources were not included.

The other publication in English on CIS gold deposits (Krivtsov et al. 1992) contains only very brief, general information concerning major gold-mining areas and key types of deposits of the CIS. This publication disclosed for the first time data on gold grades for some deposits, as well as descriptions of basic operation and processing techniques that are standard for the CIS mining industry. Unfortunately, it contains short descriptions of just six large gold deposits without data on specific tonnages. Moreover, this book was published in Moscow, making it practically unknown to the Western geological community.

More data on gold deposits in the FSU became available to Westerners in the early 1990s, when many minor and major gold-mining companies rushed to the former Soviet Union in an attempt to explore and develop the vast undeveloped gold resources of this part of the world. However, only a few projects in Russia (Kubaka, Zun Khalba, Pokrovskoye, Julietta, and recently the Kupol deposit), Uzbekistan (tailings of Muruntau, Amantaytau, and Vysokovol'tnoye deposits), Tajikistan (Taror and Jilau), and finally Kyrgyzstan (Kumtor) were successful. Most of the data on CIS gold deposits that had been generated during this phase of activity now lies buried in the files of Canadian, U.S., United Kingdom, South African, and Australian companies. The few recent publications on CIS gold deposits, some of them available on the Internet, have not changed the situation.

A number of gold deposits have been described in the excursion guidebooks published in 1999-2007 by Centre for Russian and Central EurAsia Mineral Studies (CERCAMS) of the Natural History Museum in London (R. Seltmann, editor), for field trips in the regions of Uzbekistan, Kyrgyz Tien Shan, and Ukraine.

This publication provides attempt to bridge the gap between the systematic exploration that was carried out and the ideas that were developed during the Soviet era with the understanding that has developed in the successful exploration of gold deposits in other parts of the world in the same period. For this reason, it provides systematic descriptions of different types of gold deposits in what are now the CIS countries and compares them with well-known Western models. Fifty-one of the largest or most typical gold deposits are described (see appendix 1), along with their exploration and mining histories.

The author hopes that this book will be helpful to scientists and researchers for global compilations, to mining companies searching for new acquisitions and potential exploration targets, as well as to the faculty and students of mining schools. The steady increase in the price of gold and silver in the last few years and the attendant increase in exploration investments all over the world enhance the value of the thoroughly explored gold resources of the CIS. The recent legislative changes more favorable for Western investment may have precipitated in the recent return to this part of the world such large mining companies as Barrick, AngloGold Ashanti, and BHP Billiton, as well as some smaller mining and exploration companies.

The data included in this book come from a number of different sources. The principal contribution is from the author's experience from 1956 to 1991 as an exploration geologist with different enterprises of the Soviet Ministry of Geology in Russian Far East, Ural Mountains, and the Central Asia Republics. Further, a great deal of current data on these gold deposits was gathered and compiled during numerous trips as a consulting geologist to the CIS countries in the period 1993-2008. This background, together with the author's analysis of nearly all-available published literature on gold in the FSU, in both Russian and English, has resulted in the most comprehensive database available on the gold deposits and resources of the CIS. It should be noted that detailed information on gold reserves and resources is still a state secret today in many CIS countries, even after perestroika. In such cases, information contained in this publication that does not come from published materials or other sources is based on the author's own estimates of probable gold reserves and resources.

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The author is especially grateful to Robert G. Blair, VP Exploration with the Apollo Gold Co. of Denver, Colorado (former chief geologist of the Cyprus Amax Minerals Corp.), who took a heavy load upon him to improve my English and made a lot of valuable suggestions to make the text more understandable for the Western exploration and mining specialists.

1

HISTORY OF GOLD EXPLORATION AND MINING IN THE CIS

Gold mining in the CIS countries started as early as 3000 BC, and the long history of gold exploration there has had peaks and slumps[1]. Archaeological and historical findings (Marfunin 1987) indicate that during the Bronze and Iron ages, a large amount of gold was mined in Armenia, Georgia, Kazakhstan, Tajikistan, and Uzbekistan. For example, underground workings at the Zod deposit in Armenia have been traced for 150 m. On the basis of ancient artifacts, this mining has been dated to the third millennium BC. Ancient miners at the Stepnyak deposit in northern Kazakhstan worked an open pit 150 m long, 20 m wide, and 24 m deep and developed many underground workings. These workings date from the middle of second millennium to the middle of first millennium BC (Maksimov 1977). The Baktriya and Sogdiana regions of what are now eastern Tajikistan and southern Uzbekistan, respectively, produced about 250 tonnes of gold during the Bronze Age and more than 400 tonnes in the Iron Age.

The Soviet archaeologists also outlined the ancient gold-mining regions in the Altai Mountains and eastern Kazakhstan. Gold mining continued in the region of Rudnyi ("Ore") Altai, for example, from the beginning of the second millennium BC until the first few centuries AD and beyond. Remnants of ancient gold mines dated by archaeologists to the end of

[1] For this chapter we used data from the books of Danilevsky (1959), Lokerman (1978), Maksimov (1977), Marfunin (1987), and Leshkov et al. (2000) all of which are in Russia.

second and beginning of the first millennium BC have been found in many locations in the Ural Mountains, Siberia, and Central Asia.

There must have been a very large amount of gold to account for the extensive distribution of Scythian gold jewelry (700-200 BC) over the vast area from the northern part of the Black Sea Steppe to South Siberia. It may have been mined in part from deposits in the Donbass region (Ukraine) but mainly in the southern Urals and Altai Mountains (in Russia) and in northern Kazakhstan. This assertion is supported by Herodotus's (fifth century BC) history of the Persian Wars. Herodotus mentioned rumors of gold waste in the Riphean Mountains (the Urals) at the boundary between Europe and Asia.

During numerous trips to Central Asia, the author has visited many ancient gold-mining sites in Kyrgyzstan, Tajikistan, and Uzbekistan. These were mostly open pits for lode gold with smelters in nearby river valleys or placer operations dated by archaeologists from the eighth to twelfth century AD. The largest lode-gold operations of this time (about 500,000 tonnes of ore) were found at what is now the Kyzylalma deposit in eastern Uzbekistan. The most impressive ancient placer operations are known along the Kassan River in Kyrgyzstan. Dams of panned gravel and boulders stretch along the course of the river for more than 40 km. All attempts by Kyrgyz geologists to find pillars with high gold content under the present stream have failed. Drill holes often have revealed the remains of timber for ancient workings that were cut after the watercourse had been drained. Nor could samples be found with visible gold or accessible ore in ancient open pits and dumps. Our predecessors had an exceptional ability to identify gold-bearing ore without modern laboratory equipment.

However, exploration of ancient sites for gold in the modern era often has led to the discovery of large gold deposits. The most famous example of such a discovery is the Muruntau deposit in Uzbekistan with more than 3,000 tonnes of gold reserves. Exploration of the Kyzyl Kum Desert for gold in the late 1950s was stimulated by the presence of ancient gold mines. Other noteworthy examples are the rediscovery of the Kyzylalma deposit (120 tonnes of gold) in Uzbekistan or the Stepnyak deposit in Kazakhstan.

The next stage of gold exploration in the CIS could be traced from the fifteenth century AD on the basis of Russian chronicles and later documents from state archives and historical research.

The earliest evidence of Russian government attempts to find and develop precious metal deposits dates to the end of the fifteenth century (Danilevsky 1959). In 1491 Grand Duke Ivan III sent the first known gold expedition in the government's history to the northern part of the Western Urals. However, this expedition, like many other government-sponsored or government-authorized expeditions over the next 200 years, was not successful. The first small mines for development of gold-bearing silver ore were discovered in the Transbaikal region (the Nerchinsk area) in 1702 and started operation in 1704, but gold extraction from silver-galena-sphalerite ore did not begin until 1724.

Exploration for gold and silver intensified in the early eighteenth century. Peter the Great organized the State Department of Mining, the first in Russian history, also known as the Berg Collegium, in 1700. He later (in 1719) issued the "Decree on Mining Privileges," which gave all Russians the right to explore and develop any metal deposits, including gold and silver. The first state fire-assay laboratory was organized the next year in St. Petersburg.

This decree led to the development in 1725 of a private company (the Demidov Works) at the northwest end of the Altai Mountains to mine and smelt copper ore with a high grade of gold and silver. This region had been known as a mining site for gold and silver ore since ancient times. The first silver and gold production from the Demidov Works was recorded in 1745, when it extracted 680 kilograms of silver and 6 kilograms of gold (Leshkov et al. 2000). In 1747 the Russian government expropriated the Demidov Works Company, as well as all of its land in the Altai region. Fear of losing not only companies but also land sharply reduced the value of the Decree on Mining Privileges and discouraged gold exploration.

The first quartz vein with gold-sulfide mineralization was discovered by a local peasant in 1737 in the southern Karelia region between Lake Onega and Lake Ladoga and originally was mined for copper only. This underground mine (Voyetsk) became the first Russian gold operation in 1745 but was closed in 1783 because of the high cost of production at a depth of 120 m.

The real beginning of the Russian gold-mining industry, however, must be dated to 1745, when the Beriozovsk lode gold deposit was discovered in the Ural Mountains, near the city of Ekaterinburg. The development and mining of this large deposit, consisting of quartz-sulfide veins within granitoid dikes, with resources of more than 350 t, was under way for more than 250 years, until the turn of the millennium.

The discovery and development of the Beriozovskoye deposit had considerable impact on gold exploration in the Urals. In the period 1747-1748, the first placer gold was found nearby; but industrial development of placer gold deposits did not begin to be worked until 1814, following the invention of new processing methods by Russian mining specialist L. I. Brusnitsin. There were some 200 placer mines in the Urals after just nine years.

Many quartz-vein gold deposits were found in the second half of the eighteenth century, including discoveries of the Miass's group deposits (1797) and Kochkar (1799), with gold resources of more than 250 t. Gold-bearing quartz-sulfide vein deposits become the primary exploration targets in the Russian Empire and even in the former Soviet Union until the middle of the twentieth century. However, major exploration and development efforts during the nineteenth century were focused on placer gold deposits.

Gold and silver mining throughout the eighteenth century was a state monopoly, in spite of Peter the Great's Decree on Mining Privileges. It was not until 1812 that the Russian Senate issued a new decree that once again permitted all Russian citizens to pursue the exploration and development of gold and silver deposits by paying a tax to the state. This decree partly reduced the fear of possible expropriation of deposits by the government and gave new impetus to gold exploration.

As mentioned above, in the nineteenth century, attention was focused on the exploration and development of placer gold deposits. This was due to the very low operating costs, which were about one-fourth those of lode gold, and to the very high gold grade of the placers. For example, the first placer discovered in the Miass Valley (southern Urals) had a gold grade of about 100 grams per tonne of sand and contained many nuggets. The largest Russian nugget, named "Triangle," which weighed in at 36.18 kilograms, was found in this region in 1842. Numerous rich gold placers were discovered not only in the Ural Mountains but also in Siberia. How the Russian government received the earliest information about Siberian gold makes an interesting story. In 1806 an administrator in the Irkutsk region (near Lake Baikal) reported to St. Petersburg that locals often found gold particles inside the stomachs of dead wood grouses (Danilevsky 1959).

Platinum placers also were discovered in the Ural Mountains during intensive gold-placer exploration. The first one was found in 1819 in the Iset River valley (Middle Urals) and started production in 1824. Belts of platinum placers soon stretched more than 300 km, along almost the entire length of the Middle Urals, and contained the largest and richest platinum placers in the world. Platinum production in 1846 alone reached 32 t and allowed the Russian government to mint platinum coins—an unprecedented event in the world monetary system. Coins with denominations of 3, 6, and 12 rubles were minted in a grand total of 4 million rubles.

Over a 15-year period (1826-1840) the gold rush, with development of placer deposits, encompassed all areas from the Urals and Altai Mountains to the Far East, including west Siberia, the Yenisey Ridge, the Transbaikal region, Yakutiya, Amur Oblast, Khabarovsk, and Primorsky Krai near the Sea of Japan. Gold output in Siberia increased from about 2 tonnes (23% of total output in Russia) in 1839 to 16.5 t (70%) in 1861.

Russian gold was a large part of world output in the first half of the nineteenth century: 35% in the period 1831-1840 and 39% in the period 1841-1850. The experience of Russian gold exploration and mining had a positive impact all over the world through the work of two scientists of extraordinary ability. The first, Alexander von Humboldt (1769-1869), a famous German naturalist who published more than 600 papers on astronomy, geography, geology, geophysics, and other fields, visited the Ural Mountains in 1829 as a specialist on gold and diamonds. On the basis of this visit, von Humboldt noted the similarity of the Ural Mountains to mountains of California and Australia, in that they all have a northerly trend. He also recommended taking into account the richness of the Urals in gold and mentioned the possibility of finding gold in regions similar to those referenced above.

The same possibility was substantiated by the renowned British geologist Sir Roderick I. Murchison (1792-1871), who took a five-month-long field trip to the Ural Mountains in 1841. His monograph *The Geology of European Russia and the Ural Mountains*, published in 1845, made him world famous. In this work, he identified the Permian period and demonstrated the similarity between the geological setting of the Ural Mountains and that of a mountain range along the northeast seacoast of Australia. On this basis, Murchison predicted the discovery of gold in the "Australian Cordilleras." In 1848 he tried to win over to his side the British minister of colonies, telling him of the importance of gold mining in Australia to the British Empire. This prediction became a reality in 1851 with the discovery of gold at Summerhill River.

The role of Russian gold in world production fell sharply, from 12% to 13%, in the second half of the nineteenth century with the start of the California gold rush and the discovery of rich gold placers in eastern Australia, Alaska, and South Africa. It is interesting to note that a Russian mining engineer named Doroshin from the Russian Alaska settlement Nowo-Arkhangelsk (now the town of Sitka) was sent to California in December 1848 and prospected along a tributary of the Sacramento River (Maksimov 1977). His description of the earliest stage of California gold rush was published in *Zhurnal Gornogo Dela* (St. Petersburg, No. 2, 1850).

New gold-extraction technology for lode gold deposits, including mercury amalgamation and cyanidation, that was developed in the 1880s was used on an industrial scale at the Beriozovsk and Kochkar deposits. These methods made possible an increase in gold production from lode gold deposits. A few such deposits discovered at the end of the nineteenth century in Kazakhstan, including Baladzhal (1884) and Stepnyak (1886), were at sites of ancient gold mines. However, in 1899 some 92% of gold was produced from placer deposits. The share of lode gold deposits did not begin to increase until the period 1911-1914.

Before the October Revolution, many Western mining companies participated in the development and operation of gold deposits and massive gold-bearing sulfide deposits of the Russian Empire. For example, in 1908 the Lena Goldfields Co. (Great Britain) was granted a concession for a gold mine in the Lena region of eastern Siberia. Another British company, Russia-Asiatic Consolidated, held concessions for the Kyshtym volcanogenic massive sulfide deposit (Central Urals) and the Ridder gold-bearing lead-zinc deposit (Altai region). They tried to reactivate the concessions after the revolution, but in 1928 the Soviet government terminated all agreements with foreign enterprises.

Russian gold production before the revolution totaled 2,743 t, 93.2% of that amount coming from placer deposits and only 6.8%, or 186 t, from lode gold deposits.

Official Russian gold reserves at the end of 1913 reached 1,684 t (Marfunin 1987), including 381 t in circulation and 1,303 t that served as the centralized gold reserve of the Russian Empire. This gold reserve trailed only those of the United States and France. Under a financial agreement between Russia and its allies in World War I (France and Great Britain), 498 tonnes of gold was delivered between October 1914 and February 1917 to London and in part to Canada as a special loan for credits to allies during the war. Approximately 490 t of gold was stolen as the gold reserve was being transferred from St. Petersburg to the city of Kazan on the Volga River during World War I and later, after the revolution, when it was seized by Admiral Kolchak's counterrevolutionary army (see Brian Garfield's *Kolchak's Gold* 1975). The Soviet government ultimately recovered just 317 tonnes of the gold at the beginning of 1920.

The October Revolution of 1917 and the Civil War affected all gold-mining regions and sharply decreased gold production in Russia from 60.3 t in 1913 to 17.2 t in 1918 and 1.8 t in 1921. This situation, together with the Russian government's refusal to convert its money to other world currencies, required that a large amount of gold be used to purchase machinery, equipment, and food for the Russian nation, which had been devastated by the revolution and Civil War. In October 1921, the Soviet government issued a special decree on the gold and platinum industry, under which all deposits of these metals were declared the exclusive property of the Soviet State. Eleven state gold-mining entities ("thrusts") were organized between 1921 and 1925 and merged into the closed joint-stock company Soyuzzoloto, or "Gold Thrust," in 1927.

The first new gold-placer region during the Soviet era was discovered in 1923 in the central part of the Aldan shield (southern Yakutiya). Aldanzoloto, a gold-mining enterprise, began to operate in 1925 on the basis of this discovery. A systematic geological survey of Soviet territory, accompanied by exploration for all natural resources, including gold, silver, and the platinum group of elements, was undertaken at the beginning of 1920s. Professor D. I. Mushketov, director of the Russian Geological

Survey in the period 1926-1928, wrote, "Beginning in 1920, the Geological Survey began to develop rapidly, meeting the need for exploration of new deposits and inventorying all of the country's existing mineral resources" (Mushketov 1927). According to his data, the number of prospecting parties increased from 93 in 1924 to more than 200 in 1927. The discovery of placer gold in the Kolyma region and the Baley lode gold deposit with resources of more than 300 t in the Transbaikal region (1928) was followed by many others findings. The Saraly, Kommunar, Berikol, Central (Tsentralny), and Komsomol'sk deposits were discovered and placed in operation in western Siberia. The Darasun, Klyuchi, Lyubava, and smaller gold deposits were discovered before World War II in the Transbaikal region. More than 30 lode gold deposits, including Akzhal, Bestobe, Aksu, Maikain, and Zholymbet, were found in Kazakhstan. This period was marked by a sharp increase in gold output from lode deposits, which accounted for 34.3% of total production in 1930 and almost 50% in 1933.

American mining engineers played a significant part in the revival of the Soviet gold industry, which had been destroyed by World War I, the subsequent October Revolution, and the Civil War in the former Russian Empire. A handful of American engineers were active in Russia from the winter of 1927 on. Their number increased dramatically to 175 during the next couple of years but gradually dwindled to zero in 1937.

The most detailed and interesting description of such participation was given by John D. Littlepage in his book published in 1938. A. P. Serebrovsky invited Littlepage, then the superintendent of a mining property near Juneau, Alaska, to Russia at the end of 1927. Mr. Serebrovsky, head of the Gold Thrust or Soyuzzoloto, a new entity uniting the entire gold industry of the Soviet Union, was visiting Alaskan gold mines to learn modern methods of gold mining and ore processing.

Mr. Littlepage first was sent to the Kochkar gold mines of the southern Urals as a consulting mining engineer[2]. He found that most of the mines there had been flooded, pumps destroyed, and steam power plants partially wrecked; and what remained of the mill was deemed too worn-out and obsolete to be put into operation. The same situation was encountered at almost all gold mines throughout the country. But the main problem, by his opinion, lay in

[2] In 1933 he become Deputy Chief Production Engineer of the Gold Trust.

the thousands of utterly green workers and communist managers, who had almost no experience with mechanized mining. Even many old engineers were unfamiliar with the new mining and milling equipment.

The Kochkar gold mines in the Ural Mountains were revived with American equipment in the period 1928-1929 and became the most progressive in the industry. Thousands of miners and engineers were run through the mines and mill to see how mechanized mining worked. After some training, they were sent to other gold mines and put to work. According to Littlepage, new methods and equipment were put to use in mines, and placer operations as fast as the equipment could be bought and delivered from abroad, and the workforce could be trained to operate it. This effort resulted in a sharp increase in gold production from 1.4 t in 1920 to about 30 t in 1928 and 60 t of gold in 1934 (Leshkov et al. 2000).

Yu. I. Nosyrev, general director of the Darasun Mine in the Transbaikal region in the 1970-1980s, stated in his oral presentation to the Baikal forum (2003) that American mining specialists had been invited to rebuild the mine in 1929. They proposed and planned a project to replace the dozens of existing shallow shafts with four deep ones (up to 500 m), which even now remain the major roadways and ventilation sources for the Darasun Mine. They also constructed a gravity-flotation processing plant (1934) and amalgamation and metallurgical facilities (1936) based on American technology.

According to Littlepage, Josef Stalin himself initiated an increase in gold production at the end of the 1920s and the beginning of the 1930s. He was fascinated by the history of the California gold rush and thought at this increase as a source of funds needed to buy abroad machinery for industrialization of the Soviet Union and to settle the vast undeveloped regions of Siberia and the Far East. Good examples of this settlement policy are gold exploration and the development of gold mines in the Magadan region of the Russian Far East, which led to the construction of the city and port of Magadan and many settlements around gold mines and the centers of placer operations.

It should be noted that the 1930s were marked by the establishment in 1931 of the Dal'stroi Company (or "Thrust"), one of the largest branches of the Gulag archipelago and its largest gold-mining enterprise. It was subordinate to the People's Commissariat of the Ministry of Internal Affairs and used for mining almost exclusively the prisoners of Stalin's labor camps, including many well-known Russian geologists. Dal'stroi's archives lead us to believe that the total "capacity" of these camps did not exceed 200,000 people in 1937 or 1938—the worst years of Stalin's terror. According to these archives, the total number of prisoners up until the closure of all camps in 1956 was under 2,000,000; and the total number who were executed or who died of starvation and illness were about 180,000 (Leshkov et al. 2000). However, these numbers appear to be too low. Robert Conquest estimated that even in the period 1940-1943, total "capacity" of labor camps was at least 300,000-400,000 prisoners (*Kolyma*, 1978), i.e., 50%-100% more than official statistics.

Placer gold and small lode gold deposits were mined by prisoners manually without any machinery. The first steam-driven shovels did not appear until 1940, when gold output in Kolyma region peaked at 77.5 tonnes. It fell by more than half, to 31 tonnes, in 1956 following the closure of Dal'stroi, with its unimaginable forced prisoner labor.

Dean Acheson, the U.S. secretary of state, was invited by Josef Stalin to visit the Kolyma region during the first months of World War II to verify Soviet financial wherewithal for the lend-lease program. He visited a placer operation to watch the removal of gold from washing sluices and was impressed by the amount of gold. Henry Wallace, vice president of the United States, also visited the Kolyma region in 1944 and had the same impression as Acheson. Acheson and Wallace certainly were not informed who had produced the vast amount of Soviet gold to pay for victory in the war against fascism.

The early 1930s were marked by the decision of the Communist Party Politburo to reinstate the institution of prospectors who had been banned as antisocialist elements in the second half of the 1920s. Littlepage described in his book (1938) that by 1933 all plans to put prospectors back to work in the field had been worked out and implemented as rapidly as possible. Regulations to govern relations between prospectors and Gold Thrust were drawn up, setting in motion a Soviet gold rush. To quote Littlepage,

> "The authorities took care that this gold rush should not get out of hand, as those in California and Alaska had done, but should be closely watched and regulated at all times by the Government. In order to supervise and control this gold rush, a new department was set up in the Gold Thrust, called the Prospectors' Department, which was to be given charge not

> only of prospectors but also lessees, or concessionaires, who also been restored to official favor . . . There was a little hesitation at first about going into this work. The Soviet people were "gun shy," as you might say . . . . But the old incentive of get-rich-quick began to exert its familiar pull. Veteran prospectors got back into their old work early and were soon accumulating a lot of money . . . . Within a remarkably short time, the Gold Thrust had several hundred thousand men and women working under the control of its Prospectors' Department. They quickly moved into known areas, where they received marked-off claims, got credit from the Gold Thrust for equipment and expenses during development work, and the technical assistance necessary to get them started. Meanwhile, more adventurous people were being encouraged to push farther afield, into remote areas, which Gold Thrust had not mapped out or explored . . . . Remuneration both for prospectors and lessees was deliberately designed to appeal to man's acquisitive instinct . . . . If a lone prospector or an artel finds a good unmapped deposit, the findings are reported to the gold thrust. The Thrust sends geologists to map the claim and study its possibilities. The lucky prospectors are rewarded up to a maximum of 30,000 gold rubles . . . and receive permission to work the outcroppings of the claim they have discovered for at least one year . . . . And the gold rush proved to be a pronounced success. The push to the east and south into Kazakhstan has continued without any interruptions . . . and penetrated into districts which have perhaps never before been visited by men." (Littlepage 1938, pp. 122-131)

Littlepage's book quoted at such length because this Soviet gold rush of the 1930s has never been described in the Soviet literature and is almost unknown in the West.

Most gold exploration ceased during World War II, with the exception of discoveries of a few lode gold deposits in the Kolyma region, including Natalka (more than 400 t), Pavlik, and other smaller deposits. Intensified gold exploration after the World War II discovered a large number of world-class lode gold deposits (table 1).

This table contains deposits with proven and probable reserves of more than 1.5 million ounces of gold or silver equivalent. A large number of smaller deposits with smaller reserves, but sometimes of very high grade, also were explored after World War II. Good examples of such deposits are the Aginskoye deposit (31 t of gold at 45 g/t) on the Kamchatka Peninsula and the Shkol'noye deposit (20.5 t at 25.4 g/t Au) and the Julietta deposit (23 t of gold at 21 g/t plus about 390 t of silver at 380 g/t) in Magadan Oblast. This list could be much longer and is expanded in the description of CIS gold provinces.

TABLE 1
Major Lode Gold Deposits Discovered in the Former Soviet Union after World War II

Deposit	Region, Country	Gold/Silver resources (t)/ grade (g/t)	Year of discovery
Taseevo[1, 2]	Transbaikal region, Russia	300/15.0	1941-1947
Jilau[2]	Zeravshan region of S. Tien Shan, Tajikistan	102/1.2	1949
Kuranakh[1]	Aldan Shield, Yakut-Sakha Republic, Russia	215/1.08	1950
Nezhdaninskoye	South Verkhoyansk region, Yakut-Sakha Republic, Russia	560/5.0	1951
Bakyrchik[1, 2]	Eastern Kalba, Kazakhstan	409/6.6	1953
Zod[1, 2]	Lesser Caucasus, Armenia	186/6.7	1953
Zun Kholba[2]	East Sayany, Russia	160/18.5	1955
Muruntau[1, 2]	Southern Tien Shan, Uzbekistan	3,416/3.85	1958
Mnogovershinnoye	Sikhote-Alin, Far East, Russia	129.2/9.5	1959
Sukhoi Log	Lensky region of E. Siberia, Russia	1,953/2.1	1960
Malomyr	Amur Oblast, Russia	123.6/2.58	1960s
Akbakai[1]	Zhalair-Naiman zone, Kazakhstan	120/8.5	1960
Kochbulak	Kurama-Chatkal region, Eastern Uzbekistan	74.9/13.4 Au 330/58.9 Ag	1960
Itaka	Mogocha zone of Transbaikal region, Russia	130.5/10.1	1961
Karamken[1]	Okhotsk-Chukotka Belt, Far East, Russia	59/7.9	1964
Daugyz	Southern Tien Shan, Uzbekistan	186/4.0	1964
Kokpatas[1]	Southern Tien Shan, Uzbekistan	250/4.0	1964
Vysokovol'tnoye	Southern Tien Shan, Uzbekistan	100/4.0 Au 3,000/55.0 Ag	1964

Charmitan	Southern Tien Shan, Uzbekistan	210/10.0	1966
Kysylalma[1]	Middle Tien Shan, Uzbekistan	120/6.0	1966
Dukat[1, 2]	Okhotsk-Chukotka Belt, Far East, Russia	14,384/665 Ag 19.87/1.39 Au	1967
Vasil'kovskoye	Kokchetau Massif, Kazakhstan	381/2.4	1968
Khakandzha	Okhotsk-Chukotka Belt, Far East, Russia	50.2/6.9	1968
Chore-Duoba	Southern Tien Shan, Tajikistan	77/2.68	1968
Kyuchus	N. Verkhoyansk region, Yakut-Sakha Republic, Russia	214/9.3	1963-1971
Olimpiada[1]	Yenisey Ridge, Russia	700/4.5	1970
Maiskoye	Chukotka, Russia	277/12	1971
Jerooy	North Tien Shan, Kyrgyzstan	99.8/3.97	1972
Taldybulak Leftbank	North Tien Shan, Kyrgyzstan	93/7.1	1973
Taror[2]	Southern Tien Shan, Tajikistan	84/6.78	1973
Okzhetpes	Southern Tien Shan, Uzbekistan	775/155 Ag 1.75/0.35 Au	1974
Pokrovskoye[2]	Amur region, Russia	76/4.4	1975
Amantaytau	Southern Tien Shan, Uzbekistan	180/3.0	1976
Kumtor[2]	Middle Tien Shan, Kyrgyzstan	458/3.8	1978
Kubaka[2]	Omolon Massif, Magadan Oblast, Russia	80.8/18.0	1979
Ametistovoe	NW Kamchatka, Russia	96/16.0	1980
Svetlinskoe	S. Urals, Russia	100/2.6	1981
Vorontsovka[1]	Middle Urals, Russia	98/4.9	1982
Balka Shirokaya	Ukrainian Shield, Ukraine	112/5.5	1980s
Klintsy	Ukrainian Shield, Ukraine	66/6.3	1980s
Maiskoye	Ukrainian Shield, Ukraine	60/8.3	1980s
Sergeevskoye	Ukrainian Shield, Ukraine	110/8.5	1980s
Yurievskoye	Ukrainian Shield, Ukraine	140/8.5	1980s
Kumroch	Eastern Kamchatka, Russia	120.0/15.2	1987
Veduga	Yenisey Range, Russia	68/6.0	1988
Kupol[2]	Chukotka, Russia	138/16.8 Au, 1,686/205 Ag	1995

[1]—Deposits developed in the former Soviet Union.

[2]—Deposits developed by joint ventures with Western companies.

[1,2]—Development started by the Soviet Union and continuing with Western partners.

Only 12 of the 46 world-class deposits explored after World War II and listed in table 1 had been developed and gone into production before the collapse of the Soviet Union. Four of the 12 (Bakyrchik, Taseevo, Zod, and Dukat) ceased production because of financial problems; the Russian government tried to start up production again in the 1990s with the participation of Western mining companies. Development of six other deposits (Kumtor, Kubaka, Taror, Pokrovskoye, Zun Khalba, and Jilau) did not become possible until the 1990s, when Western mining companies were given access to the CIS. Lack of funds prevented the Soviet mining industry from developing even such huge deposits as Sukhoi Log and Nezhdaninskoye. Operations at the Olimpiada deposit were started in 1996 by the Polyus Mining Association (a closed joint-stock company or *artel* in Russian), which became the most profitable gold producer in the CIS.

The situation in the gold-mining industry took a turn for the better, at least in Russia, with the arrival of the new millennium. The Russian mining giant Norilsk Nickel, one of the largest producers of copper, nickel, and platinum group of metals in the world, acquired the Polyus Mining Association and increased annual gold production from the Olimpiada deposit from 12-15 t to 25 t in 2002. The Polyus Gold Company became the largest gold producer in Russia.

Two achievements of Soviet gold exploration after World War II should be mentioned. The first was the prediction of high potential for volcanic gold and gold-silver deposits of the Mesozoic-Cenozoic volcanic-plutonic belts of the Russian Far East at the end of the 1950s. This prediction was based on the similarity of geological structures of the volcanic-plutonic belts surrounding the Pacific Ocean and on the presence of large volcanogenic gold-silver deposits along the coasts of North and South America. In the 1960s the intensification of gold exploration of the Okhotsk-Chukotka and Sikhote-Alin (Primorsky) belts led to the discovery of the largest silver deposit in Russia, the Dukat deposit, and of a few gold-silver deposits such as Karamken, Khakandzha, Mnogovershinnoye, Lunnyi, and recently the Kupol deposit.

The second achievement—exploration of veinlet-disseminated deposits within sedimentary host rocks—had its roots in successful exploration of Carlin-type gold deposits in the United States. Work on the so-called “black-shales problem” by industrial and scientific entities of the Soviet

Ministry of Geology in the 1970s resulted in the discovery of the large Olimpiada, Maiskoye, Kyuchus, Daugyz, and Kumtor gold deposits, with gold reserves of 200-650 t each, as well as many smaller ones. Most of these deposits are not similar to the Carlin type (except Kyuchus, which has typical gold-mercury mineralization), but this fact does not diminish the success of the program. Actually, no close analogues of a large sedimentary-hosted gold (arsenic)-sulfide deposits such as Olimpiada, Daugyz, or Maiskoye are known in other gold provinces of the world except the Donlin Creek deposit in Alaska.

The political and financial instability during perestroika (1985-1990) and the subsequent breakup of the former Soviet Union in 1991 resulted in the almost-complete cessation of gold exploration and in the disintegration of the previously well-developed state geological survey. Numerous reorganizations of this undertaking in CIS countries were aimed at cutting government spending and transferring exploration to the mining companies. The idea was well intended. Unfortunately, the mining companies were in no hurry to spend their profit on exploration. The very low salaries of geologists on the payroll of the Russian Ministry of Geology, later the Ministry of Natural Resources, resulted in the loss of young specialists. They simply could not support their families on less than a living wage, and looked for any opportunity outside of geology. The same process took place in the geological surveys of all other CIS countries. Not a single new gold deposit has been discovered there since the second half of the 1980s.

Weakening of the secrecy that started with perestroika and the first attempts to welcome foreign investment to improve the economic situation, particularly in the exploration and mining industry, attracted Western mining companies to explore the possibilities of a vast new region with enormous gold resources. In the early 1990s, many major American, Canadian, and Australian mining corporations (Newmont, Placer Dome, Barrick Gold, Cyprus Amax Minerals, BHP Minerals, Lonhro, Gencor, RTZ Mining, Phelps Dodge, Cameco, etc.) sent exploration teams to CIS countries and set up offices in the capitals of Russia, Kazakhstan, Uzbekistan, Kyrgyzstan, and Tajikistan. Relatively smaller mining companies (Morrison Knudsen, Santa Fe Gold, FMC Gold, Kinross Gold, ASARCO, Echo Bay, Homestake, Teck Resources) and dozens of exploration junior companies (Orvana, Celtic Resources, Nelson Resources, High River Gold, Western Pinnacle, Arian Resources, Steppe Gold) were even more active. All the companies listed above and many others as well concluded joint-venture agreements with CIS partners for gold exploration or development of known gold deposits, but few of them continue to work on their CIS projects.

The first successful Western project involves recycling of low-grade (0.034 oz/t) ore dumps at the Muruntau deposit in Uzbekistan by the Newmont Mining Corporation through the Zeravshan-Newmont joint venture. About 165 million tonnes of ore dumps have been heap-leached and about 2.8 million ounces of gold extracted. The first gold from the joint-venture project, which was established in 1992, was cast in June 1995. Annual output of the Zeravshan-Newmont JV varied between 12 and 15 t of gold. In 2002 it achieved gold production of 16 t. Unfortunately, the recent attempt by the Uzbek government in 2006 to unilaterally revoke their investment and tax-stabilization agreement and collect $48 million in disputed tax payments from Newmont led to halt of operations and eventually to the collapse of this successful joint venture, which could have operated for at least 5 more years.

In 1994 Cyprus Amax Minerals Co. concluded a joint-venture agreement with a local Russian company for development of the Kubaka deposit in Magadan Oblast (Russia). The construction of a processing plant and all supporting structures at the very remote location (500 km to the city of Magadan by winter roads or by air) was completed in record time at the end of 1996. The Omolon Gold Company produced the first gold in the first quarter of 1997. The Kinross Gold Company of Canada, which acquired this project in 1998, had annual production of up to 13.5 t of gold in 2001 and mined out the deposit in 2007 with total gold output of about 90 t.

One of the largest joint ventures concluded in 1992 was between Canadian Cameco Corporation (recently Centerra Gold Co.) and the Kyrgyz government for the development of the Kumtor deposit by the Kumtor Gold Co. The first gold production came at the start of 1997, and annual gold production since then has been 16-18 t.

Another Canadian mining company that has been successful in Russia is Bema Gold, which in 1998 merged with Arian Resources Corp. and acquired a 75% of interest in the Julietta deposit in Magadan Oblast, Russia. The mine began production in 2001 at a total operating cost of

$100/oz. Bema Gold has become so comfortable with the Russian political and economic climate that it not only has continued development of the Julietta deposit but also has started exploration in two new regions. On December 2002, Bema signed an agreement with the government of Chukotka region to explore a high-grade gold and silver prospect named Kupol for a 75% future interest in this project. In 2006, Bema started development of the Kupol deposit but merged in 2007 with Kinross Gold Corp. of Canada, which is expecting to produce the first gold in 2008. Bema also was prospecting for gold-platinum mineralization in Karelia at the Russian-Finnish border.

Since 1996, High River Gold Mines Ltd. of Canada has owned a stake of about 29% in the Buryatzoloto Joint-Stock Company of the Buryat Republic (Russia), which has mined two gold deposits—Zun Khalba and Irokinda. From 1996 to 2001, the total gold output of Buryatzoloto was in the range 2.4-3.0 t/yr. Gold production could be increased to approximately 6.0 t per year once the mining equipment is upgraded and a carbon-in-pulp processing plant has been built.

Peter Hambro Mining of Great Britain, which has a 98.6% interest in Pokrovskiy Rudnik (Amur Oblast), produced 96,000 ounces of gold in 2001. The company increased production to 267,000 ounces of gold in 2006 due to increase of processing capacity at the Pokrovskiy Rudnik and joint venture with the Susumanzoloto of Magadan region to underground mine the Shkol'noye deposit and Berelekh alluvial placer. It has started feasibility studies for the Pioneer, Malomyr, and Tokur gold deposits in the Amur region and explored possibilities in the Chita region.

In 1994, Nelson Gold Corp. of Canada joined with International Finance Co. of the UK and the government of Tajikistan and formed the Zeravshan Gold Co. to operate the Jilau deposit. The first 1.6 tonnes of gold from the open-pit operation were produced in 1996, and since then production has been about 2-2.4 t annually. Since 2003 this project has belonged to the Avocet Mining Ltd. of Great Britain, which sold it in 2007 to the Xin Jiang Zijin Mining Co., subsidiary of Hong Kong's listed Zijin Mining Co.

In 2002, Celtic Resources Holdings PLC of Great Britain began operations at its wholly owned Suzdal and Zherek deposits in Kazakhstan, producing about one ton of gold. The company is pursuing several gold, copper, and molybdenum exploration targets in Kazakhstan and Russia. In 2003 Celtic Resources recovered its interest in the Nezhdaninskoye deposit (Yakut-Sakha Republic), which it had lost a few years before, but in February 2006 sold its stake to the Polyus Co., Norilsk Nickel's gold subsidiary, for $80 million.

In 2001, the Australian-based mining group Danae Resources NL, through its subsidiary Multiplex Mining Pty Ltd., was selected by the government of Uzbekistan as the exclusive partner for development of the multimillion-ounce Charmitan (Zarmitan) deposit. Uzbek authorities terminated a previous agreement with the Australian WMC, which had held a license for the deposit since 1996 but failed to produce a final feasibility study and tried to freeze the project until a better gold price came about.

Another example of persistence in dealing with local government is the Oxus Mining PLC of Great Britain. Founded in 1996, Oxus has established a good relationship in Uzbekistan and acquired a solid portfolio of gold and base metals projects in Uzbekistan and Kyrgyzstan. In 2001 the company raised U.S. $8 million for the Amantaytau open-pit gold project in Uzbekistan. Further, Oxus has three more feasibility-stage projects: the Amantaytau underground project (phase II) and the Khandiza zinc-silver project, both in Uzbekistan, and the Jerooy gold project in Kyrgyzstan. The Amantaytau and Jerooy gold deposits have a list of Western mining companies (Lohnro and Cameco for Amantaytau and MK Gold and Cameco for Jerooy) that have unsuccessfully tried to develop them. Oxus continues mining of the Amantaytau and located nearby the Vysokovol'tnoye deposits but as its predecessors lost the license for the Jerooy deposit.

The success of most of the Western mining companies mentioned above shows that there are still opportunities in the CIS for the development of sound gold projects.

The history of gold exploration in the CIS has yet to run its course. Traditionally, CIS gold exploration has not paid attention to mineralization unless the gold grade exceeded 3 g/t. The current increase in gold price combined with open-pit mining and heap-leach ore processing could permit many explored deposits to be brought into development. The existing scientific mind-set in the CIS has not allowed granite-hosted deposits such as Fort Knox in Alaska to be explored for gold, because this environment was believed to only have potential for rare-earth elements. In addition, many inaccessible regions of the Russian North and Far East, as well as the mountains of Central Asia, could conceal unexpected new discoveries of gold. With the experience and methods widely used by Western mining companies, gold exploration in the CIS could be revitalized for the discovery of many new deposits.

2

CLASSIFICATION OF GOLD AND GOLD-SILVER DEPOSITS

To make the classifications useful for the purposes of exploration, Russian geologists, including TsNIGRI specialists[3], have used a more detailed geological description of the mineralogical types of gold deposits, coining the term "geological-industrial type of deposit." For example, the gold-sulfide-quartz mineral type of polymetal-gold formation of plutonogenic deposits usually is defined as "veins and stockworks of moderate-sulfide ore within intrusive and sedimentary-volcanogenic complexes."

In this book, the author has tried to use as much objective data as possible to classify CIS gold deposits and in principle has followed the approach outlined above, with some changes and additions (table 3). First of all, it is impossible to use the term "formation or formation type" for gold deposits, as in the Western geological literature the term "formation" usually is applied to stratigraphic units. Secondly, the geological type of deposits must be defined mainly by their relation (or the absence thereof) to intrusive and volcanic series and to the geotectonic/geological setting of the deposits, including the shape of the ore bodies. As will be shown later, the mineralogical-geochemical type of mineralization often could be the same for different geological groups of deposits.

The diverse geological and tectonic settings of lode gold deposits, together with diversity of the mineral composition and shape of the ore

[3] In the 1980s the author participated in the development of the TsNIGRI gold deposit classifications (Konstantinov et al. 1986, 1990).

bodies, can make their classification in the CIS, as well as elsewhere in the world, either too general or too detailed. Examples of the first approach are based on the origin of gold deposits, such as hydrothermal, magmatic, and metamorphic, or on the depth of their formation: near-surface (≥1.5 km), medium-depth (1.5-4.0 km), and deep-seated (>4.0 km; Smirnov 1969, 1977). Groves et al. (1998) similarly subdivided gold deposits into epizonal (<6 km), mesozonal (6-12 km), and hypozonal (>12 km). A very interesting global synthesis of orogenic gold deposits by Goldfarb and coauthors (2001, 2005) is another example of a general approach, with emphasis on the genesis of gold deposits in different geotectonic settings.

Detailed classifications widely used in the CIS are based mainly on mineral associations and the amount of sulfides typical of different gold deposits. Such classifications distinguish groups or types of deposits such as gold-quartz, gold-chalcedony-quartz, gold-quartz-sulfide, gold-sulfide, gold-silver, and gold-aluminosilicate (skarn) with large numbers of mineralogical associations or subtypes (see Petrovskaya 1960; Timofeevsky 1971; and Sher 1972).

V. M. Kreiter (1940) offers a more practical approach to the classification of endogenic gold deposits based on the shape of ore bodies, their geological setting, and the type of mineralization. He subdivided gold deposits into a few "industrial" types: (1) auriferous conglomerates within Precambrian metamorphic formations, (2) gold-quartz veins and vein zones within different rock formations, (3) veinlike and complexly shaped gold deposits within young effusive formations, and (4) stockworks with veinlet-disseminated gold mineralization within different rock formations.

R. W. Boyle (1979) also classified gold deposits mainly by the type of ore bodies (auriferous dikes, sills, and stocks versus veins, stockworks, or disseminated gold deposits) in different geological terrain (volcanic, sedimentary, and igneous) and different traps (fractures, faults, shear zones, etc.).

Similar classifications have been widely adopted recently in the CIS and combined similar mineralogical groups of gold deposits with their geotectonic settings and their connection to intrusive, volcanic, or sedimentary (amagmatic) formations. A typical example of such classification (Narseev and Kurbanov 1989; and others) is shown in table 2.

TABLE 2
Systematization of Gold-Ore Deposits (TsNIGRI, 1989)

Formation of gold deposits (formation type)	Subtypes of formations	
	Subformation	Quasi Formation[4]
Late Proterozoic—Phanerozoic Gold Ore Formations		
Polymetallic—gold plutonogenic (granitoid) type of eugeosynclinal and mesogeosynclinal orogenic systems and regions of tectono-magmatic activization[5]	Gold—sulfide—quartz Gold—skarn	Gold—carbonate (jasperoid) Gold—feldspar—quartz (gold—porphyry)
Gold—silver volcanogenic type of volcano-plutonic belts and continental rift systems	Gold—adularia—quartz Gold-telluride—adularia—quartz Gold—silver—adularia—quartz	Gold—quartz—hydromica
Gold—carbon polygenetic—metamorphic type of terrigenous mio- and mesogeosynclinal folded and orogenic systems	Gold—sulfide, Gold—quartz (carbonate)—sulfide Gold—silver—quartz-sulfide Gold—quartz	Gold (antimony)—quartz
Gold—mercury metamorphogenic-plutonogenic (ultrabasite) of ophiolite belts	Gold—calc—silicate Gold—mercury	
Early Precambrian Gold Formations		
Gold—iron, volcanogenic-ultrametamorphic type of granite—greenstone belts, ancient shields Gold—uranium, exogenetic-metamorphic type of Protoplatform		

4 Quasi Formation, by the authors of this table, are sporadic or new industrial types of gold deposits requiring further evaluation.

5 The term “activization in Russian geological literature is broadly used and has a specific meaning (see appendix II).

Classification of the Archean and Early Proterozoic gold deposits of ancient shields in the CIS (table 3) is tentative. The occurrences of such mineralization in the Aldan shield of the Siberian platform or the Ukrainian shield of the east European platform are not well explored and in many cases do not have proven or economic reserves. At least part of this mineralization may be a result of the regeneration of ancient shields during Paleozoic or even Mesozoic tectonic and magmatic activity. Such regeneration is known on the Aldan shield and has hampered identification of possible Archean gold mineralization.

Like any other existing classification of gold deposits, this one cannot cover their full variety. The author has concentrated on the main types of deposits that have a significant role in CIS gold production or have a good potential for future production.

TABLE 3
Classification of the CIS Gold and Gold-Silver Deposits

Geological Type	Mineralogical-Geochemical Type	Examples of Deposits
ARCHEAN—EARLY PROTEROZOIC DEPOSITS OF ANCIENT SHIELDS		
1. Zones of veinlet—disseminated gold mineralization in Archean granite-granulite series	Gold—sulfide—quartz	Maiskoye, Kapitanovskoye
2. Gold mineralization in Archean greenstone belts Mineralized zones of jaspilite Vein and veinlets zones related to felsic volcanics and subvolcanic bodies	 Gold—jaspilite Gold—sulfide—quartz	 Balka Shirokaya Sergeevskoye, Balka Zolotaya
3. Early Proterozoic fault-related linear zones of veinlet-disseminated gold mineralization	Gold—sulfide (arsenic)—quartz	Klintsy, Yurievskoye

Late Proterozoic—Phanerozoic Deposits		
Geological Type	**Mineralogical-Geochemical Type**	**Examples of Deposits**
SEDIMENT—HOSTED GOLD AND GOLD-SILVER DEPOSITS		
1. Vein zones, megastockworks, and zones of veinlet-disseminated gold mineralization in metamorphic sequences	Gold—quartz Gold—feldspar—carbonate—quartz Gold—quartz (carbonate)—sulfide Gold (arsenic)—sulfide	Sovetskoye Kumtor, Muruntau Sukhoi Log Bakirchik, Daugyztau, Maiskoye, Nezhdaninskoye, Olimpiada
2. Zones of veinlet-disseminated and vein gold mineralization in black-shales and carbonate-terrigenous formations	Gold—mercury—quartz (Carlin type) Gold—antimony—quartz	Kyuchus, Vorontsovka Sarylakh, Sentachan, Uderey
3. Stockworks and zones of veinlet-disseminated gold-silver mineralization in sedimentary and carbonate-sedimentary formations	Gold—silver—quartz—sulfide	Vysokovol'tnoye, Kosmanachi, Okzhetpes
INTRUSIVE-RELATED GOLD DEPOSITS OF ISLAND ARCS AND OROGENIC SYSTEMS		
1. Stockworks and veinlet-disseminated mineralization in granitoid plutons	Gold—feldspar—quartz (gold—porphyry)	Vasil'kovskoye, Jilau, Yubileinoye
2. Vein-type deposits in granitoid intrusives and their host rocks	Gold—quartz Gold—sulfide (arsenic)—quartz	Jerooy, Natalka, Shkol'noye Kochkar, Beriozovsk, Darasun, Central (Tsentralny)
3. Lenses and irregular bodies in skarn along intrusive contacts with carbonate or volcanic-sedimentary formations	Gold—aluminosilicate (skarn)	Natal'yevskoye, Sinyukhinskoye, Makmal, Taror, Kuru-Tegerek

Geological Type	Mineralogical-Geochemical Type	Examples of Deposits
VOLCANIC-RELATED GOLD AND GOLD-SILVER DEPOSITS OF VOLCANO-PLUTONIC BELTS AND CONTINENTAL RIFT ZONES		
1. Veins, stockworks, and breccia pipes of gold-telluride mineralization associated with basalt-andesite-dacite volcanics	Gold—telluride—adularia—quartz (alkalic—related)	Aginskoye, Zod, Kochbulak, Mnogovershinnoye, Ozernovskoye
2. Veins, stockworks, and metasomatic bodies of epithermal gold mineralization associated with andesite-dacite (rhyolite) volcanics	Gold—adularia—quartz (high—sulfidation)	Kubaka, Pokrovskoye, Karamken, Baley-Taseevo, Kuranakh
3. Veins and stockworks of gold-silver mineralization associated with andesite-rhyolite magmatism	Gold—silver—adularia-rhodonite-quartz (low-sulfidation)	Dukat, Lunnyi, Khakandzha

This classification serves a quite utilitarian purposes: (1) to help Western geologists better understand their Russian counterparts, (2) to provide information on the CIS gold deposits for use in global comparisons, and (3) to serve as a preliminary guide in the search for possible new discoveries.

In the description of CIS gold deposits that follows, the author will provide information to support each of the listed geological and mineralogical types of gold deposits. However, some gold deposits could combine different types, some were formed over a rather geologically long time, and some deposits have heterogeneous sources of gold.

3

ARCHEAN AND EARLY PROTEROZOIC DEPOSITS

World gold reserves for this group of deposits make up approximately 50% of total gold reserves and at least 25% of world gold production. Even without the gold-bearing Proterozoic conglomerates of Witwatersrand, which account for most reserves and production, Archean and Early Proterozoic gold deposits within the ancient shields of Africa, North and South America, Australia, and India contain about 7 to 8% of total world gold resources (Sher 1972; Nekrasov 1988; Kulish 1994).

Geological setting and major features of the Siberian and East European platforms and their shields have some similarity to those of Canadian, Indian, and Australian cratons. This serves as the basis for the quite high estimate of the gold potential of the ancient shields in the CIS and for many years of exploration efforts by Soviet geologists and scientists. The numerous attempts to find world-class Archean and Proterozoic gold deposits did not succeed until the middle of the 1980s, despite the large area occupied by the Aldan shield of the Siberian platform and by the Baltic and Ukrainian shields of the East European platform. This can be explained partly by the almost-complete cover of the Ukrainian shield by at least 50-200 m of Paleogene-Quaternary sediments and by the very intensive Mesozoic tectonic and magmatic activity within the Aldan shield. These circumstances masked Archean and Proterozoic mineralization and made exploration a fairly difficult undertaking. The only exception was the well-exposed Kola part of the Baltic shield, but at of the turn of the new millennium exploration had not identified any world-class gold deposits there.

Soviet geologists focused exploration efforts on gold-bearing Proterozoic conglomerates, jaspilite formations, and gold deposits of Archean greenstone belts typical of other cratonic structures of the world. Late Archean and Proterozoic conglomerate horizons of protoplatform and protoorogenic formations are widespread within trough—and synclinelike structures of the East European platform. These horizons are usually less than a few hundred meters thick. Thorough examination of most known conglomerate sections accessible for exploration did not reveal any important concentrations of gold (Zhadnova et al. 1973), and the possibility of finding another Witwatersrand in the CIS is doubtful.

Precambrian jaspilite formations of the East European platform have higher potential for the discovery of small- and medium-size gold deposits similar to Copperhead and Hill 50 (Australia), Morro Vellio (Brasilia), and others. Gold showings of this kind were found (Zhadnova et al. 1973) during the 1960s and 1970s within the Ukrainian shield, the Voronezh crystalline massif, and the Kola part of the Baltic shield. Gold-bearing jaspilites were found within the Krivorog-Kremenchug zone of the Ukrainian shield and in the region of the Kursk Magnetic Anomaly. Zones of sulfidization and silicification of jaspilite with a relatively high gold grade make up most of these showings, but their gold grades were too low to be of economic interest.

Precambrian gold exploration took a giant step forward in the 1980s when Ukrainian geologists found gold-bearing zones in different parts of the Ukrainian shield. The shield, which is located in the southwestern part of the East European platform, is an Archean craton consisting of the Volynsky, Dnestr-Bug, Kirovgrad, and Dnepr blocks (Scherbak et al. 1983) that are separated by Archean-Proterozoic mobile zones (Fig. 2). The classification of Archean-Early Proterozoic gold deposits shown in table 3 and their descriptions below are based on numerous articles published in Ukrainian geological journals and proceedings of scientific conferences during the 1990s.

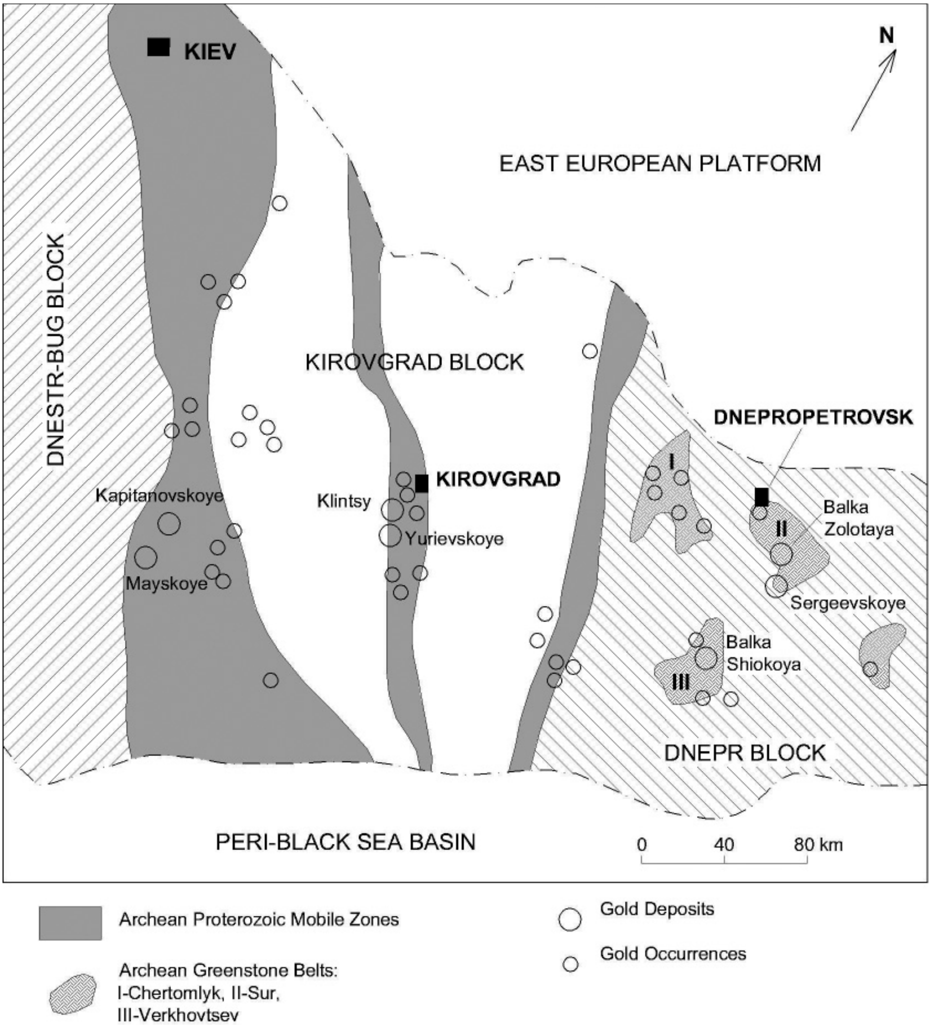


Figure 2. Distribution of gold mineralization within the Ukrainian shield.

3.1 ZONES OF VEINLET-DISSEMINATED GOLD MINERALIZATION IN ARCHEAN GRANITE-GRANULITE SERIES

3.1.1 Gold-Sulfide-Quartz Deposits

Veinlet-disseminated gold mineralization in highly metamorphosed crystalline rocks present in the Dnestr-Bug block in the western part of the

Ukrainian shield is similar to relatively small deposits such as the Renko deposit in Archean granulites of Zimbabwe or the Kvanyan deposit in granite gneisses of South Korea (Nekrasov 1988).

The Dnestr-Bug block consists of an Archean granulite-migmatite metamorphic stratum, basic-ultrabasic intrusives, and crystalline schist and gneiss. Chemical composition and distribution of rare-earth elements indicates that the basic-ultrabasic igneous rocks are possible products of the depleted upper mantle. Archean and Early Proterozoic ultrametamorphic and intrusive granites of both type I and S series are broadly distributed within this block.

The Late Archean-Early Proterozoic rocks of the Bug series consist (Yaroschuk et al. 1994) of calc-silicate marbles, ferrosiliceous rocks, and high-aluminum gneiss with subconcordant ultramafic and metaultramafic bodies. These sequences are in depressions separated by uplifts of the Early Archean basement and Proterozoic granitoid plutons. All rocks are metamorphosed to the amphibolite grade of the granulite facies and have undergone intensive granitization and retrograde metamorphism within fault zones.

Most of the gold deposits and occurrences are concentrated (Koval' et al. 1997) in the Golovanevskoye and Savranskoye ore fields. The first includes the Kapitanskoye, Demov'yarskoye, Golovanevskoye, and Chausovskoye occurrences, which are confined to the uplifted block in the central part of the Golovanevsk gneiss-granulite terrane. The second ore field, Savranskoye, is located in the Sinitsevsky block, which is separated from the Golovanevsky block by regional faults and includes the Maiskoye, Savranskoye, Koshar-Aleksandrovskoye, Bogdanovskoye, Chemirpol'skoye, Polyanetskyoe, and Bashkinskoye prospects.

Zones of vein/veinlet-disseminated gold mineralization of gold-quartz-sulfide type are hosted within tectonic structures with intensive metasomatic alteration of the host rocks. Alteration includes amphibolization, silicification, skarn mineralization, and development of sillimanite-mica-quartz-feldspar assemblages in rocks of the Bug series.

The Maiskoye Deposit (48°08'N-30°07'E)

The Maiskoye deposit is the largest one, which has been explored in detail by a combination of drilling and underground workings, and is a good example of gold mineralization within the granite-granulite series. This deposit is located in the center of the Savransk ore field originally known for its skarn-type nickel-gold mineralization. The Chemerpol'skoye and Kapustyanskoye gold occurrences lie to the north and south of Maiskoye. Less-studied gold occurrences such as Polyanetskoye, Zaval'evskoye, and Bakshinskoye are located in the western part of the Savransk ore field, while the Bogdanovskoye and other occurrences are found in its eastern part, separated by a distance of some 3-5 km (Koval' et al. 1997). Graphite and iron mineralization are also present within the ore field.

The Savransk ore field is located at the western margin of the Belotserkov mobile tectonic zone (figure 2) and is controlled by subparallel, NNW-striking and west-dipping branches of the Odessa regional fault (Nechaev 1992; Nechaev et al. 1994). Gold-sulfide mineralization within the ore field is concentrated at the intersections of NE and NW tectonic structures and is usually located at the periphery of ultramafic intrusive bodies, which have experienced skarn alteration. Core sampling shows that the nickel-bearing skarn here contains up to 1 g/t of gold.

Gold mineralization with variable grades and uneven distribution is found within steeply dipping crushed zone[6]. The host rocks for veinlet-disseminated gold mineralization consist of amphibolite (up to 10%), plagioclase-biotite gneiss (about 30%), migmatite and plagioclase granite (30%), and pegmatite granite (20%), which form conformal injections within the amphibolite-gneiss-migmatite matrix. The radio isotopic age of zircon in the plagioclase gneiss is 2.7 Ga; the most likely time of metamorphism in migmatite is 2.2 Ga, while the age of the granitoids varies between 2.2 and 1.9 Ga. Gold mineralization has been dated to 1.85-1.86 and 1.625-1.615 Ga, respectively (Nechaev et al. 1994).

The amphibole-rich gneissic rocks, up to 80 m thick, found on margins of the ore zones. In addition to amphibole (sometimes up to 95%), these rocks contain quartz, biotite, plagioclase, and ore minerals such as magnetite, ilmenite, pyrrhotite, pyrite, chalcopyrite, and sphalerite.

The amphibole zones contain later quartz-biotite-sericite alteration, which forms numerous steeply dipping zones with variable amounts of

6 Unfortunately, the author could not find any published geological map of the Maiskoye deposit.

biotite (60-90%) and quartz (7-40%). Silicified and sericitized wall rocks containing over 0.01 g/t of gold (Koval' et al. 1997) are up to several tens of meters thick, but zones with gold grades over 0.1 g/t have a thicknesses of just 2-3 m.

Ore bodies of the Maiskoye deposit, up to several meters thick, are cataclastic shear zones with elevated amounts of hydromica, chlorite, carbonate, and sulfide mineralization. They are confined to steeply dipping, pipelike ore shoots, and fold's flexures. One of the ore zones has been traced (Koval' et al. 1997) more than 1.2 km along the strike and to a depth of 350-370 m.

Pyrrhotite, pyrite, sphalerite, chalcopyrite, molybdenite, galena, electrum, sulfoarsenides (loellingite, gersdorffite, rammelsbergite), native gold, and tellurides of gold, silver, and bismuth are main ore minerals. Realgar, bornite, wurtzite, acanthite, and native bismuth and silver also are found in the ore bodies. A gold-bearing mineral association of chalcopyrite-sphalerite-pyrrhotite-pyrite-gold ± telluride occurs, usually along the contact between amphibolite and pegmatoid granite.

Drill holes have revealed about 80 intersections of ore, 23 of which contain visible gold as flakes and irregular grains up to 1-2 mm in size in a granitoid matrix, as smaller particles in quartz or as rims around sulfide minerals. Nechaev (1992, 1994) has described irregular segregations of gold up to 12 mm in length along cleavage in biotite. Gold fineness ranges from 150-400 to 980-992, with admixtures mainly of silver and up to 0.3% copper, antimony, and mercury.

The average gold grade of 7-8 g/t increases at the intersections of subnortherly shear zones with northeasterly fractures and forms ore shoots. A 4.2 m thick ore shoot with gold grade of 139 g/t, containing a 1 m interval with a grade of 328 g/t, was intersected during drilling (Koval' et al. 1997). Identified gold resources at the Maiskoye deposit are about 7.23 million tonnes of ore, with an average gold grade of 8.3 g/t, or some 1.94 Moz (60 t) of gold.

Strong halos of Ni and Cr at gold-bearing intervals may be a good exploration guide. Such halos are associated with thin impregnations of millerite, nickel-bearing pyrite, and Cr-rich magnetite and are formed during quartz-biotite alteration of the host rocks.

The presence of moissanite (carborundum) in bonanza gold ore, gold-tellurium compounds (calaverite), tellurium bismuthinite, and native tellurium suggest that deep (mantle?) fluids were involved in the ore deposition (Yatsenko et al. 1998).

The gold mineralization of the Kapitanskoye occurrence to the northwest of Maiskoye has similar geological setting and mineralogical-geochemical composition, except for the presence of arsenopyrite in the gold-bearing association.

The metamorphic-metasomatic character of gold mineralization in the granulite series of the Dnestr-Bug block has resulted from several stages of gold remobilization (Koval' et al. 1997). The initial gold mineralization is related to the high-temperature formation of ferromagnesian skarn upon calc-silica marble and ultrabasic rocks. The age of this early skarn stage, according to the uranium-lead data, was 2,050 ± 62 Ma, i.e., close to the emplacement of the potassic granitoids.

Gold remobilization occurred in a later stage, which is characterized by lower temperatures and pressures but an elevated acidity, sulfur and oxygen partial pressures, and the H_2O/CO_2 ratio. The products of this stage are close in age (1,963 ± 100 Ma) to the intrusion of aplite-pegmatite tourmaline granite and correspond to an intermediate depth (T = 430-250°C and P = 3.5-1.0 MPa). They are widespread at the Maiskoye deposit and contain most of the coarse-grained recrystallized gold particles with the highest fineness. The process of gold remobilization was concluded during the late, low-temperature, alkaline stage, which resulted in carbonatization, chloritization, and low-temperature silicification resembling argillization in local fracture zones.

3.2 GOLD MINERALIZATION IN ARCHEAN GREENSTONE BELTS

Gold deposits of the Archean greenstone belts are a major type of gold mineralization worldwide and include such world-class deposits as Kolar (India), Porcupine and Hemlo (Canada), and Kalgoorlie (Australia), with huge reserves of up to 1,300 tonnes of gold, and many deposits with smaller reserves. Similar greenstone belts with gold mineralization are known in the eastern part of the Ukrainian shield in the Dnepr block (figure 2). Elongated fragments of the Late Archean greenstone belts with calc-alkalic, tholeiite, and shoshonite island-arc volcanic series as well as gabbro-tonalite and tonalite-plagioclase granite intrusive series (Galetsky 1998) are located between large granite-gneiss domes. At least four greenstone structures in the central part of the Dnepr block, specifically the Chertomlyk, Sursk, Verkhovtsev, and Belozersk, have gold occurrences.

The fragments of greenstone structures contain gold mineralization that associated with ferruginous quartzite in basalt-jaspilite formations and with vein-veinlet zones related to felsic volcanics and subvolcanic bodies. A few gold occurrences are related to intrusive bodies of the dunite-peridotite and dunite-pyroxenite-gabbro series (Koval et al. 1997), but these are poorly studied.

3.2.1 Mineralized Zones of Jaspilite

Gold-bearing mineralized zones of jaspilite are known in the Chertomlyk (the Balka Shirokaya deposit and Kirov occurrence) and Sursk (the Yuzhno-Petrovsk occurrence) greenstone fragments. The description of this type of mineralization is based mainly on exploration of the Balka Shirokaya deposit (Esipchuk et al. 1992; Pet'ko et al. 1994; Fomin et al. 1994; Koval' et al. 1997).

The Chertomlyk structure is the southern fragment of a 160 km long and 30-70 km wide northerly greenstone belt and is composed of volcanic and volcanic-sedimentary sequences forming an NNW-oriented syncline. The lower section of the syncline consists of metavolcanic andesite-basalt and ultrabasic intrusive series. The middle part is made up of tholeiite basalt, komatiite, ferruginous cherts, and schists. The upper section of the syncline contains metavolcanic dacite-andesite-basalt and rhyolite-dacite formations intruded by subvolcanic bodies of blue-quartz, potassium-low granite (plagiogranite in Russian terminology). The average isotopic age of these rocks is 3,150 ± 35 Ma (Koval' et al. 1997). All these units belong to the lower part of the steeply dipping Late Archean Konsk series that underwent greenstone facies regional metamorphism and now has chlorite, carbonate-chlorite, actinolite, talc-chlorite, sericite-quartz, carbonate-chlorite-quartz, and other schist's varieties.

The gold-bearing jaspilite basalt formation consists of ferruginous quartzite, quartz schist, ferruginous silicate rocks, metamorphosed tholeiitic and komatiitic volcaniclastics, as well as metadolomite, marble, and carbonatite.

The Balka Shirokaya Deposit (47°47'N-34°20'E)

The Balka Shirokaya deposit is located in the northeastern part of the Chertomlyk greenstone fragment, where a tonalite-greenstone series is complicated by a northerly-trending regional fault. The basement of this structure consists of potassium-low granite and amphibolite. Gold mineralization is mainly within the middle section of the greenstone belt, where chlorite-quartz-carbonate schists and sericite-quartz schists, metabasites, and metaandesites alternate with horizons and lenses of ferruginous quartzite. Metadolerite, metagabbro, and metadiorite sills and dikes are known within the deposit area.

The Balka Shirokaya deposit is located at the intersection of NW—and NE-striking faults in the eastern and northern flanks of the greenstone belt. The ore-controlling, East Chertomlyk, fault contains shear, brecciation, and mylonite zones subconcordant with the host rocks and crossed by numerous fractures running in different directions. Host rocks within the fault zone and along fractures underwent extensive hydrothermal and metasomatic alteration resulted in development of quartz, carbonates, sericite, fuchsite, chlorite, albite, magnetite, and pyrite. In Russian terminology, such type of alteration is considered as listwanite-beresite series.

Gold mineralization is concentrated within steeply dipping zones of intense alteration forming subparallel northwest-striking zones 2-80 m wide that can be traced up to 2-3 km along the strike and 500-600 m downdip. Lenticular and bedlike bodies of ore-bearing jaspilite ranging from 1 meter to 20 meters thick alternate with quartz-albite-sericite and quartz-sericite-carbonate-chlorite schist and massive metabasic intrusive rocks (Fig. 3). The jaspilites near the ore bodies are quartz and sulfide-rich and contain Mn-rich siderite and ankerite, as well as calcite and Fe-rich chlorite.

The principal mineral assemblages of the gold ore are gold-pyrrhotite-pyrite-arsenopyrite, gold-pyrite-pyrrhotite-arsenopyrite-sulfosalt-polymetal, and gold-quartz. The first is concentrated in jaspilite and consists of quartz, sideroplesite [(Fe, Mg)CO_3], dolomite, pyrrhotite, chalcopyrite, pyrite-marcasite, arsenopyrite-loellingite, and small amounts of sphalerite, galena, Fe-rich tetrahedrite, and native gold. Fine-grained gold is concentrated in pyrite (4-2,100 g/t) but often is associated with other sulfides. Native gold forms 5-200 μm inclusions in quartz, carbonate, pyrrhotite, and magnetite. The gold distribution in such ores is irregular, ranging from a few grams per tonne to 20-40 g/t in some intervals.

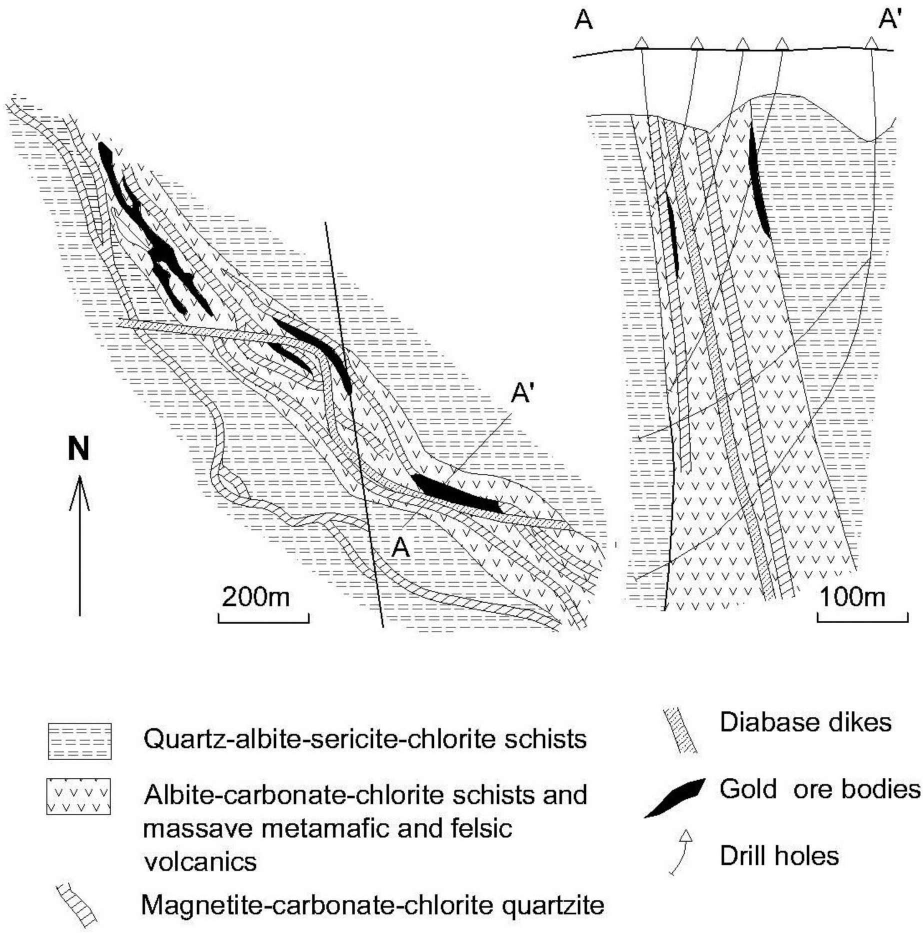


Figure 3. Schematic geologic map and cross section of the Balka Shirokaya deposit (after Pet'ko et al. 1994).

The second, gold-polymetallic, type of mineralization is usual in the northern part of the Balka Shirokaya deposit and is associated with rocks of jaspilite formation, which underwent alteration in narrow, lenticular cataclastic and steeply dipping breccia zones. Ore minerals constitute from 1 to 30 vol. % of zones containing quartz, carbonates (sideroplesite, Fe-dolomite, and Mg-ankerite), and tourmaline with a few generations of pyrite, arsenopyrite, pyrrhotite, chalcopyrite, sphalerite, galena, sulfosalts of lead, copper, and silver, native silver, electrum, and native gold of 825-931 fineness. Finely dispersed gold is concentrated mainly in pyrite (1-7 g/t) and is less common in other sulfides, magnetite, and sulfosalts. Inclusions of electrum, up to 80 μm in size, are found most often in galena, pyrite, and quartz. Particles of native gold are concentrated in quartz-carbonate-pyrite veinlet salvages. Gold grades reach 5-8 g/t and silver grades 400-430 g/t in this type of ore.

Boulangerite-freibergite-galena-sphalerite mineralization with gold was formed later than the pyrite-pyrrhotite-arsenopyrite assemblage. Silver-bearing sulfosalts and boulangerite form impregnations in galena, while gold occurs as thin inclusions in carbonate and quartz.

Based on a study of fluid inclusions, temperature of ore formation decreases from 280-220°C for the quartz-pyrite-arsenopyrite association to 260-180°C for the sulfosalt-polymetallic assemblage.

The third, gold-quartz, type of mineralization forms thin, low in sulfide quartz veins and veinlet zones and is of no practical interest. Native gold is present as rare inclusions in quartz usually less than 100 μm in size.

Despite having different mineralogical composition, all ore types are similar in host-rock alteration, isotope ratios, and thermobarometric geochemistry and were formed at a pressure of 1-0.8 MPa and a temperature of 300-180°C from weakly alkaline solutions (pH 6-8) having elevated concentrations of H_2, CO, N_2, and CH_4. The age of the Balka Shirokaya mineralization, based on the lead-isotope ratios of galena and pyrite (Nechaev and Naumov 1998), is 2,700 ± 200 Ma, which indicates a postmetamorphic origin. Nechaev and Naumov (1998) have described three stages of gold mineralization in the Chertomlyk ore field (2.3-2.0, 1.7-1.3, and 0.7-0.4 Ga) and indicate that it is younger than the uranium mineralization in Early Proterozoic metaconglomerates dated to 2.6-2.45 Ga.

The indicated resource of the Balka Shirokaya deposit, computed on the basis of more than 260 drill holes, is about 20 million tonnes of ore grading 5.5 g/t, or 3.6 Moz (112 t) of gold.

The Balka Shirokaya deposit, the first deposit of gold-jaspilite mineralization discovered in the Ukrainian shield, verified the possibility of finding economically viable projects involving deposits of this type in the CIS. Analogous gold-jaspilite occurrences are known within the Sursk, Verkhovtsev, and other fragments of Archean greenstone belts of the Dnepr block. They typically contain 1-3 g/t gold but need to be explored further.

3.2.2 Gold-Sulfide-Quartz Vein and Veinlet Zones Associated with Felsic Volcanics and Subvolcanic Bodies

This type of gold mineralization has considerably higher economical potential than gold jaspilite and forms the largest deposits in the greenstone belts of the world outside the CIS. Gold occurrences associated with Archean felsic volcanics and subvolcanic intrusive bodies were identified within the Sursk and Verkhovtsev greenstone fragments of the Dnepr block of Ukrainian shield during the 1960s (Esipchuk et al. 1992). Exploration during the 1980s revealed significant gold resources of the Sergeevskoye and Balka Zolotaya deposits within the Solonyansk ore field in the Sursk greenstone fragment and found similar occurrences in the Chertomlyk and Verkhovtsev greenstone fragments (figure 2).

All occurrences of this type of gold mineralization are found in zones of metasomatic alteration and quartz veinlets with up to 30-35% disseminated sulfides located near contacts with granite-granodiorite porphyry and quartz-albitite subvolcanic intrusives. Veinlet-disseminated mineralization changes to the quartz vein and veinlet type with increasing distance from the contact of subvolcanic bodies.

Gold-bearing metasomatic assemblages include propylitic, quartz-sericite-chlorite-carbonate-pyrite, pyrite-biotite (chlorite)-albite, tremolite-quartz-carbonate, and quartz-carbonate-amphibole varieties. Pyrite is the main ore mineral; but pyrrhotite, arsenopyrite, and chalcopyrite also are present. Gold forms inclusions within sulfide minerals and also is present as free particles.

The Sergeevskoye Deposit (48°10'N-34°49'E)

The Sergeevskoye deposit belongs to the Solonyansk ore field (Fig. 4) and is located (Dischuk et al. 1994; Monakhov et al. 1994; Koval' et al. 1994 and 1997) in the southern part of the Sursk greenstone belt. Two subsequent Archean volcano-plutonic complexes are present in the deposit area. The lower one belongs to the Konskaya series and consists of metabasalts and subordinate metaandesites and ultramafites with subvolcanic metadolerite and metagabbro intrusions. This complex underwent regional metamorphism to upper greenschist and epidote-amphibolite facies with a transition into amphibolite schists.

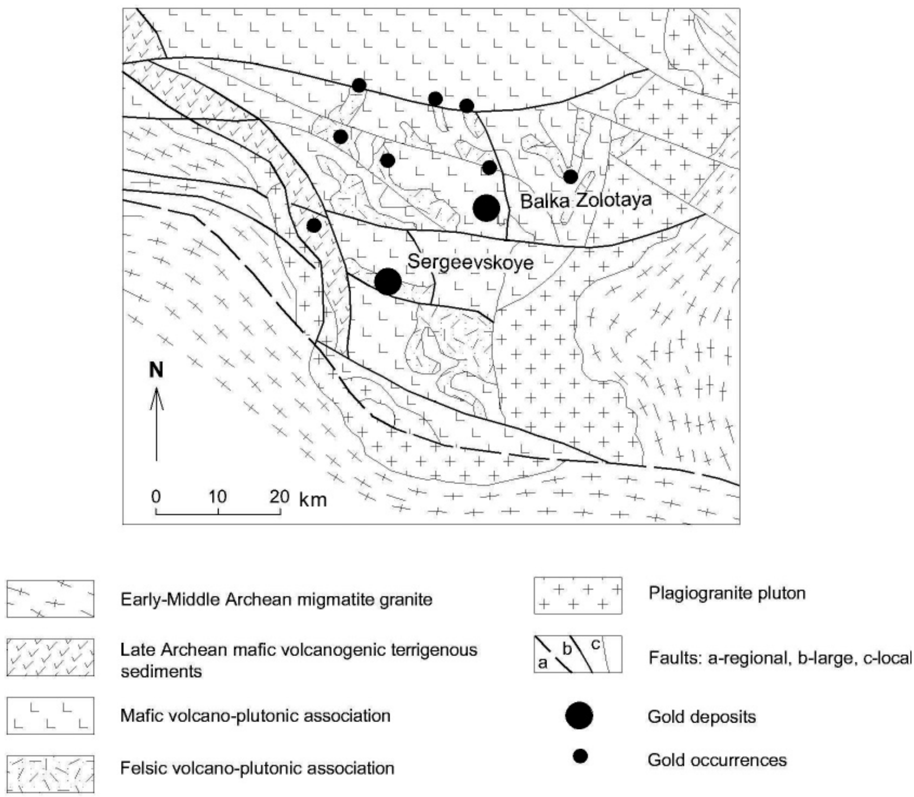


Figure 4. Schematic geologic map of the Solonyansk ore field (ater Dischuk et al., 1994)

The upper complex (the Solenovsk series) consists mostly of various sizes, numerous dikelike bodies of metadacite and granodiorite porphyry, which are concentrated within a subwesterly belt approximately 600 m wide. The belt is generally discordant to the structural pattern of the lower complex, but there are some dikes, which are confined to earlier northerly faults.

The main ore-controlling structure is the shear zone of the southern Sergeevsky fault, which contains a slablike body of subvolcanic granodiorite porphyry (Fig. 5) dipping 50-70° to the north. Host rocks for the gold mineralization, which cut by granodiorite porphyry, are sericite-albite-quartz schists with blastoporphyritic and cataclasite textures. The U-Pb isochronal age of zircon in the host rocks varies between 3.1 and 3.2 Ga (Koval' et al. 1994, 1997).

Gold-bearing mineralization is developed along the hanging wall and footwall of the granodiorite porphyry, with more ore bodies along the hanging wall and higher gold grades at the intersections of north-south tectonic zones with northwest- and northeast-trending zones. Gold mineralization has been traced by drill holes for 1,500 m along the strike and to a depth of 600 m.

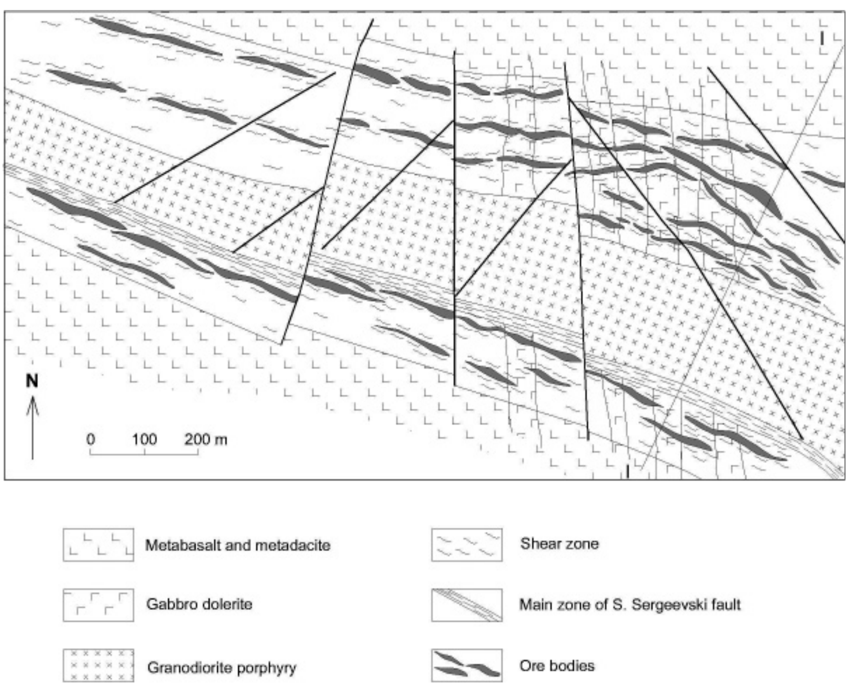


Figure 5. Geologic map of the Sergeevskoye gold deposit (ater Dischuk et al., 1994)

Ore zones are accompanied commonly by quartz-carbonate-amphibole alteration of the schists, with complex zoning. An inner zone consists of carbonate (mostly calcite)-quartz mineralization surrounded by the intermediate sericite zone of actinolite-tremolite with chlorite, carbonate, quartz, and talc mineralization. The outer zone contains mostly chlorite mineralization. Gold-bearing amphibole-rich alteration was formed at 380-450°C. The ore bodies are systems of quartz, carbonate, and quartz-carbonate-tremolite veins and veinlets containing sulfide, sulfosalts, and telluride mineralization.

Three main types of gold ore bodies can be distinguished by morphology and mineral composition (Dischuk et al. 1994):

(1) Quartz-carbonate veinlets within silicified zones of metabasic and felsic metavolcanic rocks. This type is located in the footwall of granodiorite porphyry. The veinlets are relatively low-sulfide; but disseminated pyrite, pyrrhotite, and rare chalcopyrite in the host rocks can reach up to 30% of the volume.
(2) Zones of quartz-carbonate-tremolite alteration with stockworklike distribution of quartz veins and veinlets containing pyrite, pyrrhotite, and smaller amounts of arsenopyrite, chalcopyrite, galena, sphalerite, and sulfosalts. This type is located in the hanging wall of subvolcanic intrusive.
(3) Ankerite-sulfide-quartz veins and veinlets also are developed in the hanging wall of granodiorite porphyry and contain up to 20% sulfides; predominantly pyrite and pyrrhotite, but only arsenopyrite contains up to 0.4% Au. The intergrowths of bismutite, hessite, and telluric bismutite are found in galena, while hessite, altaite, and cosalite are described within quartz veins.

The main, gold and silver-bearing, mineralization is concentrated in the northern and the central ore zones. Mineralization consists of magnetite, scheelite, pyrrhotite, chalcopyrite, a few generations of pyrite, arsenopyrite, sphalerite, galena, native bismuth, cosalite-cannizzarite, bismuthinite, hessite, petzite, sylvanite, and native gold of 696-946 fineness. Gold, up to 100 μm in size, forms inclusions in quartz or intergrowths with other sulfide minerals and is concentrated in sylvanite (23.5-24.15 wt. % Au), petzite (23.6-24.9 wt. %), and pyrite (up to 14 g/t). Gold content in this type of ore varies from 0.5-3 g/t up to 100 g/t.

Less important is the gold-copper-molybdenum type. It is common to the eastern part of the northern zone and occurs in silicified metadacite and potassium-low granite (plagiogranite) porphyry dikes. Quartz veins and veinlets contain disseminated chalcopyrite, rhenium-bearing molybdenite, and rare galena with inclusions of native gold.

Low in gold (1-3 g/t), massive sulfide type is located in the southern ore zone and partly in the central ore zone. It forms stratiform bodies within quartzite horizons and consists of gold-bearing pyrite, less often pyrrhotite, chalcopyrite, and sphalerite, and rarely native bismuth, antimony- and lead-bismuth sulfosalts, and gray copper ore.

The highest gold grades are found in the zones of amphibole alteration, while the lowest grades are in quartz-carbonate veinlets. Molybdenum increases and gold decreases approaching the granodiorite porphyry.

Based on a study of the lead isotopes of uranium-bearing rocks (Koval et al. 1994), gold was introduced in four stages: (1) 2,900-2,700 Ma, as a result of the action of plagioclase granite on the greenstone rocks; (2) 2,700-2,300 Ma during the formation of pink-colored microcline-plagioclase granite; (3) 2,300-2,000 Ma during listwanite-beresite (quartz-carbonate-sericite-chlorite-pyrite) alteration synchronous with the alkaline uranium-producing stage; and (4) 1,700-1,300 Ma during uranium and gold redistribution, which accompany uranium-albitite alkaline metasomatism.

Isotopic study of the minerals shows that $\delta^{34}S$ is 2.3-2.7‰ for sulfides; $\delta^{18}O$ is 1.2‰ for magnetite; and $\delta^{13}C$ is 0.5-0.9‰ for carbonates, while $\delta^{18}O$ of carbonates is 11.1-12.9‰ and 9.2-10.7‰ for quartz, which suggests magmatic-metamorphic origin of the ore fluids.

The average gold grade for the Sergeevskoye deposit is 8.5 g/t with isolated values up to hundreds of grams per tonne within quartz veins and veinlets. Fifty intersections of ore by drill holes contain visible gold particles. Indicated and inferred resources of the deposit as of the mid-1990s are about 13 million tonnes of ore containing approximately 3.55 Moz (110 t) of gold.

The Balka Zolotaya (48°13’-34°52’) is also located in the Sursk greenstone belt to the north of the Sergeevskoye deposit, has a similar geological setting and mineralogy, but requires further exploration.

Gold mineralization in similar zones of amphibole metasomatism of the Archean greenstone fragments is known in the Kola part of the Baltic shield but has a much lower degree of exploration and smaller known resources.

3.3 EARLY PROTEROZOIC FAULT-RELATED LINEAR ZONES OF VEINLET-DISSEMINATED GOLD MINERALIZATION

3.3.1 Gold-Sulfide (Arsenic)-Quartz Deposits

Gold occurrences of this type are located in the uplifted Kirovgrad geotectonic block in the center of the Ukrainian shield (figure 2), which is famous for its uranium mineralization. The Novoukrainsky and Bobrinetsky granitoid plutons intrude in this block flyschlike metagraywacke of the Early Proterozoic protoplatform cover. Gold mineralization occurred (Yatsenko et al. 1998) during the Early Riphean (Eocambrian ~1.7 Ga) tectonic and magmatic events.

Most of the gold occurrences are located in the Ingulets shear zone to the east of the Novoukrainsky pluton. Similar fault zones to the west of it also host gold mineralization. These are the Kirovgrad and Mikhailov zones, which coincide with regional thrust zones of the same name (Babynin et al. 1992; Metalidi et al. 1992; Koval' et al. 1997). The 50-60 km long and 20 km wide metallogenic zones consist of mainly plagioclase gneiss, as well as biotite, garnet-biotite, and amphibole crystalline shales.

These gold-bearing structures occupy steeply dipping northerly zones of gneiss with intensive cataclasis, boudinage, silicification, chloritization, and sulfidization that are intruded by younger granite bodies, pegmatite aplite, and quartz-feldspar veins. Such zones contain relatively high in arsenic "gold-sulfide (arsenic)-quartz" type of mineralization. Low-sulfide gold mineralization is confined to linear zones of silicified gneiss accompanied by local K-feldspathization and biotitization. Pyrite, pyrrhotite, arsenopyrite, loellingite, sphalerite, galena, tennantite and tetrahedrite, native gold, and bismuth form disseminated and veinlet-disseminated zones with subordinate veins.

Similar gold mineralization is also found in the Krivoy Rog-Kremenchug zone in association with ferruginous quartzites and schists of the Saksagansk series.

The Klintsy Deposit (48°24'N-32°23'E)

The Klintsy ore field is located (Babynin et al. 1992; Metalidi et al. 1992; Koval' et al. 1997; and Yatsenko et al. 1998) on the east side of the Novoukrainsky granite pluton in the Kirovgrad deep fault zone. It is about 15 km long in the north-south direction and includes the Klintsy deposit, the West Klintsy deposit to the northwest, and the Gubovskoye gold occurrence to the southeast of Klintsy. Host rocks for gold mineralization are biotite and amphibole-biotite plagioclase gneiss with interlayers of cummingtonite gneiss. All the gneisses have a spotty texture with high microcline and the extensive development of quartz veinlets and veins.

The mineralized zone of the Klintsy deposit, 3 km long and 50-120 m wide, is located at the intersection of the main N-S gold-bearing structure by northwesterly faults (Fig. 6). This zone is characterized by the presence of planar distributed biotitization, by oligoclase in the groundmass and along quartz vein selvages, and by abundant microveinlets, lenses, and veins of quartz. Six generally parallel ore bodies, up to 14.0 m thick (mainly 1.2-1.9 m), have average grades of more than 3.0 g/t gold. The ore bodies contain 15-70% quartz-oligoclase veins/veinlets, which vary in thickness from 1-2 to 50 cm. Silicified gneiss between veins contains pyrrhotite-arsenopyrite mineralization, biotite, amphibole, and oligoclase. Veins and large veinlets are surrounded by 2-20 cm wide halos of skarn and amphibole alteration.

Higher gold grade zones exhibit multiple stages of overprinting by quartz-oligoclase vein/veinlets. The vein material has been repeatedly crushed and is healed by quartz. Zones containing single veins generally have gold grades below 1.0 g/t.

Veinlet-disseminated and vein-type ore commonly is low-sulfide (3-4%) but contain high sulfide lenses up to 3.0 m long and 0.3 m wide. The main ore minerals are pyrrhotite, loellingite, arsenopyrite, and pyrite with minor amount of chalcopyrite. Sphalerite, galena, gersdorffite, safflorite, bismutite, native bismuth, gold, and arsenic are rare. The diopside-rich phyllite and skarnlike-altered rocks around the ore bodies contain scheelite.

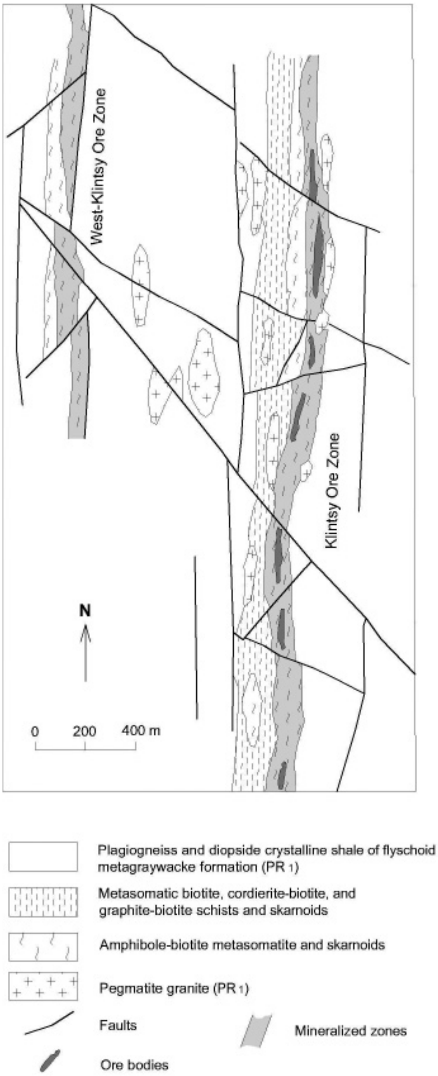


Figure 6. Schematic geological map of the Klintsy ore field (after Yatsenko et al. 1998).

Several stages of mineral deposition include (1) the pre-ore stage with tourmaline- and scheelite-quartz associations formed during iron-magnesium-calcium metasomatism; (2) the productive stage consists of loellingite-arsenopyrite-quartz association with pyrrhotite, pyrite, and gersdorffite; arsenopyrite-pyrrhotite-quartz assemblage with chalcopyrite; and gold-sulfide-quartz association with siderite, pyrrhotite, arsenopyrite, pyrite, chalcopyrite, sphalerite, galena, native bismuth, and arsenic.

Gold is present in all three of the productive mineral associations but in the first one does not exceed 0.5-1.0 g/t. The gold grades for the arsenopyrite-pyrrhotite association vary between 0.3 and 5.0 g/t. Higher gold grades are typical of the latest gold-sulfide-quartz association, ranging from 5.0 g/t up to a few hundred grams per tonne. One of the indicators of this mineral paragenesis is association of gold with native bismuth. Post-ore veins contain only a carbonate-quartz association with quartz, calcite, pyrrhotite, pyrite, and chalcopyrite.

Pre-ore, scheelite-quartz and tourmaline-quartz, mineral associations were deposited at a temperature of 345-335°C and a pressure of 890-1,150 atm. The three productive assemblages described above were formed at temperatures of 500-460, 440-380, and 270-230°C, respectively, and at pressures decreasing from 1,100-1,130 to 750-790 atm. Gold-bearing mineralization developed between 1.7 and 1.6 Ga and is close to the age of the potassium-rich granite (Yatsenko et al. 1998).

Native gold particles, 0.07-5.0 mm in size, constitute for 70-85 wt. % of the total amount of gold; fine-grained gold particles (0.001-0.07 mm)—for 15-20 wt. %; and finely dispersed gold (less than 0.001 mm)—for 5-10 wt. %. Clusters of gold particles occasionally form nests 3-20 cm in size. Native gold is concentrated mainly in quartz and quartz-oligoclase vein selvages and as inclusions in arsenopyrite and other sulfides. Gold distribution is extremely uneven. The gold of 870 to 950 fineness contains admixtures of bismuth (up to 3.2 wt. %), silver (0.9%), platinum (0.78%), and of lead (0.24%). Native bismuth and, rarely, arsenic are found in association with the gold. The greatest amount of gold is found within arsenopyrite or in quartz, which contains arsenopyrite.

The average gold grade for the Klintsy deposit is 6.3 g/t. Gold-rich intervals are surrounded by sulfide aureoles in gneiss up to 20 m wide with a grade of 0.1-1.0 g/t. Probable gold resources estimated on the basis of drilling and underground workings are 10.48 million tonnes of ore, with about 2.13 Moz (66 t) of gold. Laboratory metallurgy tests show 95-97% gold recovery by the combined gravity-flotation method.

The West Klintsy and Gubovskoye gold occurrences, about 600 m northwest and southeast, respectively, of the Klintsy, are similar to it. The entire zone consists of a few segments displaced by local faults.

The Yurievskoye Deposit (48°18'N-32°14'E)

The Yurievskoye deposit is located to the south of Klintsy within the same tectonic structure, along the east contact of the Novoukrainsky granite pluton. Gold mineralization (Koval' et al. 1997) is hosted by Early Proterozoic gneiss on the western limb of Priingul'sk syncline, which is cut by the Kirovgrad fault zone. The host rocks are biotite, much less commonly cordierite-biotite, garnet-biotite, and amphibole gneiss, which contain pyroxene, up to 5% graphite, and pegmatite-aplite veins.

Structural setting of the Yurievskoye deposit is defined by its location on the hanging wall of the northerly-trending Kirovgrad fault zone, at the intersection with a series of NE fractures.

Low-sulfide gold mineralization occurs in linear silicified zones of north-south and also east-west directions. Silicification was preceded by intense brittle deformations accompanied by formation of thin zones with K-feldspar, ankerite, quartz, biotite, chlorite, pyrite, and pyrrhotite mineralization, often with gold. Gold-bearing silicification zones usually are spatially related to graphite-rich gneiss.

The main ore minerals are pyrite, pyrrhotite, chalcopyrite, arsenopyrite, loellingite, sphalerite, galena, gray copper ore, native gold, and bismuth. High-fineness (930-990) native gold inclusions, 125-200 μm in size, are present in quartz and sometimes as intergrowths with native bismuth, tennantite, tetrahedrite, and galena. Formation of the deposit includes stages similar to those of the Klintsy deposit, but with more complex composition. A pre-ore stage consists of quartz-feldspar, tourmaline-quartz, pyrrhotite-pyrite-quartz, and carbonate-quartz associations. The gold-productive stage includes quartz-pyrite, sphalerite-galena, and the main productive chalcopyrite-pyrrhotite associations. The post-ore stage includes quartz-carbonate and carbonate-quartz assemblages.

An isochronal lead-isotope age of pyrite and arsenopyrite in the Yurievskoye gold mineralization (Koval' et al. 1997) dated to 2,000 ± 80 Ma is in a good agreement with 2,000 ± 150 Ma age of sphalerite.

Thermobarometric geochemical study sets the upper temperature limit for the productive mineral association at 500-360°C and the lower limit at 190°C at pressures of 0.65-0.45 MPa. The variations of $\delta^{18}O$ (-7.8 to +0.4‰) and δD (-83 to -41‰) of the water in inclusions support its mainly meteoric origin.

The main source of sulfur and carbon for the ore-forming solutions is from the host rocks, as the original sulfur fractionation is similar to that in the region's Early Proterozoic Checheleyevskaya formation. The results of this study (Koval' et al. 1997) show the dominance of low-temperature, meteoric-derived hydrothermal solutions in the origin of the gold mineralization, making the Yurievskoye deposit different from all other metamorphic-magmatic deposits of the Ukrainian shield.

According to available data, the Yurievskoye deposit has an even larger gold resource than Klintsy, with approximately 140 tonnes of gold grading 8.5 g/t, or 4.5 Moz.

Gold mineralization similar to that at Yurievskoye has been found in the Mikhailov metallogenic zone along the western contact of the Novoukrainsky granite pluton. This zone has been traced by sparse geochemical drill holes for more than 30 km and is verified by several lines of inclined drill holes. A metavolcanogenic cherty-shales host formation is associated here with tonalite granitoids and flyschlike metagraywacke similar to the described in the Klintsy deposit of the Kirovgrad zone. A few of the gold occurrences discovered in the Mikhailov zone have yet to be explored.

The mineralized zone can be traced by gold grades of more than 0.1 g/t in drill holes, but some of the drill holes cut intervals with higher gold content of up to a few grams per tonne. Gold mineralization of the Mikhailov zone has relatively higher content (up to 6%) of the copper, silver, arsenic, and bismuth sulfides than the Klintsy zone. This difference in mineralization could be the result of different host rocks—mainly biotite gneisses at the Klintsy deposit versus amphibole gneiss and crystalline shales in the Mikhailov zone.

A potential for discovery of similar zones with gold-sulfide (arsenic)-quartz mineralization also exists in the Volynsky block in the northwestern part of the Ukrainian shield (Yatsenko et al. 1998). Its basic tectonic setting and metallogenic characteristics are like these of the Kirovgrad block. The granitoid-metasedimentary and later volcanogenic-sedimentary metamorphic formations of the Volynsky block contain more diverse gold mineralization, with silver and molybdenum hosted not only by the metagraywacke but also by granitoids and calc-silicate metasomatic zones.

The discovery of significant Archean and Early Proterozoic gold deposits in the Ukrainian shield is an evidence of the good exploration potential of this region and other such structures of the CIS. It is possible that future exploration of the more than 800 known gold occurrences in the Ukrainian shield may outline even larger gold reserves within this region.

Potential of Archean-Proterozoic gold mineralization in the Kola part of the Baltic shield of the East European platform also is quite high, although the many gold occurrences discovered in this region have been small in size. However, exploration along the Russian-Finnish border in the 1990s led to the discovery of several interesting prospects.

One of the prospects is located in the south Vygozerskaya area of the Medvezhegorsk and Segezh administrative districts in the Republic of Karelia (Russian Federation). Vein-type and veinlet-disseminated gold quartz-sulfide mineralization there is in a Late Archean greenstone metamorphic sequence similar to the Dnepr block of the Ukrainian shield. Indicated and inferred resources of this area estimate 100 t of gold with an ore grade 2-10 g/t to a depth of 300 m (*Interfax, Mining & Metals Report*, vol. 4, issue 7, 1998).

Exploration of the Proterozoic (1.88-1.89 Ga) Svecofennian structures of the Ladoga region (Ivaschenko et al. 2002) led to discovery of the Pakyla gold prospect in 1999 and substantiated the high potential of this area for gold deposits similar to those of the adjacent region of Finland.

Finnish geologists in the nearby area of the Baltic shield found more than 140 gold occurrences. According to the Geological Survey of Finland, as reported by Pekko Nurmi on the Internet in 2002, a few occurrences may be of future interest.

The Kiannaniemi gold prospect on the Finnish side of the Karelian Peninsula is associated with altered shear zones in Archean intermediate and mafic metavolcanics of the Suomussalmi greenstone belt. The most prominent occurrence, Kuikka, is a 1 km long and 15 to 30 m wide zone in metabasalt (quartz-biotite schist) with free gold and individual high grades intercept of up to 115 g/t over meter lengths in deformed quartz veins.

The Suurikuusikko deposit is located in the middle of the Lapland greenstone belt in Northern Finland. It reportedly contains various ore types associated with brecciated and strongly altered tholeiitic volcanics controlled by a fault zone that can be traced for more than 15 km. Evaluation of this deposit by the Riddarhyttan Co. revealed (as of 2002) 6.0 million tonnes of indicated and inferred resources grading 6.0 g/t, but it may become a multimillion-ounce gold project.

The Finnish data cited above, together with current Russian material, support the possibility of finding viable gold projects within the greenstone belts of the Baltic shield.

Fragments of Late Archean (?)—Early Proterozoic greenstone belts also are known in the Aldan shield (Zonenshain et al. 1990). They are small (3 to 10 km wide and a few tens of kilometers long) and consist mostly of mafic rocks formed by remelting of ancient basalt crust at high pressure, while the Olondin belt only contains bimodal metavolcanics.

The fragmental nature of the greenstone belts within the Aldan shield, together with the previously mentioned intensive Mesozoic tectonic and magmatic activity, could be responsible for the failure to find economic Archean-Proterozoic gold deposits in this region. The only gold occurrence in Proterozoic metasedimentary rocks known to author, the Temny-Tabornyi occurrence, has inferred resources of 12.5 million tonnes of ore grading 1.5-1.7 g/t, or 0.65-0.81 Moz of gold.

The Anabar shield of the Siberian platform has received almost no gold exploration because of its location north of the Arctic Circle, the lack of any infrastructure, and intractable logistical problems.

4

LATE PROTEROZOIC-PHANEROZOIC DEPOSITS

Gold deposits of this time group have broad development in the CIS from regions of Baikalian (Late Precambrian) orogeny such as Yenisey Ridge to Alpine fold and fault systems of Lesser Caucasus and Kamchatka, but distribution of gold deposits between regions of different age in the CIS is different from the rest of the world.

Almost 60% of historic world gold output comes from Archean and Early Proterozoic metallogenic provinces of cratons, approximately 34% (without CIS) is from Mesozoic-Cenozoic provinces, less than 6% is mined from Hercynian provinces, and less than 0.1% is from Baikalian and Caledonian provinces (Sher 1972). At the same time, Baikalian, Caledonian, and especially Hercynian provinces are the main gold regions of the CIS, containing roughly more than 80% of resources and equal amount of postproduction.

Three main groups of deposits can be distinguished on the basis of their geotectonic setting and relation to intrusive or volcanic magmatism:

* Sediment-hosted gold and gold-silver deposits
* Intrusive-related gold deposits of island arcs and orogenic systems
* Volcanic-related gold and gold-silver deposits of volcano-plutonic belts and continental rifts

Deposits within the same geotectonic setting may have different ages. For example, sediment-hosted zones of veinlet-disseminated mineralization in black-shales and carbonate sedimentary formations are developed during

Late Proterozoic, Paleozoic, and Mesozoic era. It means that origin of gold mineralization depends not on the age but on the properties of host rocks, ore-bearing solutions, and structural-chemical traps for these solutions.

At the same time, similar mineralogical types of gold deposits occur in different geotectonic setting. Gold-quartz mineralization, for example, is known in sediment-hosted and intrusive-related gold deposits. Gold-sulfide-quartz mineralization is typical for all three main geological (geotectonic) groups of gold deposits with some geochemical differences such as presence of high arsenic in intrusive-related deposits and its near absence in sediment-hosted deposits in metamorphic sequences (see table 2).

4.1 SEDIMENT-HOSTED GOLD AND GOLD-SILVER DEPOSITS

The distinctive feature of this group is the sedimentary and carbonate-sedimentary host rocks. They can be found in a variety of tectonic settings, such as in trough structures located on the periphery of platforms (Sukhoi Log deposit in Bodaibo trough and Olimpiada in Yenisey trough on the periphery of the Siberian platform) or rigid massifs (Kumtor on the periphery of Sarydzhaz massif of the Hercynians Central Tien Shan). Another favorable geotectonic setting is in intracontinental structures of accretionary complexes such as in the Hercynian southern Tien Shan in Uzbekistan (Muruntau, Daugyz, Chore, and other deposits) and in the west Kalba in Kazakhstan (Bakirchik deposit) or in the Mesozoic Kolyma Loop in northeast part of Russia (Maiskoye deposit).

This group of deposits includes the largest world-class gold deposits of the CIS such as Muruntau, Sukhoi Log, Kumtor, Olimpiada, Bakirchik, and Natalka. Another of their common characteristic is the absence of any direct connection with magmatism. Although some deep granitoid plutons are supposedly under the deposits by geophysical data (Sukhoi Log, Olimpiada) or detected by drilling (Muruntau), any connection between deposits and granitoids is uncertain. Other features such as mineralogical and geochemical characteristics of the deposits vary and depend on geotectonic setting.

Sediment-hosted gold deposits can be divided into two main geological types: (1) vein zones, megastockworks, and zones of veinlet-disseminated mineralization in metamorphic sequences and (2) zones of veinlet-disseminated and vein mineralization in black-shales and carbonate-sedimentary formations.

Sediment-hosted gold-silver deposits form a third, less known, and currently less potential type and are represented by stockworks and veinlet-disseminated zones of gold-silver mineralization in sedimentary and carbonate-sedimentary sequences.

4.1.1 Vein Zones, Megastockworks, and Zones of Veinlets-Disseminated Gold Mineralization in Metamorphic Sequences

This type of deposits becomes recognizable after exploration of the Kumtor deposit in Kyrgyzstan at the early 1980s. The Sovetskoye deposit of the Yenisey Ridge and the Sukhoi Log of the Bodaibo region (both in east Siberia, Russia) as well as Muruntau (Uzbekistan) has previously been assigned to the broader group of mesothermal amagmatic deposits in black shales. All these deposits are characterized by (1) vein/veinlet-disseminated mineralization in carbonaceous sedimentary sequences, (2) absence of a clear connection with magmatism, and (3) large ore zones and reserves suitable for open-pit operations.

The gold deposits in metamorphic host rocks have specific features that distinguish them from the gold-sulfide deposits hosted by low-metamorphosed black shales. In the metamorphic host rocks, the ore is mainly pyritic with lower amount or no arsenic admixture in the pyrite and was formed deeper and at higher temperatures.

Gold deposits in metamorphic sequences, according to V. Buryak and other geologists (Narseev 1991), are characterized by a few common features. First is their location in megablocks of mature continental crust and sialic composition of granitized basement. Good examples are the Yenisey and Bodaibo troughs with the Sovetskoye and Sukhoi Log deposits, as well as the periphery of Sarydzhaz rigid massif which hosts the Kumtor deposit. A second common feature is the large thickness and uniform composition of the host sandstone and shales of flyschoid type similar to cover complexes of ancient platforms and rigid massifs. Typical also is a high amount of carbonate in these complexes including not only calcareous siltstones and sandstone but also interlayers of limestone and dolomite. Host rocks usually contain disseminated pyrite mineralization and have undergone greenstone facies regional metamorphism.

The association of gold mineralization with carbonaceous sedimentary sequences of different age suggests the presence of syngenetic gold dispersed within these sequences. Redistribution and concentration of gold could be caused by diagenetic alteration and regional metamorphism (Narseev 1991) and finalized by hydrothermal solutions. Such genesis of gold and gold-silver mineralization in metamorphic sequences is considered by many of Soviet specialists as metamorphic-hydrothermal (Narseev et al. 1986) or syngenetic-epigenetic (Gar'kovets 1973).

Gold deposits in metamorphic formations contain three main mineralogical/geochemical types of mineralization: gold-quartz, gold-feldspar-carbonate-sulfide, and gold-quartz (carbonate)-sulfide.

4.1.1.1 Gold-Quartz Deposits

Gold-quartz deposits in metamorphic sedimentary host rocks are widely distributed as singular quartz veins and vein zones but usually do not contain large reserves. They occur typically as pyritic, low-sulfide (1-3%) mineralization in segregated veins developed during metamorphism of the host rocks.

The Sovetskoye Deposit (60°21'N-93°07'E)

The Sovetskoye deposit, the largest one of this mineral type in the CIS, is located in the Severo-Yeniseysk region of the Yenisey Ridge on the outskirts of the town of Severo-Yeniseysk. Gold placers in this area have been exploited since the 1840s. Development of the Avenir lode gold deposit (later renamed Sovetskoye) started in 1908 and produced since then more than one hundred tonnes of gold to the depth of 590 m, but mineralization continues at least to a depth of 1,400 m (Rusinova et al. 1999).

The Sovetskoye deposit is located in the Yenisey trough of the Baikalian (Late Precambrian) orogeny that is adjacent to the Siberian craton on the west. Crystalline basement of the trough consists of Archean—Early

Proterozoic (up to 1,450 Ma) metamorphic sequences of the craton (Gorzhevsky and Konstantinov 1998).

The trough is filled by the Late Proterozoic (up to 850 Ma) sedimentary sequences, which are covered by Late Proterozoic-Cambrian orogenic and platform sediments. The lower sequence, Kordinsk, consists of schist-gneiss and a limestone-sandstone-shales with concordant bodies of diabase (Gorzhevsky and Konstantinov 1998) and is conformably covered by the ore host sequence of the Uderey formation containing carbonaceous siltstones, shales, and phyllite. All sedimentary sequences are folded into long northwesterly-striking folds up to 2-5 km wide. The host sequence for mineralization underwent epidote-amphibolite and high-grade greenstone facies regional metamorphism at 500-460°C (Rusinova et al. 1999). Carbon contents ($C_{org.}$) in the host rocks reaches 0.2-0.42 wt. % in a form of dispersed organic materials and graphite. Host rocks contain lenses of intense pyritization.

The trough sequences are intruded by leucocratic granite and migmatite-granite series (900-1,050 Ma) and by granite batholith (850-600 Ma) accompanied by cordierite-amphibole-plagioclase hornfels. The location of the Sovetskoye deposit 12-15 km from the nearest concealed granite batholith (Gorzhevsky and Konstantinov 1998; Konstantinov et al. 1999) indicate that the batholith has no direct connection to its development except for perhaps a similar time frame.

The Sovetskoye deposit is hosted by intensely deformed, thin-layered phyllite-slate sequence in the hanging wall of regional thrust, which deformed the limb of an anticlinal fold. The anticline axis is oriented along the edge of the thrust, which appears to be main ore-controlling structure of the deposit. The tectonic lens containing the deposit is 18-20 km long and up to 3-4 km thick and represents the fragment of allochthonous part of the thrust.

The ore zones of the Sovetskoye deposit are vein-veinlet type and can be traced for several kilometers in length. There are two zones in the northern part of the deposit, three at the center, and five large vein-veinlet zones at the southern part of the deposit.

Ore bodies, from 5 to 120 m long and from 2 to 12 m thick, are located in shear zones and form seven subparallel, steeply dipping vein zones of complex shape separated by barren intervals (Rusinova et al.

1999). Quartz comprises up to 80% of vein zones volume and contains fragments of sericitized host rocks and carbon substance along fissures. Ore minerals (from 1 to 5 %) are primarily pyrite and pyrrhotite, along with rare arsenopyrite, galena, sphalerite, chalcopyrite, bismuthinite, freibergite, marcasite, native gold, and silver. Vein zones consist of veins, lenses, and stringers in pipe—and lenseslike bodies of tectonites that appear spiral-like in cross section (Fig. 7).

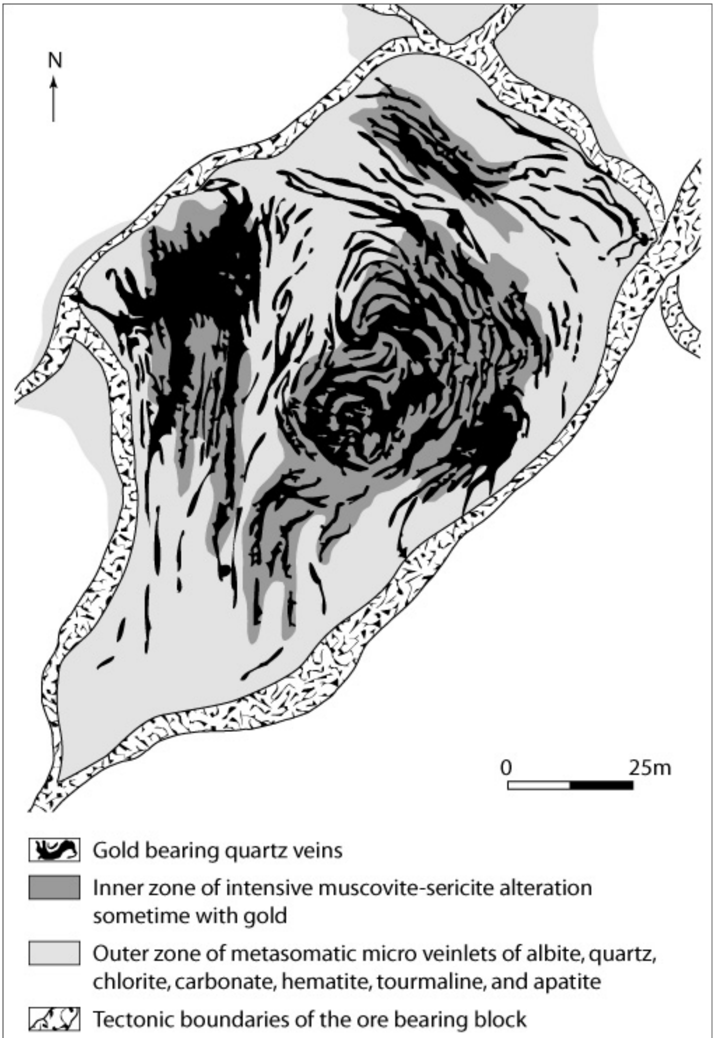


Figure 7. Cross section of vein zone within an active tectonic block of the Sovetskoye deposit (after Simkin 1993).

N. V. Petrovskaya (Smirnov 1977) identified the following sequences of mineralization: (1) semimilky quartz with minor muscovite and sericite, (2) pyrite and arsenopyrite; (3) pyrite, comb quartz, siderite, pyrrhotite, sphalerite, galena, chalcopyrite, marcasite, and very rare bismuthinite, native silver, freibergite, and violarite (main gold-productive); (4) gold with minor calaverite; and (5) carbonates and colloform pyrite. The quartz of phase 1 is probably much earlier than the subsequent phases' sulfide mineral associations because quartz underwent intensive metamorphism and recrystallization before deposition of sulfides.

Fluid inclusions in quartz (Tomilenko et al. 2001) are of three major types. Early fluids (stage 1 quartz veins) are predominantly aqueous but contain small amounts of CO_2 (<12.5 mol. %), CH_4 (0.3-1.3), and N_4 (0.2-1.7 mol. %). The fluids have salinity of 4 to 8 wt. % NaCl equivalent, homogenization temperatures from 100 to 410°C, and fluid pressures about 0.5-1.5 kbar. These data suggest that the widespread barren quartz veins were formed during regional greenschist-facies metamorphism.

Gold-bearing quartz veins (stage 2) contain fluid inclusions with higher salinity up to 20-25 wt. % NaCl equivalent. CO_2 typically ranges from 29.3 to 62 mol. % and N_2 from 2.7 to 13.2 mol. %. Homogenization temperatures suggest that gold mineralization occurred at 200 to 380°C and pressures of 0.7-2.0 kbar. Gold-bearing fluids possibly generated at significant depth and moved upward along fault zones.

Inclusions in quartz of stage 3 veins have homogenization temperature ranging from 100 to 200°C and salinity between 0 and 4.5 wt. % NaCl equivalent. This late fluid is H_2O dominant and contains less CO_2 than pre-ore and ore-stage fluids.

Native gold of high fineness (850-980) is predominantly free (96-98%). Its angular particles and veinlike or lumpy-shape flakes are located in quartz in association with galena, sphalerite, pyrite, and pyrrhotite. The average gold grade is 15 g/t using a cutoff grade of 3 g/t. Gold distribution is highly irregular (bonanza type) with numerous shoots having complex, branching outlines elongated in vertical direction and sometimes replacing each other in an *en-echelon* pattern.

Bonanza shoots contain about 90% of gold reserves with gold grades varying between 100 and 350 g/t and sometimes up to 2,600 g/t near margins of quartz breccia bodies. Inner parts of ore bodies with massive, sulfide-poor quartz have lower grades.

Hydrothermal alteration overlaps metamorphic alteration of the host rocks and forms an outer and inner zones (Rusinova et al. 1999). The outer zone contains muscovite, quartz, chlorite, ilmenite, and carbonaceous matter. According to muscovite and chlorite geothermometers, it formed at 380-270°C. The inner zone contains mainly muscovite and rutile, which replace ilmenite, and was formed at 440-320°C.

Lack of vertical mineral zones to depths of more than one kilometer and the high temperature of mineral deposition near the temperature of metamorphism indicate a deep level of ore formation of the Sovetskoye deposit.

Total initial reserves of the Sovetskoye deposit were about 130 t of gold; about 100 t of gold is already mined.

Gold deposits of this geological and mineralogical type are known in the Yenisey (Eldorado, Pereval'ninskoye, and smaller veins) and Bodaibo (numerous quartz veins) regions of east Siberia. Small low-sulfide quartz veins are known in Precambrian and Early Paleozoic metamorphic formations of southern Appalachians, as well as in the Late Proterozoic-Early Paleozoic Adelaide fold belt of southern Australia.

4.1.1.2 Gold-Feldspar-Carbonate-Quartz Deposits

This type of deposits is playing a significant role in gold reserves of the CIS and contains the Kumtor and Muruntau giant deposits. Gold-feldspar-carbonate-quartz deposits are differentiated from the gold-quartz type by more extensive development of dolomite, ankerite, calcite, and siderite in ore zones, feldspar (sodium and potassium varieties) alteration, and relatively larger amount (3 to 5%) of sulfides.

The Kumtor Deposit (41°57'N-77°51'E)

The Kumtor deposit is located on the Akshiirak Ridge of eastern Kyrgyzstan in the Central Tien Shan fold and fault belt. It seats at an altitude of 3,900-4,150 meters with an arcticlike climate (-40°C to +25°C) and problematic oxygen deficiency.

The deposit was discovered in 1978 by geophysicists who sampled gossan at a frontal moraine while alpine climbing. Samples returned 5-12 g/t of gold. Detailed exploration of the deposit includes three levels of underground workings (about 30 km long) and intensive drilling (77,000 m) done between 1979 and 1990. The Kumtor Gold Company, a subsidiary of Centerra Gold Corp. of Canada in joint venture with Kyrgyzian government, has been operating the Kumtor deposit since 1996.

The part of Central Tien Shan metallogenic province containing the Kumtor deposit lies along the contact of the Early Proterozoic Sarydzhaz rigid massif and the Late Caledonian riftlike Dzhetymtau trough (Narseev and Kurbanov, eds. 1989). The trough is developed in the Eocambrian (Riphean) platform cover at the north periphery of the rigid massif. A Late Proterozoic volcanic-sedimentary sequence up to 1.5 km thick forms the basal part of the trough. It contains layers of basalt-rhyolite volcanics and is covered unconformably by the Vendian (Late Proterozoic) Dzhetymtau formation, 0.8-1 km thick, which hosts gold mineralization. The Dzhetymtau formation consists of altered and deformed carbonaceous argillite, and siltstones transformed into chlorite-quartz-sericite and quartz-sericite phyllitelike shales of low greenschist grade. Phyllitelike shales are replaced on the flanks of the mineralized area by a schist with dolomite, carbonaceous chert, and graphite shales with abundant pyrite and pyrrhotite impregnations and are overlain by Cambrian dolomite and limestone. The host rocks contain up to 18% carbon and high values of tungsten (up to 0.08-0.1%).

The deposit is located in the hanging wall of the Kumtor fault zone, a branch of the Nikolaev lineament that divides parageosyncline of the Central Tien Shan from the Caledonides of the North Tien Shan. The 100-250 m thick Kumtor fault zone dips southwestward (30-50°) and is characterized by tectonic mélange, boudinage, shearing, and limonitization.

The structure of the deposit is influenced by its location at the node of the westerly-trending Kumtor fault zone, where concealed northwesterly faults produce flexural bending of the Nikolaev lineament. Regional faults are mostly steeply dipping thrusts (up to 70°) while numerous relatively gentle dipping large and small thrusts (30-50°) are also known. The latter often act as a barrier for the hydrothermal solutions. Zones of intensive corrugating, schistosity, and mylonitization are developed along all types of faults.

The deposit area does not contain any significant granitic rocks except for a few felsic dikes intruding host rocks in the northeast part of the ore field.

Zones of ductile deformation in carbonaceous phyllite are intensely altered and contain veinlet-disseminated and stockwork gold-bearing mineralization. Sericitization is the main type of regional alteration. Ore zones are typically silicified, along with pyrite-albite-carbonate and pyrite—K-feldspar—carbonate alteration. Introduced or remobilized graphite is sometimes present as well.

Mineralization extends intermittently for more than 10 km. The main zone of gold mineralization, 100-300 m thick, is formed at the intersection of two 40-65 m thick subparallel and subconcordant linear zones (Fig. 8). These 1.5 km long zones strike east-northeast (35-55°), dip to the southeast (45-50°), and connect at the northeast into single stockwork, 500 x 100 m, which is the deposit itself. Ore mineralization had been tested by drill holes to a depth of 1,100 m from the surface.

Ore of the Kumtor deposit (Narseev 1991) belongs to the feldspar-carbonate-pyrite type with five successive mineral assemblages. Quartz-pyrite association forms uneconomic veins, veinlets, and lenses on the flanks of ore bodies.

The first productive, pyrite-albite-carbonate, stage of mineralization consists of quartz-muscovite-albite and gold-scheelite-carbonate associations. Pyrite averages between 5 and locally up to 20% and contains inclusions of chalcopyrite, pyrrhotite, cobaltite, and gold. Scheelite with admixture of rare-earth elements forms single grains up to 15 vol. % of veinlets. This stage has low gold grades of about 1.2 g/t.

The second productive stage of mineralization, pyrite—K-feldspar—carbonate, coincides usually with local zones of brecciation and contains also two mineral associations: quartz—K-feldspar with a small amount of sericite and gold-dolomite-pyrite. Pyrite in these associations contains inclusions of tetradymite, native gold, and tellurides.

The third productive, pyrite-carbonate, assemblage includes late gold-pyrite-calcite and low-grade barite-sulfide-calcite associations with pyrite, chalcopyrite, hematite, sphalerite, galena, scheelite, cassiterite, and strontionite. Native gold, calaverite, sylvanite, altaite, and tetrahedrite are in minor amounts. This assemblage contains from 15 to 80% pyrite and the highest gold grades, but its distribution is limited.

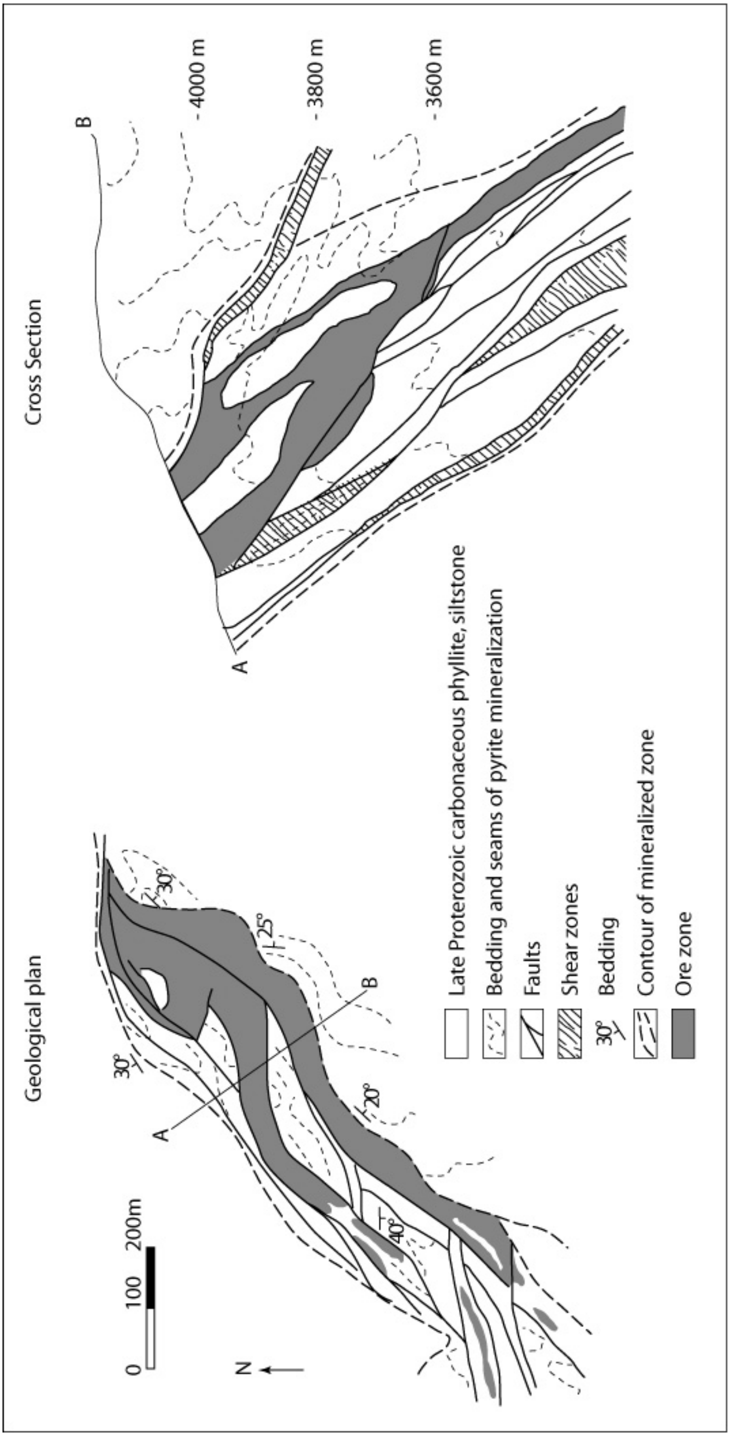


Figure 8. Simplified geologic map and cross section of the Kumtor deposit (after Konstantinov et al. 1992).

Native gold (Jenchuraeva et al. 1999) is closely associated with pyrite, chalcopyrite, pyrrhotite, calaverite, and altaite. The size of gold particles varies from less than 0.03 mm to more than 0.9 mm.

The two last associations, hematite-siderite and barite-polymetallic, do not contain gold. Hematite in the hematite-siderite association is typically replacing pyrite of all productive mineral associations. The barite-polymetallic-calcite association is locally developed within ore bodies and only occasionally forms visible concentrations of calcite, barite, chalcopyrite, and gray copper ore. Galena, sphalerite, pyrrhotite, hessite, petzite, prustite, argentite, and native silver also occur in small amounts.

A recent description of Kumtor's ore deposition (Ivanov et al. 2000) identified four stages of mineralization: (1) weakly auriferous (<1.2 g/t) pervasive quartz-carbonate-chlorite-sericite-pyrite alteration and rare small veins and veinlets accompanied by removal of carbonaceous matter and recrystallization of sericite and chlorite; (2) intensive stockwork veining and hydrothermal brecciation associated with sericitization, chloritization, and silicification; pyritization, carbonatization, and feldspathization are less important; (3) stockwork veining and hydrothermal breccia almost completely of carbonate and pyrite composition without K-feldspar, which occupy the central part of mineralized zone and contain the highest gold concentration; and (4) carbonate-pyrite assemblage in layered or massive planar, often brecciated ore bodies, which associated with zones of intense deformation and boudinage of previously altered phyllite.

Of the two contrasting sets of description given above, the first was produced during exploration and is focused on mineralogy. The second study concentrated on stages and morphology of mineralized zones, which become observable during mine operations.

Gold fineness is changed from 935-960 in productive associations to 720-750 in the late barite-polymetal-calcite assemblage. Ore grade varies from 1.5 to 4.5 g/t gold and averages 3.58 g/t. According to some studies (Konstantinov et al. 2000), the Kumtor deposit contains 1.06-1.21 g/t platinum and 2.46-3.01 g/t palladium, but these data require verification.

Temperature of gold-bearing solutions (Ivanov et al. 2000) was 320°C. This relatively high temperature is consistent with the associated albite-potassium feldspar alteration.

The Ar-Ar plateau ages for bulk-rock, sericite, and ore samples range from 284 to 288 Ma (Mao et al. 2004). Late Hercynian granite magmatism, common in parts of the South Tien Shan accretion zone, is not known in the vicinity of the Kumtor deposit of the central Tien Shan; and there is little evidence supporting speculations that Kumtor is associated with this magmatism.

The gold production of the Kumtor mine during 1997-2005 totaled about 5 Moz. According to Centerra's 2005 annual report, current proven ore reserves of the Kumtor deposit are 40,162,000 tonnes grading 3.8 g/t or 4.953 Moz (153.5 t) of gold. Measured and inferred ore resources of the deposit are 24,007,000 tonnes grading 3.9 g/t, i.e., 3.021 Moz (93.65 t) of gold. Geological resources of the deposit estimated by Soviet geologists are significantly larger.

In addition to gold, tungsten may be of economic interest (Jenchuraeva et al. 1999). The tungsten mineralization is represented by a very fine-grained scheelite. The Kumtor deposit commonly contains 0.01 to 0.3% WO_3 while in the stockwork and southern ore zones its content increases up to 0.5%.

The Muruntau Deposit (41°31'N-64°35'E)

Another example of gold-feldspar-carbonate-sulfide mineralization in metamorphic sedimentary rocks is the Muruntau deposit—one of the largest individual gold mine in the world with total gold resources exceeding 5,200 t. The open pit is about 3.5 km x 2.5 km x 340 m in size and since its development in 1967 produced approximately 1,800-1,900 t of gold. According to Shayakubov et al. (1999); 1,186 t of gold were produced during 1967-1995, leaving 2,230 t of proven reserves at depth of less than 700 m. An additional 1,830 t of gold are contained in inferred resources to 1,500 m depth.

The Muruntau deposit is located in the southeastern part of the Tamdytau Mountains, 400 km west of Tashkent, Uzbekistan. This region is part of the Hercynian fold and fault system of South Tien Shan that lies along the west-northwest striking suture zone between the Karakum-Tajik and the Kazakh—North Tien Shan plates during Late Carboniferous—Early Permian collision of continents (Moras and Fibridge 1997). The collision was accompanied by intense calc-alkaline volcanism along the south border of Kazakh—North Tien Shan continent, development of major nappes, and obduction of an ophiolite complex onto Karakum-Tajik continent (Zonenshain et al. 1990).

Muruntau is located near the two regional shear zones: the northwesterly-striking Sangruntau-Tamdytau, which is concordant to the regional structure, and the transverse Muruntau-Daugyztau (Drew et al. 1996). A. T. Bendik, G. A. Ivanov and Sh. Sabdyushev, N. V. Kotov and I. G. Poritskaya, N. K. Kurbanov, P. A. Mukhin, S. D. Sher, and many other geologists have described the geology of the Tamdytau Mountains including the Muruntau area in numerous publications. Drew et al. (1996) and Shayakubov et al. (1999) have compiled this information.

The oldest formation in the Tamdytau region belongs to the Taskazgan suite of the Eocambrian-Late Precambrian (Riphean-Vendian in Russian, 1,650-590 Ma) epoch. The suite consists of marine siliclastics, mafic volcanics, carbonaceous shales, and dolomitic carbonate rocks now metamorphosed to chlorite-actinolite-epidote-albite schists. The rocks are isoclinally folded and are exposed to the west of Muruntau in a southern Tamdytau nappe.

The ore-hosting assemblage at Muruntau is the Cambrian-Ordovician Besapan suite, about 5 km thick. It is subdivided into four units from bS1 (oldest) to bS4. The oldest one (bS1) consists of light brown to greenish, ferruginous, and sericite-chlorite mica schists after carbonaceous siltstones with some sandstone and shales. The bS2 unit is also carbonaceous but darker and consists of mainly metasandstone with grit, gravel, and abundant biotite. The main ore host unit (bS3) consists of phyllitic to schistose carbonaceous metasiltstones, metasandstone, and metatuff all variably calcareous. This unit is referred to as a “Variegated Besapan” because of its red and green color in outcrops. The uppermost unit (bS4) is mainly quartz-clay sandstone with metasiltstones, argillite, and lenses of metagritstone. It is referred to as the “Green Besapan” because of its abundance with metamorphic chlorite and sericite.

The Proterozoic and Paleozoic sequences form a regional syncline in the central part of Tamdytau and adjacent anticline to the south, which are complicated by smaller folds.

Low-angle, intraformational thrust faults present at Muruntau are related to early ductile deformation and concentrated mainly within the Variegated Besapan (bS3) unit (Shayakubov et al. 1999). The main thrust zone, 300-800 m thick, with several thrust planes is located at the base of this unit. The main thrust planes served as barriers to ore solutions while the interlayered ones host some gold-bearing ore bodies.

Young, northerly- and northeast-trending, steep-dipping faults are the main ore-controlling structures. The most important are the South and Northeast faults (Fig. 9). The former is a steeply dipping shear zone of sinistral strike-slip displacement with vertical extent of 500 m and a lateral displacement of more than 1,000 m. Extension fractures, which accompany the northeast fault, are filled with gold-rich "axial" quartz veins, widespread in the central part of the Muruntau deposit.

The nearest granodiorite pluton is located about 12 km southeast of Muruntau and has an Rb-Sr isochrone age of 286.2 ± 1.8 Ma (Kostitsyn 1996). A body of leucocratic granite intersected by a deep drill hole (SG-10) at 4,005-4,296 m beneath the deposit has a similar Rb-Sr isochrone age of 287.1 ± 4.6 Ma. This granite contains 27.9-34.2 vol. % of quartz, 31.4-36.3% of plagioclase, 27.9-33.9% of K-feldspar, 1.4-5.4% of biotite, and up to 1.5 vol. % of muscovite (Shayakubov et al. 1999).

Swarms of younger felsite, syenite, and lamprophyre dikes are exposed on the edge of the ore field within regional shear zones. A. Bendik (in Shayakubov et al. 1999) described four stages of magmatic activity in the region as rare Early Paleozoic silicic dikes, Middle Carboniferous isolated gabbro-diorite stocks, Late Carboniferous small granodiorite stocks, and Permian (244-277 Ma) dikes of various compositions.

Stockworklike vein/veinlets gold mineralization at Muruntau has complex shape. (Sher 1972; Smirnov 1977). Three main elements of the stockwork are large quartz veins of simple and complex shape, zones and "nets" of quartz veinlets, and sulfide-rich quartz veinlets. Ore bodies typically contain combinations of steeply and gently dipping quartz veins and veinlets zones that are discordant or concordant to the host rocks.

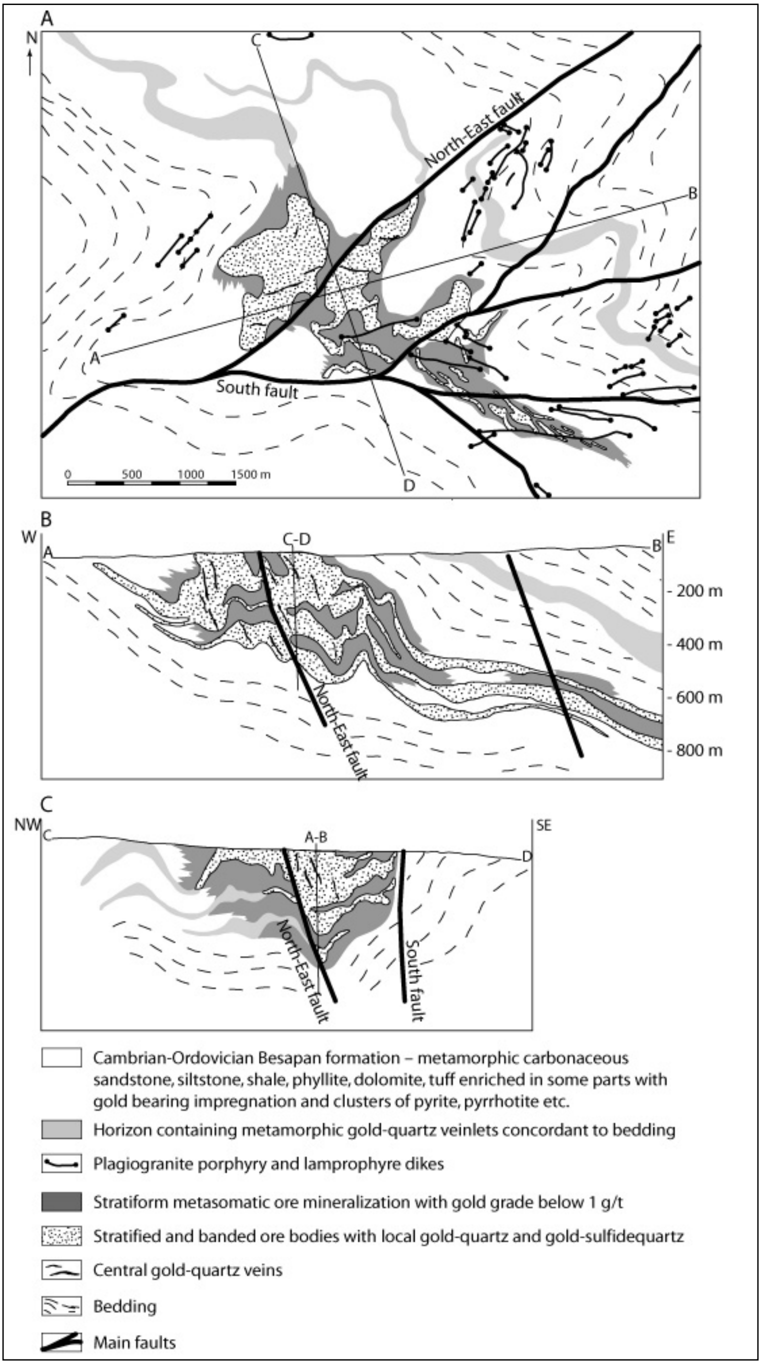


Figure 9. Geology of the Muruntau mine area (simplified after Drew et al. 1996): plan (A), east-west cross section (B), and northwest-southeast cross section (C).

Discordant, steeply dipping parts of the ore bodies are richest in gold and consist of parallel quartz veins and bands of thin quartz, quartz-sulfide, quartz-tourmaline, and carbonate veinlets. Numerous conformably bedding, gently dipping veinlet zones extend outward from the discordant parts. Quartz veins and veinlets of the discordant zones are localized in slip joints dipping at 60-70°. The largest veins are lenslike and up to 14 m thick but usually are 20-30 cm thick and can be traced for 50-150 m. Veins have sharp contacts with phyllite while in metasandstone and siltstones they are accompanied by numerous veinlets.

Veinlet zones conformable with sheared strata consist of micrometer—to centimeter-wide veinlets forming layerlike zones commonly boudinaged or folded. These zones are usually low-grade and become ore-grade mainly in combination with discordant vein-veinlets zones. According to Drew et al. (1996), discordant veins are formed along high-angle faults, which crosscut zones of conformable veinlets. The ore bodies generally are up to 100-400 m thick, from 800 to 1,350 m long, and have vertical extent up to 1,000 m. Stockworklike mineralization generally extends in a northeast-southwest direction, but in the southern part of the deposit, sinuous ore bodies are elongated northwest to southeast (see figure 9).

The hydrothermal alteration and veining at Muruntau can be divided into two stages (Drew et al. 1996). The first stage is represented by biotite-chlorite-plagioclase clots in schists with the addition of cordierite and sillimanite at depth. This type of alteration formed a bulbous-shaped zone surrounding the Muruntau deposit and becomes narrower to the west and southeast.

During the second stage, quartz-albite-biotite-chlorite-oligoclase assemblage was developed in association with subparallel zones of quartz veins and veinlets. It occurs along the northern part of the Sangruntau-Tamdytau shear zone.

Five mineral assemblages at Muruntau (Shayakubov et al. 1999) are (1) pyrite-chlorite-biotite-quartz, (2) scheelite-gold-carbonate-chlorite-potassic feldspar-quartz sometimes with pyrite and arsenopyrite, (3) gold-arsenopyrite-quartz, (4) quartz-albite-pyrite-tourmaline, and (5) polysulfide-carbonate-quartz. The most important is the second, scheelite-gold-carbonate-chlorite-potassic feldspar, assemblage, which accounts for about 85% of the ore. It occurs as quartz veins and stockworks in banded and brecciated altered rocks. The third assemblage occurs in steeply dipping veins and system of veinlets, up to 1 m thick. While these contain the highest gold grades (up to 11 g/t), their contribution to ore bodies is less than 5%. Shayakubov et al. (1999) consider this assemblage to be the first post-dike while Drev et al. (1996) described it as a pre-dike.

The fourth, quartz-albite-pyrite-tourmaline, assemblage is concurrent with or occurs immediately after intrusion of siliceous dikes, forms veins with K-feldspar and dolomitic carbonate. These veins crosscut dikes and are present along brittle fractures that also controlled mineralization of the previous stage.

In the last stage, calcite veins with sparse pyrite are associated with pervasive calcite replacement of the host rock matrix.

The Muruntau ore contains between 0.5 and 1.5% sulfides with mainly pyrite, minor amounts of arsenopyrite and scheelite, and rare sphalerite, galena, chalcopyrite, wolframite, bismuthinite, and native bismuth. Gold occurs within quartz in association with sulfides (Borodaevskaya in Smirnov 1977). It forms fine inclusions in quartz, veinlets, and small nests in accumulation of sulfides and along the boundaries of the quartz grains. Gold in sulfides forms fine (0.001-0.99 mm) segregations and thin, short veinlets in broken sulfide grains or on their surface. Native gold contains traces of silver, copper, bismuth, lead, arsenic, and iron and has a high fineness of 830-980.

Several phases of the hydrothermal fluid circulation are interpreted (Graupner et al. 2001). Primary fluid inclusions are found in angular fragments of quartz crystals in steeply dipping veins. They have intermediate to high temperatures of homogenization (260 to more than 350°C), are CO_2-rich, and contain NaCl as the cation-anion component of the fluid. Secondary inclusions in quartz of all vein types have lower temperatures (100 to 250°C), low salinity, and aqueous composition.

Similarities between the Muruntau and Kumtor deposits include high-grade metamorphism of host rocks, high temperature of alteration and ore formation with broad development of albite and K-feldspar as a gangue minerals, high fineness of gold, and composition of fluid inclusions.

Many Russian and Uzbek geologists relate gold mineralization at Muruntau to intrusion of late Hercynian granite plutons known in the vicinity of the deposit and inferred to lie under it. However, $^{40}Ar/^{39}Ar$ ages of hydrothermal sericite (Wilde et al. 2001) and an Rb-Sr isochronal age of gold-bearing quartz veins (Kostitsyn 1996) suggest that ore formation occurred during two stages at about 245 and 220 Ma. Thus, ore mineralization appears to have occurred at least 30 million years after granite intrusion. In addition, the intrusion age can be considered only as an approximation (Wilde et al. 2001) given the probability of hydrothermal resetting of the magmatic Rb-Sr system during alteration related to the Muruntau mineralization. That age difference between granitoid intrusion and development of gold mineralization can be even larger.

A recent geochronological study at the Muruntau deposit based on Re-Os dating of arsenopyrite (Morelli et al. 2007) has determined that the age of main-stage gold mineralization is 287.5 ± 1.7 Ma and this stage overlaps the time of post-tectonic granitoid magmatism emplacement in the region. This study shows that arsenopyrite yields relatively unradiogenic initial Os and elevated $^{3}He/^{4}He$ ratios, relative to purely crustal Os-He reservoirs, and suggests the presence of mantle-derived components in the ore system. Assuming that post-tectonic granitoid magmatism itself was triggered by mantle-derived heat and fluids, it is perhaps permissible but not necessary to conclude that the Muruntau deposit is intrusive-related and to require the reexaminations of the accepted model of other giant "orogenic gold" deposits worldwide as is suggested by the authors.

Origin of hydrothermal fluids responsible for the formation of the Muruntau deposit requires additional study. However, it seems unlikely that the 300 m thick leucocratic granite intrusion intersected under the deposit is alone responsible for such a huge volume of the mineralization.

The Svetlinskoe deposit of the southern Urals is another example of a zone with veinlet-disseminated gold mineralization in metamorphic sequences. Relatively similar gold deposits in metamorphic host rocks are known in the Appalachian of the USA, but they are much smaller than Muruntau.

4.1.1.3 Gold-Quartz (Carbonate)-Sulfide Deposits

The Sukhoi Log deposit is a lone known example of this type of gold mineralization in metamorphosed sedimentary sequences, but almost 2,000 tonnes of gold reserves warrant its detailed description as an individual mineral type.

The Sukhoi Log Deposit (58°37'N-115°15'E)

The Sukhoi Log deposit is located in Bodaibo region of Irkutsk Oblast (East Siberia) about 850 km northeast of the city of Irkutsk and 130 km north-northeast of the town of Bodaibo—the center of the famous Lena gold placer district. This region has produced more than 1,500 t of placer gold since the middle of the nineteenth century. The deposit was discovered in 1957 and explored during the 1960s.

It is situated in Bodaibo synclinorium along the southern rim of the Siberian platform and was formed during the Baikalian (Late Precambrian) orogeny. Archean and Early Proterozoic highly metamorphosed schists and marble form the basement of the synclinorium. Late Precambrian (Riphean-Vendian in Russian terminology) sedimentary sequences of synclinorium up to 15 km thick are preserved in the axial trough zone and consist of conglomerates, carbonaceous and calcareous siltstones, slates, phyllite, and limestone. These rocks are metamorphosed to chlorite-sericite greenschist facies at the central part of the synclinorium and to epidote-amphibole facies at its periphery.

Gold mineralization is hosted exclusively in the Late Riphean (Neocambrian) flyschlike Khomolkho formation, which consists of alternating layers (0.1-3 m) of carbonaceous and calcareous siltstones, shales, and sandstones with abundant diagenetic sulfides. Organic carbon contents of the host rocks vary between 2 and 7 wt. %. The highly carbonaceous rocks were deposited in a continental margin sea basin (Distler et al. 2004).

The synclinorium is characterized (Sintsov 2001) by practically uniform deformation of the Riphean-Vendian sequences into west—east-trending folds up to 100 km long and several kilometers wide. The synclines usually have U shape, while the anticlines are isoclinal or V-shaped. Easterly-trending sinistral and NW-SE-trending dextral faults form conjugate shear zones. These strike-slip faults are developed in folded rocks of the synclinorium only and do not penetrate the basement. Geological-geophysical data interpreted by A. Fel'dman and E. Pototskaya (TsNIGRI) indicate the presence of throughgoing concealed faults of N-S and NE-SW trends related to an Early Proterozoic graben.

Magmatic rocks are represented at the Sukhoi Log area by the small Konstantinovsky granitoid massif exposed 6 km southwest of deposit and associated granite porphyry and quartz porphyry dikes (Laverov et al. 2000a). A large gravity minimum in the deposit area could be interpreted as a concealed granitoid pluton some 110 km^2 in size. The Konstantinovsky massif and the Sukhoi Log deposit are located in a gradient zone on the periphery of this gravity minimum.

The Sukhoi Log deposit is situated in an overturned, isoclinal anticline of second order near the intersection of northerly- and northeast-trending concealed deep faults. The fold hinge is gently dipping (0-13°) to the west. The deposit is located at the anticline bend where small drag folds, secondary cleavage, and corrugation along local fractures and faults have developed (Buryak and Khmelevskaya 1997). The most intensely deformed core part of anticline is a crush zone up to 200-250 m wide and dipping 20-30° to northeast.

The ore zone located mainly within the crush zone. It can be traced for about 5 km along strike, and its thickness increases downward from 20-25 m up to 200-250 m due to increasing thickness of the ore-hosting sequence. A roughly tabular, stratiform ore body up to 140 m thick and 2.2 km long is outlined at the cutoff grade 1.0 g/t. It has bulges and pinches (Fig. 10), which coincide with layers of unmineralized sandstone and siltstones.

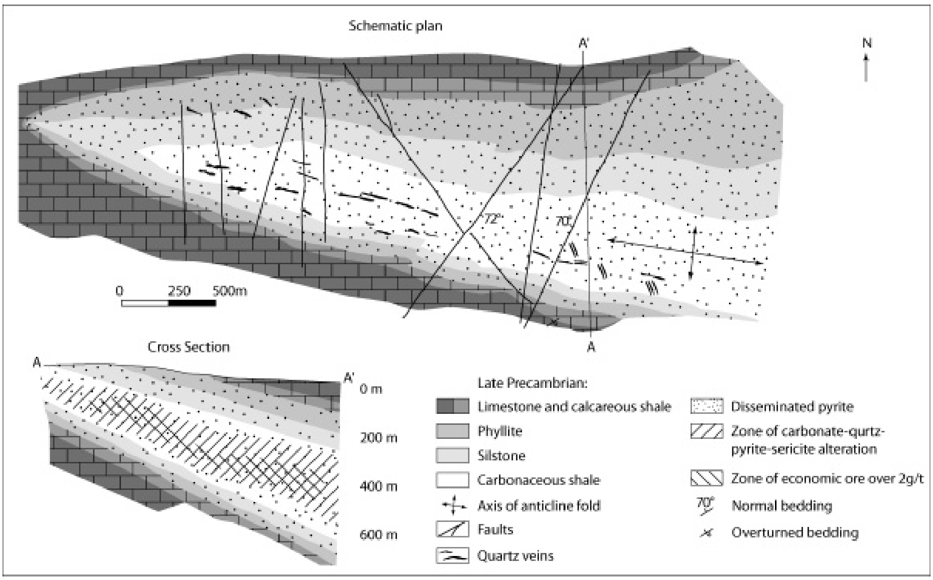


Figure 10. Schematic geologic plan and cross section of the Sukhoi Log deposit (modified after Kurbanov 1993).

The ore zone containing veinlets and nests of sulfides and quartz has undergone multiphase Mg-carbonatization (siderite, manganosiderite), silicification, and pyritization. Pyrite is the main ore mineral of the quartz-pyrite and quartz-carbonate-pyrite zones; but about fifty another sulfides (pyrrhotite, chalcopyrite, sphalerite, galena, molybdenite, argentite, arsenopyrite, etc.), tellurides (altaite, calaverite, petzite, joseite, etc.), antimonides and sulphosalts (dyacrasite, tetrahedrite, galenobismuthite, etc), and tungstates (scheelite, wolframite) are known (Distler et al. 2002). These minerals occur mostly as inclusions in pyrite but form also individual grains. In addition, ore contains native metals such as gold, platinum, silver, and alloys including gold-silver, copper-zinc, platinum-copper, and many others. Total sulfide content varies from 0.5 to 1.5-2.0%.

The most widely distributed form of pyrite that have been documented at the Sukhoi Log (Zvereva et al. 1982) is the inclusions of individual cubic crystals and their aggregates formed in the early stage of mineralization. Veinlets and lenslike accumulations of pyrite are formed at a later stage. They are conformable with layering of host rock as well as following cleavage fractures in high-grade parts of the deposit. Pyrite in such veinlets has higher arsenic content than the earlier pyrite of inclusions. Some pyrite is found in boudinlike segregations of sandstone and/or siltstones in phyllite shales. Such pyritized segregations typically have high gold grades.

Gold grade shows (Yanovsky 1990) a slight increase with depth from less than 1 g/t at 430 m level up to 4 g/t or higher at the 830 m and 1,030 m levels of the Sukhoi Log deposit (Fig. 11).

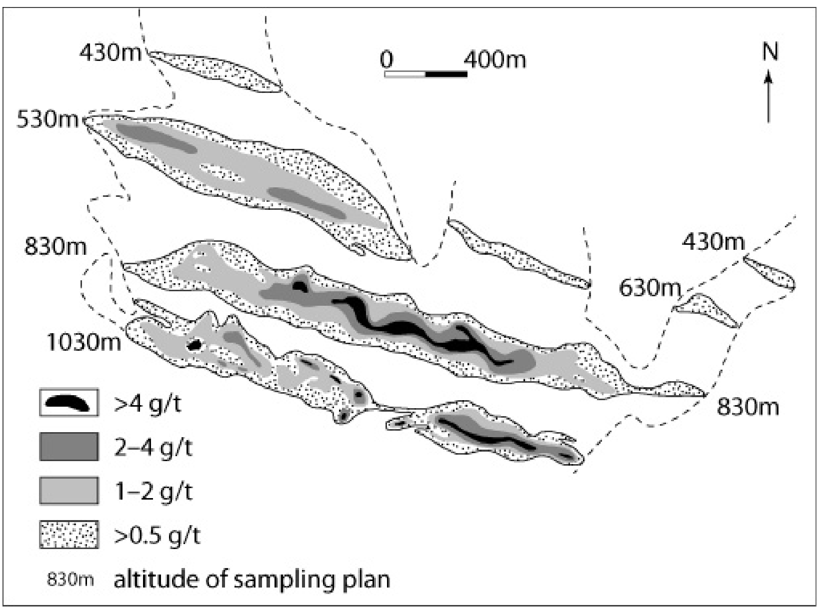


Figure 11. Gold-grade distribution in horizontal sections of the Sukhoi Log gold-bearing bed (after Yanovsky 1990).

Native gold forms particles of 0.01-0.3 mm in size almost exclusively as inclusions in or along fractures and boundaries of pyrite. Its fineness varies between 840 and 920. The gold grade of monomineralic pyrite crystals is different within high-grade and low-grade parts of the ore body. Neutron-activation instrumental analyses of pyrite at TsNIGRI (Moscow) showed a high fluctuation in gold grades from 1 g/t up to 2,940 g/t in the high-grade parts of ore body and from 0.05 g/t to 28.7 g/t in lower grade zones. Analyses of gold are showed also overall lower gold grade but higher gold fineness in individual pyrite crystals of the early stage in comparison with pyrite in veinletslike aggregates of later stages.

While exact data about the Sukhoi Log deposit gold reserves are not openly published, they probably are between 33 and 47 million ounces. According to Dr. Bryce Wood, who participated in a bankable feasibility study on the deposit in 1992-1996 with Australian Star Mining Co., geological reserves at a cutoff grade of 1 g/t are 384 million tonnes of ore with average grades of 2.5 to 2.7 g/t Au, i.e., about 998 t or 32 Moz of gold. Additional resources include 165 million tonnes at 2.0 to 2.3 g/t in low-grade possible pit extensions, equal to approximately 355 t or 11.4 Moz of gold. Another 205 million tonnes of ore at 0.8 g/t Au (164 t or 5.27 Moz of gold) are contained in the mineralized envelope with total resources of the deposit of 48.67 Moz. Dr. Wood mentioned that the highest ore grades occur in pyritic black shales beds, especially where they cross the anticline axis and form two higher-grade (4-9 g/t) cylindrical zones along the gently plunging anticline crest.

Accessible Soviet data indicates proven gold reserves of the Sukhoi Log deposit as 1,029 t or 33 Moz of gold, but 2007 reevaluation of the deposit resources sharply increased balance reserves of the Sukhoi Log up to 1,952.9 t or about 63 Moz grading 2.1 g/t (Mineral.ru, 2/13/2008).

Some Russian geologists suggest that the economical value of this giant gold deposit could be even higher due to the discovery in Sukhoi Log of platinum mineralization (Distler et al. 1996; Laverov et al. 2000; Wilde et al. 2002). Platinum group of elements (PGE) mineralization (Distler et al. 2002) consists mainly of native Pt, as well as Pt-Fe and Pt-Cu alloys, as well as palladium tellurobismuthide and rhodium. The PGE-bearing minerals are accompanied by a large number of native metals and alloys such as native iron, chromium, tin, lead, nickel, tungsten, and titanium. The PGE mineralization is stratabound and coincides with gold ore but also is developed in overlaying it metasedimentary rocks. According to analyses of mineral assemblages, termobarometric, and isotope data, PGE mineralization was formed earlier than gold.

Specific published data on platinum and palladium grades in the Sukhoi Log deposit are very rare. Two samples from drill holes analyzed by atomic absorption technique (Razvozzhaeva et al. 2002) did not detect platinum while the third one returned 0.03 ppm. According to Russian *Mining Journal* (March 2004), a 102.4 m drill hole intersection at the Sukhoi Log deposit contained 1.45 g/t PGE including 40.5 m grading 2.42 g/t.

However, Dr. Frank Bierlein and his colleagues of the Monash and Saskatchewan universities who analyzed 45 carbonaceous whole-rock samples from different deposits (Ballard, Muruntau, Kumtor, Sukhoi Log, and others) received completely different results. According to their progress report (Bierlein et al. 2002), platinum grade at Sukhoi Log varies from <2 to 15 ppb, palladium—up to 30 ppb, and rhodium grade is 3 ppb and less. It means that platinum contents at least with current analytical and processing methods do not have any real significance. The results of control analyses taken by Placer Dome and Barrick Gold Corp. also support such conclusion since they did not reveal any significant grades of PGE in the ore.

Three main stages of gold mineralization at the Sukhoi Log deposit (Laverov et al. 2000) are syndiagenetic, metamorphic, and hydrothermal-metasomatic. The gold ores were deposited from high-temperature CO_2-rich hydrothermal solutions, which interacted with organic carbon of the host rocks under highly variable redox conditions.

The isotope data (Distler et al. 2002) show that slightly altered rocks contain a fraction of soluble and volatile organic matter of bitumen-petroleum composition (^{13}C=28.7 ppm) and a fraction of insoluble organic matter (^{13}C=17.5 ppm). The total isotope composition of organic and carbonate carbon within the ore zone is heavier (^{13}C=11.64 ppm). An increase of total carbon in the ore zone is probably caused by a greater contribution of carbonates formed in the ore zone during oxidation of organic carbon. This process favored segregation of native metals at the earlier stages of the ore-forming process.

The ^{34}S isotope composition has a tendency to be lower in the ore zone and higher in the surrounding rocks. Sulfur isotope ratio increases from early to later generation of pyrite. It indicates (Distler et al. 2000) wide temperature interval of sulfide deposition and introduction of an endogenous source with the mantle sulfur into the ore zone.

The Sukhoi Log giant deposit is a unique one. The Homestake deposit of the U.S. has some similar features to the Sukhoi Log but cannot be viewed as a full analog. Both deposits have similar amount of gold resources over one thousand tonnes each and are hosted by Late Precambrian sediments. The host rocks underwent the same metamorphic alteration in greenschist and amphibolite facies. Ore bodies of both deposits are located at the anticline folds near intersection of two regional fault systems and contain disseminated and veinlets mineralization of sulfides. However, amount of sulfides at the Sukhoi Log deposit is much lower (2.5-3.0%) than in the Homestake deposit (up to 8%), and the prevalent sulfide is pyrite while the Homestake mineralization contains higher amount of pyrrhotite and arsenopyrite and has higher gold grades (5.5-9.0 g/t versus 2.8-3.0 g/t). While not identical, the Homestake is the closest analog for the Sukhoi Log deposit.

Concepts on genesis of the Sukhoi Log gold mineralization and for all other gold deposits in metamorphosed sediments are different. Some geologists assert that its mineralization is related to metamorphic and metasomatic events, which extracted precious, nonferrous, and rare elements from the carbonaceous host rocks of the Bodaibo synclinorium (Buryak 1964; Kotkin 1984; Buryak and Khmelevskaya 1997; Buryak et al. 2002; etc.). Other geologists (Drew et al. 1996; Laverov et al. 2000, 2000a; etc.) assume that significant role in formation of gold mineralization belongs to hydrothermal solutions related to granitoid pluton. Goldfarb et al. (2001) and Groves et al. (2003) mentioned the Sukhoi Log deposit along with Olimpiada, Kumtor, and Muruntau as an orogenic one in metamorphic belts indicating that deeply sourced magmatic fluids are possible in their deposition alongside with mid- and lower-crustal metamorphic fluids.

Presence of granitoid plutons under the gold deposits in metamorphic sequences (Sovetskoye, Kumtor) has been based commonly on gravimetric data and was verified only at the depth of 4 km by a single superdip drill hole (SG-10) at the flank of the Muruntau ore field. According to seismic data (Lishnevsky and Distler 2004), the base of the earth's crust at the Bodaibo synclinorium is located at the depth of 35-37 km, and an uplifted anomalous mantle relatively rich in fluids underlies the crust there. The conclusion that such hot, ore-bearing mantle fluids are responsible for granitization and generation of the possible granite pluton under the deposit (Laverov et al. 2000a; Lishnevsky and Distler 2004) requires additional study.

4.1.2 Zones of Veinlet-Disseminated and Vein Gold Mineralization in Black-Shales and Carbonate-Sedimentary Formations

This type of deposits has a broad development in the CIS gold provinces of different age but with similar ore-hosting sedimentary sequences metamorphosed to greenschist facies. The deposits are hosted by carbon-bearing sedimentary, carbonate-sedimentary, and sometimes volcanic-sedimentary sequences of intercontinental troughs, accretionary complexes, and troughs along passive continental margins with very low or complete absence of volcanogenic material.

There are three main mineralogical-geochemical varieties of this type of gold deposits in the CIS: (1) gold (arsenic)-sulfide (Bakyrchik, Daugyz, Nezhdaninskoye, Olimpiada, Maiskoye, and other), (2) gold-mercury-quartz (Kyuchus, Vorontsovka), and (3) gold-antimony-quartz deposits (Sarylakh, Sentachan, Uderey, and smaller ones). The former two have predominantly veinlet-disseminated mineralization, while the third one contains combination of veinlet-disseminated and vein mineralization.

The gold (arsenic)-sulfide variety of deposits is one of the main sources of gold reserves in the CIS but is quite rare in other gold provinces of the world. At the same time, the gold-mercury-quartz deposits, which share many characteristics to the Carlin type, have quite limited distribution in the CIS. In both cases, it is caused by their specific tectonic settings that will be discussed later.

It is not clear yet if gold-antimony-quartz mineralization should be distinguished as an independent geological/geochemical type of deposits (Narseev 1991). Such mineralization exists commonly as the final stage of both the gold (arsenic)-sulfide and gold-mercury-quartz deposits and could be genetically related to them. However, hypertrophic deposition of quartz-stibnite mineral association sometimes is leading to formation of the rich-in-gold-antimony deposits such as Sarylakh or Sentachan (Yakutiya). A possibility to find other deposits of this geochemical type is high enough to justify its separate description.

4.1.2.1 Gold (Arsenic)-Sulfide Deposits

The discovery in 1953 of the veinlet-disseminated Bakirchik deposit with acicular arsenopyrite and arsenical pyrite containing micron-size gold inclusions and large (13 Moz or about of 400 t) gold resources in carbon-bearing black shales of eastern Kazakhstan made this type of gold deposits very significant for the CIS.

Similar world-class gold deposits with reserves 4.8-20.97 Moz (150-650 t) of gold such as the Daugyz and Kokpatas (western Uzbekistan), Nezhdaninskoye (Yakutiya), Maiskoye (Chukotka, Russian Northeast), Olimpiada, and Veduga (Yenisey Range, E. Siberia) were explored during the 1960-1980s. Smaller deposits of this type are Chore (Tajikistan, 2.6 Moz), Savoyardy (Kyrgyzstan, 1.45 Moz), and Tokhtarovskoe (W. Kazakhstan, 0.65 Moz). These deposits are located within different tectonic settings from Late Proterozoic (Baikalian) structure of the Yenisey Range to Mesozoic terranes of Verkhoyano-Chukotsky fold belt.

The Soviet classifications defined this type of the deposits as gold-sulfide (Timofeevsky 1971) or gold-carbon (Gar'kovets 1973; Yanovsky 1981) formation. It was named later (Narseev 1991) as a subtype of a larger category of deposits designated as the "black-shales" type of gold deposits.

Zones of veinlet-disseminated mineralization within black-shales and carbonate-bearing flyschlike and molasse sequences are located usually within intercontinental troughs and accretionary zones.

Sedimentary sequences hosting veinlet-disseminated gold mineralization have specific features (Konstantinov and Levitan 1990): (1) coarse and uneven rhythmic layering; (2) disseminated and lenslike stratified aggregates of sulfides, siderite, and phosphorus concretions; (3) high calcareous facies, which contain stratified or remobilized into fractures carbon substance and sometimes coal lenses; and (4) gold concentrations commonly 1-2 times higher than the average Clarke in such sediments.

Ore mineralization is usually situated within regional shear zones, which exhibit intensive plastic deformation and boudinage in connection with tectonic thrusts especially in favorable horizons enriched by clay-carbon-phosphate nodules. Some deposits are located under barriers of more dense shales or carbonate layers and thrusts.

All deposits regardless of the age of the ore-hosting sequences have similar features: (1) significant thickness of ore bodies from a few to tens of meters, (2) high grade of arsenic due to spatial and temporal association of gold with the pyrite-arsenopyrite mineral association, (3) acicular arsenopyrite containing up to hundreds gram per ton of gold and arsenical pyrite with low gold grade, (4) mainly micron-sized dispersed gold in sulfides unfavorable for placer development, and (5) presence of antimony mineralization at the late stages of ore deposition. All deposits are characterized by high level of carbon in the ore and moderate gold grades (5-10 g/t) without large fluctuations.

The micron-level inclusions of gold in sulfides, the high arsenic content, and the refractory carbon in these ores require high-cost metallurgical processes.

The origin of these deposits is rather controversial. Some of the CIS geologists suppose that veinlet-disseminated sulfide mineralization in black-shales sequences represents the "roots" of epithermal gold deposits (Sidorov and Novozhilov 1982; Sidorov 1987). Such an origin is possible for the periphery of the Mesozoic Okhotsk-Chukotka volcanic belt, but it cannot explain veinlet-disseminated mineralization in the Proterozoic sediments of the Yenisey Range without any indication of younger volcanic belts and epithermal deposits.

More general approach (Narseev et al. 1986; Narseev 1991) suggests three stages of ore deposition. The first stage includes deposition of gold-bearing sediments in the structures similar to the rift of Red Sea as a product of thermal solutions or sedimentation. It is possible that intercontinental character of sedimentation has a main role in accumulation of chemogenic and clastic gold derived from consolidated bordering structures. The second stage—diagenesis and early metamorphic alteration—resulted in redistribution of silica, carbonate, carbon, and sulfides with an increase of a gold-content up to low-grade ore. Economical-grade ore was formed during the final, third, stage under influence of metamorphic-hydrothermal solutions containing additional amount of gold, silver, tellurium, bismuth, and other metals.

The Donlin Creek deposit with resources of about 25 Moz (Goldfarb et al. 2004) recently explored in the Kuskokwim flysch basin of southwestern Alaska is similar to the CIS sediment-hosted, gold (arsenic)-sulfide deposits in carbon-rich rocks with refractory gold related mainly to acicular arsenopyrite. Similar but smaller veinlet-disseminated gold deposits in black-shales sequences are known in China.

The Bakirchik Deposit (49°29'N-81°31'E)

The Bakyrchik gold deposit is located in the Semipalatinsk Oblast of eastern Kazakhstan, approximately 110 km southeast of the Semipalatinsk City. The deposit lies in an east-west-trending graben-syncline that is bordered on the north by the 17 km long Kyzylovskaya shear zone. This shear zone cuts northwest fold structures of the Kalba synclinorium, which is part of the Late Paleozoic Zaisan accretionary zone. The graben-syncline also contains smaller gold deposits (Promezhutochnoye, Bol'shevik, Sarybas, and Zagadka) between two major northwesterly-striking faults.

Middle Paleozoic carbonate and volcanogenic shales form the lower part of the stratigraphic sequence, which includes a 1,500 m thick the Lower Carboniferous volcaniclastic sandstone containing lenses and interlayers of gritstone, conglomerate, and carbonaceous-chert siltstones. The upper part of this sequence consists of 600-800 m thick sandstone unit with layers of carbonaceous siltstones and shales and a basal horizon of sedimentary breccia and conglomerate.

The gold mineralization is localized in the Middle Carboniferous (Kazhgeldin 1996) or Late Carboniferous (Fogelman and Pavlova 1984) thin-rhythmic layering of carbonaceous shales, argillite, siltstones, felsic tuffs, and sandstone. These schistose rocks contain carbon and sulfide impregnation (up to 5-10%). The highest amount of gold-bearing arsenopyrite and pyrite is localized in siltstones with 0.2-0.4% carbon and presence of the carbonates. This Carboniferous clastic sequence fills grabenlike depression—the Kyzylovsky graben. The north slope of the graben is complicated by the 20-45° north-dipping Kyzylovsky thrust, by which the Lower Carboniferous folded sequence is overthrusting the ore-bearing formation (Fig. 12). The southern side of the graben is bordered by high-angle parallel fault. Both graben boundaries are typical shear zones. Fogelman and Pavlova assumed that this graben has been formed within a riftlike structure.

Pre-ore gabbro diabase and diorite porphyry dikes in the Kyzylovsky graben (Narseev et al. 1986) are altered by hydrothermal solutions and contain veinlet-disseminated gold-bearing mineralization. Isolated small bodies of granite porphyry and gabbro are known to the south and east of the graben, but their relations to the gold mineralization are not clear.

The Bakyrchik deposit structure is defined by form of the Kyzylovsky graben and thrust. A 2-3 m thick zone of crushed and boudinaged rocks accompanied by branching faults with feather cracks in the less deformed hanging wall rocks marks the thrust suture. The footwall contains sheared, boudinaged, and corrugated tectonic lenses. Redistribution of carbon substance near the faults that divide tectonic lenses has resulted in the formation of carbonaceous shales with sheared graphite-rich surfaces.

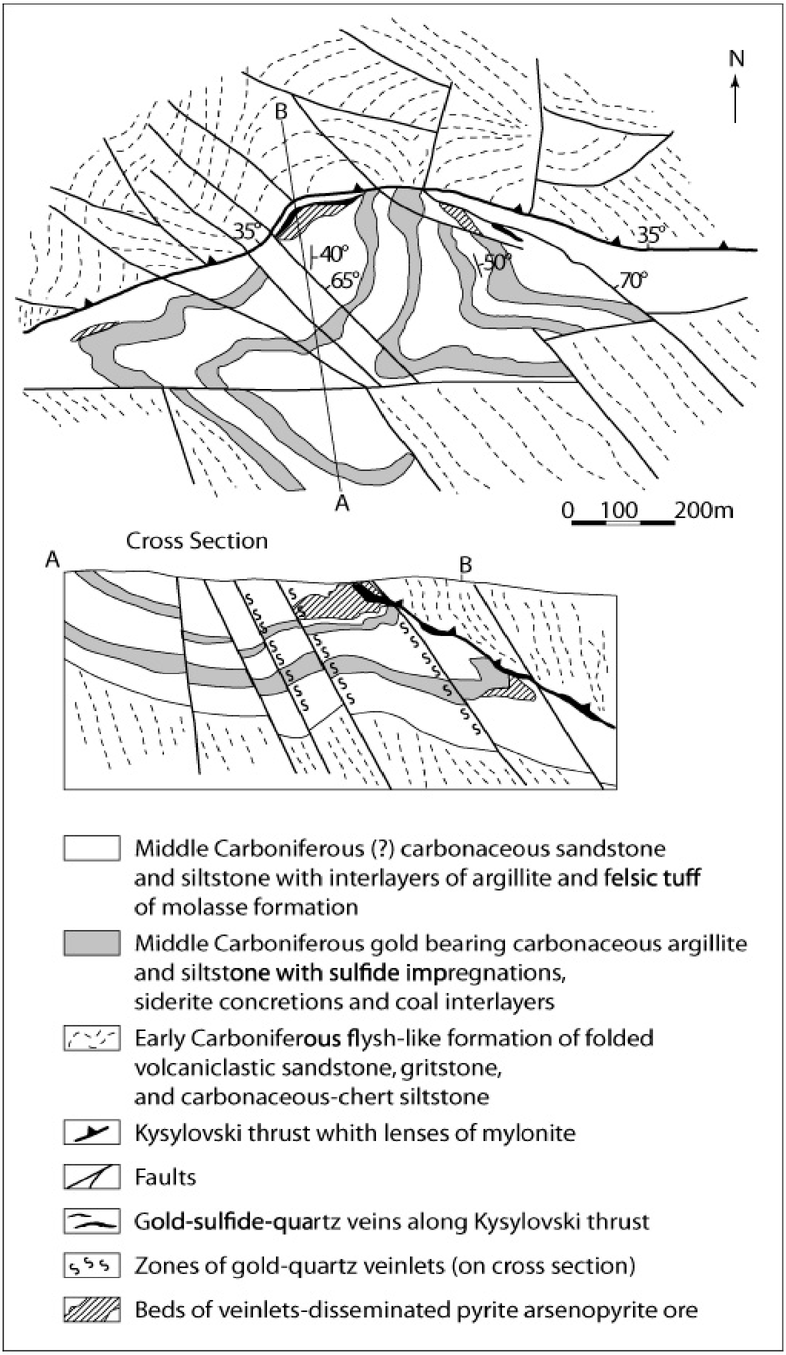


Figure 12. Schematic geological model of the Bakirchik deposit area (modified after Kurbanov 1993).

The quartz-carbonate-sericite hydrothermal alteration, which accompanied the gold mineralization, is clearly shown in the dikes but is less visible in sedimentary host rocks and consists of irregularly developed sericitization, silicification, and carbonatization.

All occurrences of veinlet-disseminated gold-bearing mineralization are concentrated under the Kyzylovsky thrust plane in intensely boudinaged and schistose host rocks. The ore bodies are system of echelon-like five zones of mineralization and have been numbered 1, 3-5, 8, 9-10, and 12. Mineralized zones, up to 20 m thick and 500 m long, are traced by drilling to a depth of 1,200 m from the surface. They have lenseslike, bandlike, or more complex shapes. Ore with gold grades over 5 g/t forms wide stripes with relatively straight contacts that commonly cut the bedding planes of the host rocks. More than 90% of the veinlet-disseminated gold ore is located in sedimentary rocks, and the rest is in altered dykes.

The mineralogical composition of the Bakirchik gold ore is simple (Kazhgeldin 1996): pyrite, arsenopyrite, rare stibnite, pyrrhotite, chalcopyrite, tennantite and tetrahedrite, galena, sphalerite, and very rare mercury. The total sulfide content of the ore ranges from 0.5 to 10%.

Three main mineral associations are present: (1) pyrrhotite, globular pyrite, marcasite, greigite, pyrite, and carbonaceous substance (barren stage); (2) quartz, pyrite, arsenopyrite, and gold (first productive stage); and (3) pyrite, sphalerite, galena, chalcopyrite, tennantite and tetrahedrite, bismuthinite, and aikinite (second productive stage). In addition, gold-quartz association with pyrite, chalcopyrite, sphalerite, and scheelite is detected in the deep horizons; and a post-ore, quartz-stibnite association with native antimony, silver, and mercury is found in the upper part of the deposit.

Gold as microscopic and submicroscopic particles (0.002-0.005 mm) is localized in acicular arsenopyrite and pentagon-dodecahedron shaped pyrite II. Gold grades in arsenical pyrite (1.6-5.6% of As) can reach 60 g/t and in arsenopyrite—150 g/t and more. Larger gold particles (up to portions of mm) are found along microfractures in pyrite and arsenopyrite and occur in association with galena, sphalerite, chalcopyrite, quartz, and carbonate. Sometimes, gold forms inclusions in quartz-sericite-carbonate salvages around sulfides. Free gold of 900 fineness constitutes for no more than 10% of the recovered amount and has a positive correlation with arsenic. The quartz of shear zones does not contain gold.

Homogenization of two- and three-phase inclusions in quartz occurs at 410-360°C with 1,300-1,100 atm of pressure. Homogenization of such inclusions in post-ore, quartz-stibnite mineralization occurs at 210-180°C.

Strong geochemical halos of Au, As, W, Sb, Co, V, Mo, and Cu are found around the Bakyrchik deposit. The upper zone of the mineralization is characterized by Sb, Au, and As; the middle zone by Au, As, Sb with W, Co, V, Mo, and Cu; and lower part of the mineralization has a strong geochemical association of Au with W, As, Cu, and Mo.

Reliable radiometric data on the age of Bakirchik ore mineralization are not known, but geological relationships suggest a Late Paleozoic formation.

According to the Ivanhoe Mines Ltd. news release (July 2006), the measured and indicated resources of the Bakirchik deposit are 62,500,000 tonnes of ore grading 6.6 g/t (cutoff grade 3.0 g/t) or 13.2 Moz of gold.

The Daugyztau Deposit (41°11'N-63°59'E)

The Daugyztau (Daugyz) deposit is located in the Kyzyl Kum-Nuratau gold district of South Tien Shan Hercynian fold belt of western Uzbekistan approximately 60 km southwest of the Muruntau deposit and 80 km of the town of Zerafshan.

The geological and structural features of the Daugyz ore field and deposit are taken mainly from Gureikin et al. (1978, 1979), Gureikin and Arifulov (1986), and Zverev et al. (1999) all of whom participated in exploration of the deposit. The deposit is situated at the western part of Hercynian nappe and fold belt of the South Tien Shan accretionary structure situated between the Kazakh-North Tien Shan and Karakum-Tajik continental plates.

The deposit is controlled by Daugyztau offset of the Daugyz-Muruntau fault. Chert-carbonate, tholeiitic basalt, and chert-shales of the Late Proterozoic Auminza-Taskazgan formation form the base of stratigraphic sequence. The ore-hosting volcanogenic-chert-sedimentary sequence belongs to the Ordovician-Silurian Besapan series and is carbon-rich (0.5-5.0%). The ore-hosting sediments are overlain by Devonian-Carboniferous bituminous dolomite and limestone with siltstones-sandstone interlayers.

The Besapan series has been folded into large linear, NE-striking gentle folds complicated by faults. This earlier folding has been overprinted by younger folds, 3.5-5.0 km long and 1.5-2.5 km wide, as well as NNW faults that are reflecting ore-concentration structure 8-10 km wide (Levitan et al. 1986).

The Daugyztau deposit is located at the intersection of NE and NNW-trending fold and fault structures. The NE faults are related to regional folding (Fig. 13) and form 5 to 6 subparallel tectonic fractures 0.2-3.0 m thick within a 200-300 m wide ore-controlling zone. NNE and NNW dextral faults and slip type fractures are located at the core parts of young folds and have amplitude of displacement up to the tens of meters.

Numerous gold occurrences are located at the intersections of the younger arcuate fold with northeast-trending faults or at the intersections of ore-controlling northeast faults with ore-hosting north-northeast fractures.

Gold mineralization is concentrated in the middle part of ore-hosting sequence that consists of rhythmically interstratification of carbonaceous sandstone, silt sandstone, and siltstones. Some interlayers contain impregnation of fine-grained pyrite with low gold grade. A significant role in ore location belongs to the barrier effect of the overlaying Devonian-Carboniferous carbonate sequence. This carbonate sequence is eroded at the deposit area, but according to N. Gureikin, the upper level of mineralization was formed at the distance of 300-600 m below the limestone.

The early, albite-chlorite-quartz, alteration is controlled by northeast faults while younger and more proximal to ore sericite-carbonate-pyrite, sericite-hydromica, and quartz-argillic alteration is localized along north-northeast fractures.

The total length of the 100 m to 450 m thick mineralized zone found between major northeast-trending faults is approximately 2.5 km. Fractures at the footwall are steep-dipping (75-90°) to the west. In the central part of mineralized zone, tectonic seams have gentler dips (55-65°) whereas the hanging wall structures are near vertical. Amount of subparallel ore-hosting fractures is increasing near NE bordering faults, and their seams become thicker in the same direction.

Replacement type ore bodies are steep-dipping, lens—and bandlike zones of veinlet-disseminated mineralization, 3 m to 22 m thick and 300-400 m long, with a vertical extent of 650 m.

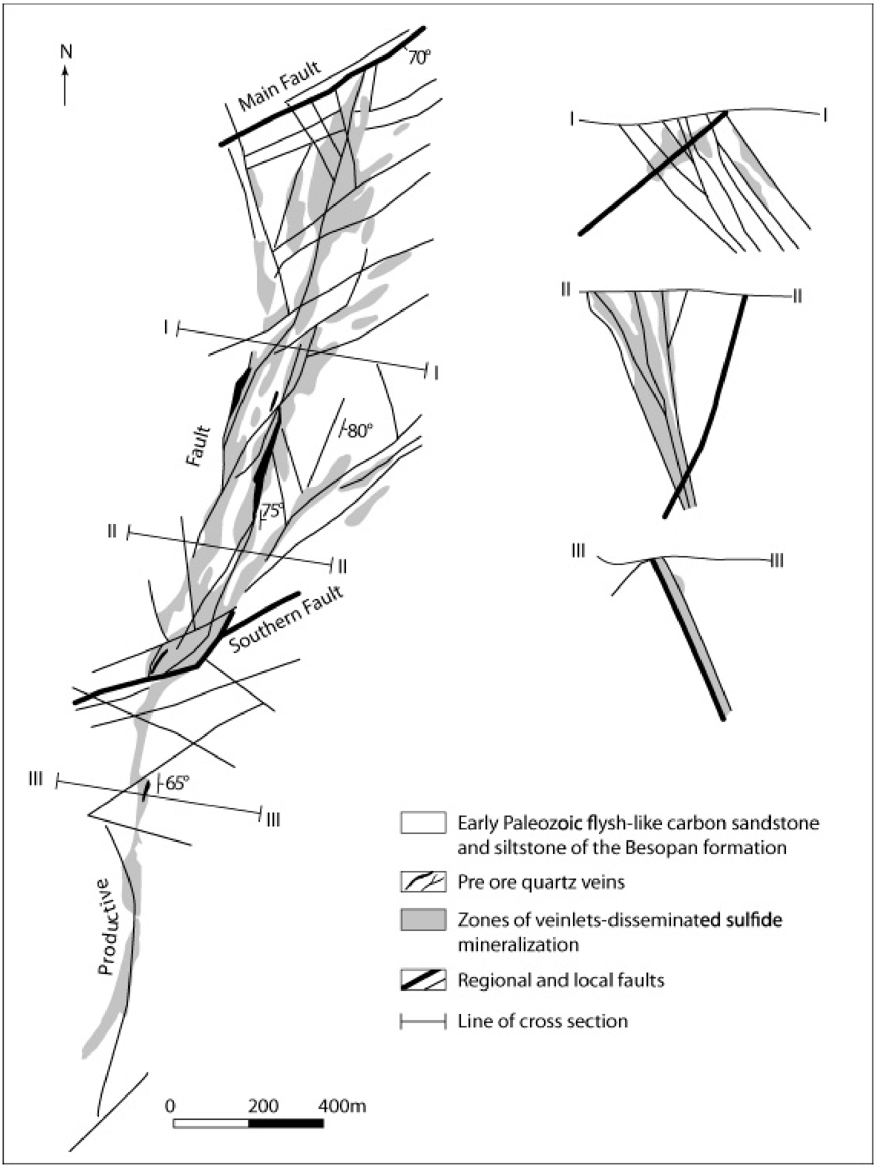


Figure 13. Structure of the Daugyztau deposit (after Gureikin et al. 1979).

The main portion of gold mineralization is concentrating in three large ore beds. The largest one, western, is traced through all deposit with average gold grades from 5.8 g/t to 7.5 g/t. The high-grade ore shoots usually gently and steeply dipping parts. The gently dipping parts are common in the upper levels of ore shots and in general conformal with large folds. Their upper edges are subparallel to the reconstructed position of the Devonian limestone base. The steeply dipping parts of high-grade ore shoots are controlled by intersections of NE and northerly-trending fractures.

Hydrothermal alteration of the host rocks includes (Gureikin and Arifulov 1986) three main stages: (1) chlorite-quartz, (2) quartz-gold-sulfide, and (3) carbonate-cinnabar. Pre-ore, chlorite-quartz, stage of alteration consists of coarse-grained allotriomorphic quartz, dolomite, graphite, rutile, cubic pyrite, and albite. Quartz veins and veinlets of this stage fill up fractures of different directions and are accompanied by dolomite-quartz alteration. The average homogenization temperature of inclusions in quartz is 290°C.

The main, gold productive, stage of mineralization contains a few mineral associations. The gold-bearing, disseminated and veinlet-disseminated arsenopyrite-pyrite, mineralization is accompanied by sericite-carbonate-pyrite alteration and consists of sericite, siderite, ankerite, gold-bearing arsenical pyrite, arsenopyrite, and carbon minerals. This mineralization is concentrated in a form of lenticular and ribbonlike bodies with pinches and bulges. The gold forms thin-dispersed inclusions in pyrite and arsenopyrite. The gold grade in pyrite is about 50 g/t, while in arsenopyrite it reaches 250-300 g/t. The carbon content remains stable at the level of 0.5-1.5%. Homogenization of gaseous inclusions in quartz occurs below 240°C.

The next, sphalerite-gray copper ore, association with high silver and lower grade of gold is localized in the axial zones of pyrite-arsenopyrite mineral association nearby main ore-hosting fractures. These zones contain idiomorphic quartz, ankerite, dolomite, sphalerite, tetrahedrite, freibergite, chalcopyrite, Se-rich galena, pyrite, pyrrhotite, bornite, bournonite, polybasite, zinkenite, and particles of native gold (800 fineness) up to 50 micron in size. This association is not known below a depth of 300-400 m and pinches out at upper levels of the deposit. Deposition temperature for this association is 10-30° lower than for the previous stage.

A boulangerite-stibnite or silver-sulfoantimonite (Zverev et al. 1999) mineralization is common at the northern flank of the deposit where it forms veinlets and clusters in the main ore zones. It consists of idiomorphic quartz, dolomite, stibnite, boulangerite, clausthalite, Ni-rich pyrite, and native antimony. Homogenization temperature of inclusions in quartz occurs at 200-170°C.

The latest, carbonate-cinnabar, mineral association forms thin veins and veinlets of dolomite, calcite, dickite, hydromica, allargentum, Te-canfieldite, pyrargyrite, coloradoite, cinnabar, and an Hg-rich gold and amalgam of silver. This mineralization occurs in areas of brecciated sphalerite-gray copper ore association of the stage 2. Temperature of crystallization for this association is 110-125°C.

More than 90% of gold found in the Daugyztau deposit is thinly dispersed in arsenical pyrite and acicular arsenopyrite; small amounts of visible gold are associated with sulphosalts.

The close time and space relationship between pyrite-arsenopyrite and boulangerite-stibnite mineralization is related most likely to vertical and lateral zoning and barrier effect of Devonian limestone. Lateral zoning is defined by an almost-tenfold increase of the silver grade from northeast to southwest, increase in the same direction of the sphalerite-gray copper ore association, and a simultaneous decrease of the pyrite-arsenopyrite association. The most obvious evidence of this lateral zoning is the Vysokovol'tnoye gold-silver deposit, which is found on the southwestern extension of the main Daugyztau ore zone that will be described later together with other gold-silver deposits in black shales.

Vertical zoning (Gureikin and Arifulov 1986) is defined by weak aureoles of As, Sb, Ag, and Hg at the upper level of mineralization around veinlet-disseminated silver ore, while gold productive levels are characterized by strong aureoles of As, Au, Sb, Cu, Zn, Pb, and Ag. Weak halos of W, Sn, and Co are also found at the lower levels of mineralization.

The age of ore deposition at the Daugyztau deposit is based on the barrier effect of the Devonian-Early Carboniferous limestone formation and is definitely younger than Devonian.

According to Zverev et al. (1999), the total gold resources of the Daugyztau deposit are 42,600,000 tonnes of ore grading 4.02 g/t of gold (185.7 t) and 2.19 g/t of silver (101 t).

The Nezhdaninskoye Deposit (62°34'N-139°18'E)

The Nezhdaninskoye deposit is located about 450 km east of the Yakutsk City, Sakha Republic capital—in the northern part of the South Verkhoyansk synclinorium, which is a part of the Mesozoic Verkhoyansk-Chukotka fold and fault belt. Its description is given mainly according to the TsNIGRI geologists (Yanovsky 1990; Gorzhevsky and Konstantinov 1998; and many previous publications).

The South Verkhoyansk synclinorium can be traced for hundreds of kilometers along the eastern rim of the Aldan shield of the Siberian platform and has an intercontinental position between the Aldan shield and Okhotsk microcontinent.

Volcanogenic-sedimentary (PR_2), sedimentary-carbonate (PR_3), and carbonate (Pz_{1-2}) sequences are situated at the base of stratigraphic succession and are covered by the Late Carboniferous—Jurassic (C_2-J_{1-2}) ore-hosting Verkhoyansk sandstone-shales complex. This complex, 10-13 km thick, consists of carbonate-sedimentary lagoon and sandstone-clay shales marine (flysch—and molasselike) formations; but gold mineralization is localized only in the Permian sandstone-shales sequence about 1,500 m thick.

The ore-hosting sequence consists of argillite with thin layers of sandstone (lower part) and thin-bedded argillite and siltstones (upper part), which has been folded into simple synclines and anticlines. The gold-hosting rocks contain up to 3% dispersed and segregated humus, kerite, anthraxolite, and anthracite, as well as up to 9 ppb of gold; the elevated gold content is significantly higher than the Clarke of concentration for sandstone-shales sediments.

Small granite-granodiorite stocks of Cretaceous age (96-124 Ma) are known in the region, but the deposit area contains only pre-ore diorite porphyry and lamprophyre dikes, while granite dikes and pegmatite veins are located on its periphery.

The dominant structure of the South Verkhoyansk synclinorium is defined by system of northerly-trending faults conform to its border with the Sette-Daban horst-anticlinorium and faults of the northeast direction.

The Nezhdaninskoye deposit is located at the regional flexure and its structure defined by zone of dislocations along north-northeast regional fault of steeply west-northwest dipping that can be traced for about 500 km (Bortnikov et al. 1998) along mentioned above flexure. The ore-controlling zone consists of fractures accompanied by shear and fold deformation up to 10-12 m wide. Northerly-trending fractures, which contain steeply dipping to the west shear and crush zones up to 40 m wide (Nezhdaninskaya zone) are also ore hosting and are accompanied by pre-ore sinistral and post-ore dextral shearing (Fig. 14).

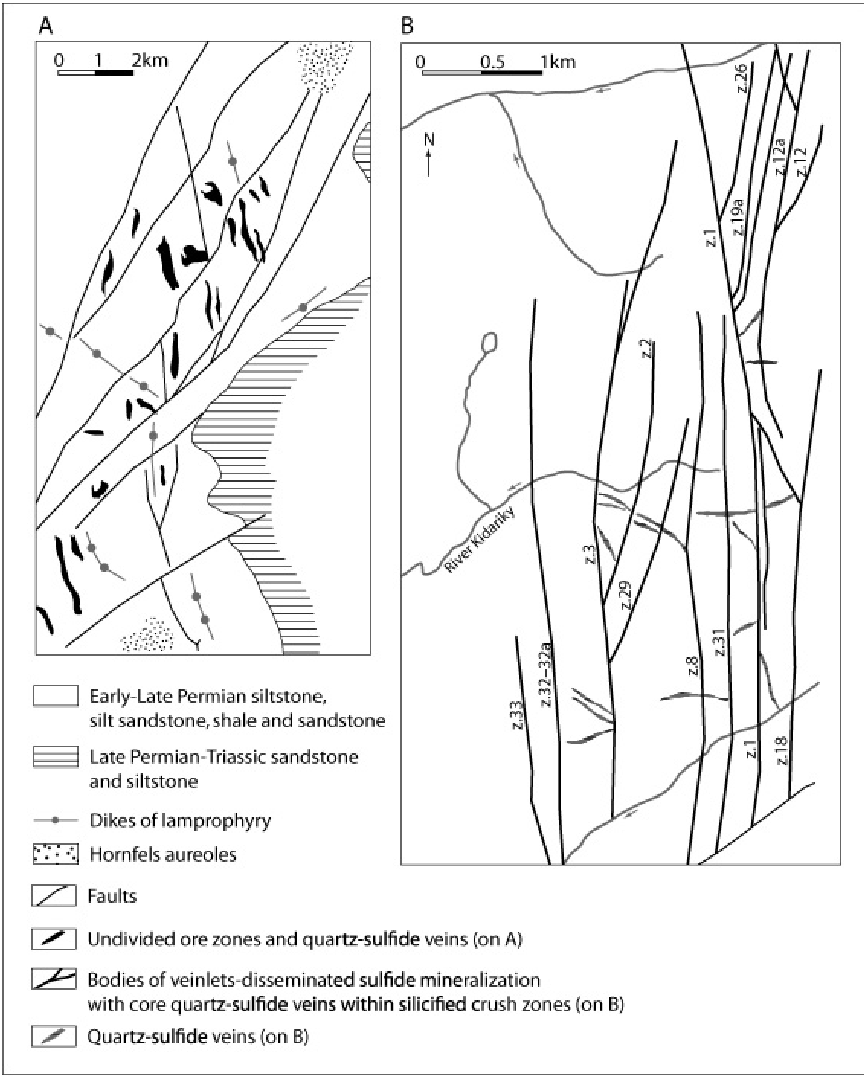


Figure 14. Structure of the Nezhdaninskoye deposit: (A) structure of the deposit area (after Kurbanov, 1993) and (B) distribution of main ore zones (after Celtic Resources Holding PLC, news release, 1996).

The host rocks in these zones are silicified, sericitized, and contains veinlet-disseminated mineralization and quartz-sulfide veins. Quartz-carbonate-sericite and quartz-carbonate-albite-sericite is the most common rock alteration and is related in time and space to the ore mineralization in shear zones. Tectonic dislocations within specific carbon-bearing beds have resulted in a regrouping and migration of the contained carbon into veinletslike accumulations that cut bedding or as clots surrounded by carbon-barren rocks. The carbon contents within these tectonic dislocation zones have been increased 150% and vary from 0.5 to 5% carbon, the most of which could not be dissolved in organic solvents and have high sorption power.

More than fifty separate ore bodies are known within the main zone of the Nezhdaninskoye deposit. The principal ore bodies consist of zones of veinlet-disseminated mineralization in silicified rocks; this type constitutes for more than 85% of the reserve. The thickness of individual zones varies from 1-3 up to 40 m. Undisturbed lenses of rocks in between the zones of tectonic dislocations usually do not contain mineralization. The main ore body (Zone 1) of the deposit is 2 to 40 m thick and can be traced for about 10 km in strike length and up to 1.9 km deep.

Another type of ore bodies include quartz-sulfide veins, which are localized in mineralized zones along bordering faults or in plumage fractures. The thickness of these veins varies from centimeters up to 4 m, and they often could change along the strike and dip to veinlets zones.

The early stage of mineralization consists of disseminated and veinlet-disseminated pyrrhotite-pyrite-arsenopyrite-quartz association with 4-7% of sulfides containing micron gold inclusions. The main ore minerals are pyrite and prismatic or acicular arsenopyrite. Pyrrhotite is known only at the deep horizons of the ore zones, which are surrounded by aureoles of quartz-carbonate-sericite, quartz-carbonate-albite-sericite, and quartz-carbonate-albite alteration. The ore mineralization forms lengthy zones up to tens of meters wide with pyrite-arsenopyrite in the core enveloped by pyrite. At the deeper levels, such core zones consist of pyrrhotite, pyrite, and arsenopyrite enveloped by pyrrhotite-pyrite association. Arsenopyrite content in these core parts varies from 3-5 to almost 100% total sulfide. Monomineral pyrite of this stage contains from 15 to 50 g/t gold while arsenopyrite carries from 50 to 385 g/t. Mossbauer spectroscopy showed that the gold of this early mineral association is located in the crystal structure of the arsenopyrite (Bortnikov et al. 1998).

The second stage of mineralization consists of vein and veinlets of gold-galena-sphalerite association with free gold, sulphoantimonite, and argentite-pyrargyrite (aerosite) mineral associations with high silver grade. Post-ore stage contains scheelite-carbonate mineral association.

The average gold grades in zones of veinlet-disseminated mineralization varies between 5 and 7 g/t while the quartz-sulfide veins contains 10-13 g/t and higher. Gold is present as submicroscopic within sulfides of the early mineral association and can reach 0.8 mm in the late stage of mineralization. Its fineness ranges from 677 to 847 with prevalence of 720-760 fine. Gold of the late stage contains up to 27% of silver and admixture of As, Sb, Cu, and Hg.

As reported by V. Alpatov, vertical zoning of the Nezhdaninskoye deposit is defined by high silver grade (Au/Ag = 0.1-0.05) at the upper levels of ore bodies and deposition of pyrrhotite only at its deep levels. Strong aureoles of As, Au, Zn, Pb, W, Cu, Sb, Ba, and Ag are changed naturally in this succession from deep to the upper part of hydrothermal column.

The geological resource at the Nezhdaninskoye deposit, according to Russian data, amounts to 18 Moz (560 t) of gold with about 2.6 Moz (80 t) already mined out from core quartz-sulfide veins. In 1996, the Celtic Resources Holdings PLC had audited and converted Russian categories of resources to western standards (see table 4 below). Celtic stated in news release of February 5, 2003 that only 37 of the 117 known ore bodies have been explored sufficiently to be classified as “mineral resources” as defined by JORC code.

The table shows only stated gold grades and gold reserve/resource. The average silver grade, according to Celtic Resources, ranged from four to six times the average gold grade.

TABLE 4
Audited Mineral Reserves/Resources of the Nezhdaninskoye Deposit (According to Celtic Resources Holdings PLC)

Reserve/Resources	Ore (Million tons)	Gold grade (g/t)	Contained gold (Moz)
Reserve:			
Proven	1.2	7.4	0.3
Probable	13.8	6.0	2.6
Total Reserve	15.0	6.1	2.9
Resources:			
Measured	3.1	6.7	0.7
Indicated	34.6	5.2	5.8
Inferred	40.2	5.7	7.4
Total Resources	77.9	5.5	13.9

The Nezhdaninskoye deposit differs from other deposits of this type found in carbon-bearing black-shales sequences by the presence of significant numbers of quartz-sulfide veins with late-stage mineral associations and free gold. Originally, this deposit was considered as a typical quartz vein type. The shear zone-hosted veinlet-disseminated mineralization was explored here only after discovery other large veinlet-disseminated gold (arsenic)-sulfide deposits during the 1960s and 1970s.

The Olimpiada Deposit (59°52'N-92°53'E)

The deposit is located in the central part of the Yenisey Range (eastern Siberia) approximately 100 km to the south of the town of Severo-Yeniseysk.

Gold placers have been known in this area since the end of nineteenth century, but the geological mapping and exploration during the 1950s and the beginning of the 1960s discovered only occurrences of tungsten and antimony. Analyses of isolated grab samples at the middle of the 1960s conducted by Longin V. Lee showed presence of gold and initiated additional exploration. Economical gold mineralization was verified at the end of the 1970s.

The Olimpiada deposit is located in the Late Proterozoic (Baikalian in Russian terminology) trough of Yenisey Range along the passive margin of Siberian continent (platform). The basement complex is represented here by Early Proterozoic (2,000-1,650 Ma) kyanite-staurolite, biotite-amphibole, and amphibole-bearing slates with interbeds of quartzite and marble.

The Middle-Late Proterozoic Kordinskaya and Gorbilokskaya suites of the Sukhopitskaya series consist of the marine carbonate-clay sediments that form the middle structure stage of the Yenisey trough. The Late Proterozoic-Cambrian orogenic and platform sediments represent its upper structure stage.

The Kordinskaya suite hosts the Olimpiada ore. The lower, 200-500 m thick, part of this suite consists (Lee et al. 1990) of calcareous to quartzose, biotite-rich shales with intercalated quartzite, recrystallized limestone, marble, and rare amphibole-bearing shales. The upper part of the Kordinskaya suite is 500-550 m thick and consists of amphibole-, biotite-muscovite-, quartz-carbonate-mica-, and quartz-biotite shales with a distinctive horizon of coaly phyllite at the bottom of this section.

The host rocks to mineralization contain 0.2% to 2.5% of dispersed C_{org} and are intensely altered by carbonatization, silicification, and sericitization. Relics of higher temperature, pre-ore skarn, and greisen alteration are known in the ore zones. Gold-bearing veinlets and impregnation of sulfides are accompanied by deposition of muscovite, biotite, hydrobiotite, and chlorite with minor zoisite, sphene, rutile, and carbonates.

The sedimentary-metamorphic sequences of the Yenisey trough are intruded (Gorzhevsky and Konstantinov 1998) by leucocratic and migmatitic granite (1,050-900 Ma) and granitoid batholiths (850-760 Ma).

The main fold structure in the deposit area is an ENE inverted anticline of S shape (Fig. 15) with both wings dipping to the northeast 50-70° (west and south parts) and 35-45° at the east and north. Gold mineralization is located at the north pericline of this fold consisting of Kordinskaya formation. Smaller-scale folds with almost horizontal axial planes and normal slip faults with displacements up to a few hundred meters complicate this anticline. The mineralized area is bordered on the west and east by northwesterly-trending regional faults and on the north and south by E-W faults.

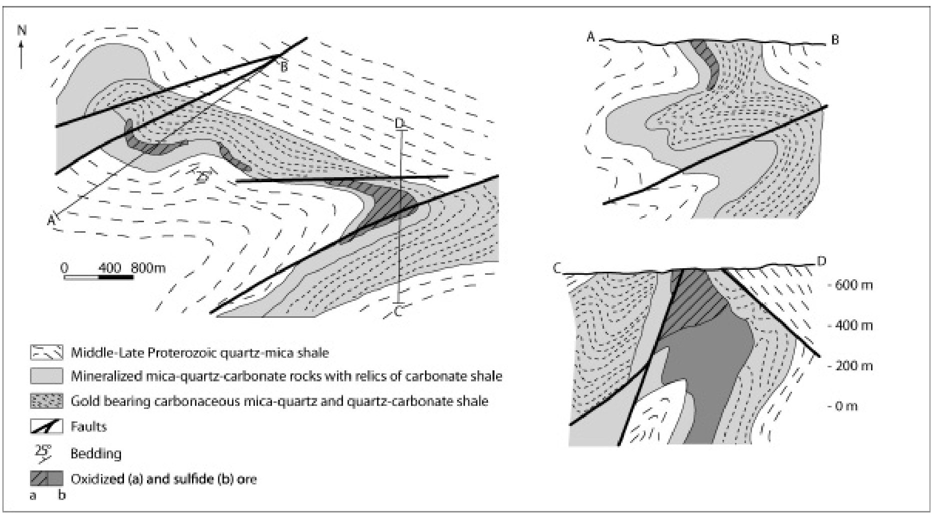


Figure 15. Geologic model of the Olimpiada deposit (modified after Konstantinov and Narseev 1989).

The major ore-hosting structure is east-northeast-trending, brittle-ductile fault (Genkin et al. 1998) with a series of subparallel fractures and associated secondary NW-trending, high-angle faults.

The total length of the known mineralized structure is 4-5 km, but the lithologic horizon favorable to veinlet-disseminated sulfide mineralization is approximately two times longer and has a good potential for new discoveries.

The stratiform type ore bodies are lenseslike zones of veinlets and disseminated mineralization. The main ore body is traced for about 600 m at the eastern part of the deposit and contains 90% of resources, while three ore bodies on the western flank contain about 10% of the total resource. The ore bodies are localized in flexurelike bends of fold structures and are commonly located in the limbs of inverted and recumbent folds along the tectonically disturbed contacts of the carbonaceous shales and marble with quartz-mica-carbonate rocks. The thickness of the ore bodies varies from 1-2 m at the limbs of folds up to 40 m at the fold bends while the main ore body is reaching 150-170 m at the fold bend. Ore bodies commonly do not have distinct contacts and are outlined mainly by sampling.

Disseminated and veinlet-disseminated gold mineralization contains from 2-5 to 12% sulfides, mainly pyrrhotite, arsenopyrite, pyrite, and stibnite. Lesser amounts of scheelite, chalcopyrite, sphalerite, galena, gray copper ore, and native antimony are also present. Cinnabar, jamesonite, gudmundite, bismuthinite, and berthierite are rare. The earliest (pre-gold) quartz-scheelite mineral association forms disseminations or thin quartz-scheelite stringers in the banded, metasomatic carbonaceous sericite-quartz and zoisite-carbonate-quartz rocks (Genkin et al. 2002).

The main gold-bearing association consists of arsenopyrite, pyrrhotite, and pyrite. Pyrrhotite is the most widespread sulfide and forms idiomorphic grains and clusters. Monomineral pyrrhotite without visible gold particles contains, according to S. Yablokova (TsNIGRI), up to 150 g/t gold. Native gold sometimes associates with second generation of pyrrhotite at the core of ore bodies containing abundant arsenopyrite and stibnite mineralization.

Small acicular and prismatic crystals of arsenopyrite, from 5 μm to 2 mm in size, constitute up to 5% of ore but are not known outside of the ore bodies. Arsenopyrite contains often inclusions of other minerals and submicroscopic particles of gold. The gold content in an individual arsenopyrite grain varies from 140 to 2,600 ppm (Genkin et al. 2002). In the quartz-carbonate micaceous schists, arsenopyrite occurs in sulfide-rich bands, 1-2 to 20 mm thick, parallel to the schistosity (Genkin et al. 1998). Arsenopyrite porphyroblasts replace pyrrhotite aggregates. Pyrite is found both in the ore bodies in weakly altered carbonaceous, mica-quartz shales and usually contains low level of gold, at least 10 times less than that found in pyrrhotite.

The youngest, stibnite-berthierite-quartz-carbonate, mineral association forms thin veinlets or lenslike clusters, which cut all earlier associations. A low correlation between antimony and gold (+0.17) and a high correlation between gold and arsenic (+0.62) suggests that gold is unrelated to the stibnite mineralization of the Olimpiada deposit.

Native gold (920-1,000 fineness) forms very thin (0.005 to 0.05 mm) inclusions in pyrrhotite, arsenopyrite, and very rare in stibnite or nearby of these minerals in quartz. Aurostibite also associated with arsenopyrite in a form of inclusions ranging between 2 and 105 μm in size.

Study of primary fluid inclusions in quartz (Genkin et al. 2002) of the pyrite-pyrrhotite-arsenopyrite association indicated that gold-bearing arsenopyrite crystallized at temperatures above 400°C and pressure of 1.3-2.7 kbar from Mg-Na chloride solution with a salinity of 3.6-17.8 wt. % NaCl equivalent; gaseous phase includes nitrogen, methane, and minor carbon dioxide. Pyrrhotite crystallization occurred at a temperature of 269-460°C and pressure of 1.0-1.9 kbar.

The average gold grade for primary ore of the Olimpiada deposit is 4.6 g/t but reaches 10.9 g/t for oxide ore. In addition, the ore contains up to 0.1% of W_2O_3. Oxidation of reported Cretaceous-Paleogene age with abundant clay substance, ocher, and quartz spills can be traced to the depth for more than 350 m at the eastern part of the deposit. Gold in the oxide ore is mainly free.

The age of the Olimpiada deposit (Distanov et al. 1975) is between 794 Ma (age of pre-ore metasomatic alteration) and 609 Ma (age of late-stage antimony mineralization).

Total in situ gold resources of the Olimpiada deposit including oxide and sulfide ore are estimated as 22.5 Moz or 700 t (Nekrasov 2005). Cumulative production of gold at the deposit, mainly from the oxide zone through the beginning of 2006, exceeds 200 t.

The Olimpiada deposit is the only veinlet-disseminated deposit of gold (arsenic)-sulfide mineralization in the Middle-Upper Proterozoic carbon-bearing black shales in the CIS. Its mineralization has stronger stratiform character than the other deposits of this type; the highest gold grades occur not in arsenopyrite but in pyrrhotite, and gold is unusually associated not only with arsenic but also with tungsten.

The Veduga Deposit (~59°04'N-93°41'E)

The Veduga deposit is very similar to Olimpiada and is located about 100 km south of it in a similar geological and geotectonic setting of the Yenisey Range gold province. The deposit mineralization is controlled by similar ENE-trending, brittle-ductile structures within the Early Proterozoic (Genkin et al. 1998) carbonaceous phyllite shales and sericite-chlorite schists that underwent carbonatization and silicification during retrograde metamorphism.

The mineralized zone, 2.5 km long and 200 to 500 m wide, is located in the northwesterly-striking anticline, at the intersection of an ENE regional fault. Twelve ore bodies, 200 to 500 m in strike length and 2 to 22 m wide, are found to be conformable to the contact between carbon-rich, carbonate sequence and sedimentary one. Ore bodies consist of strata-bound lenses of sericitized and silicified rocks containing abundant veinlet-disseminated sulfide mineralization. Thin sulfide and quartz-carbonate-sulfide veinlets have thickness up to 1.5 cm. Banded gold-bearing structures defined by alternating silicate and sulfide bands are a major difference between this deposit and Olimpiada.

The early mineralization of the Veduga deposit includes pyrite, arsenopyrite, and pyrrhotite, which occur as patches and small lenses mainly outside the ore bodies.

The first gold-bearing mineral association in the ore body consists of arsenopyrite II, native gold, and pyrite (Genkin et al. 1998) disseminated in sericite and quartz-sericite altered rocks. The inner part of this alteration halo, 900 m by 7 km in size, is confined to a major shear zone where intergrowths of sulfides, sericite, and quartz form pseudomorphous aggregates replacing earlier metamorphic minerals. Acicular crystals of arsenopyrite II form banded aggregates. Tiny grains of native gold, up to 20 μm in size, crystallized later than sulfide minerals.

The second mineral assemblage contains an arsenopyrite III, quartz, and carbonate, which form short veinlets, lenses—and nestlike aggregates in early sulfide bands, and sericitic rocks. Arsenopyrite of this association is no more than 10 μm in size.

The third association of gold mineralization consists of stibnite, gudmundite, galena, native gold, and aurostibite in quartz-carbonate veinlets cutting arsenopyrite II-bearing sericitized rocks. Native gold of this association replaces berthierite and gudmundite, but its crystallization cannot be interpreted as a remobilization of native gold associated with arsenopyrite II (Genkin et al. 1998).

Resources of the Veduga deposit, defined at the end of first stage of exploration in 1995, are 11,300,000 metric tons of ore grading 6 g/t or 2.2 Moz. Additional exploration during 1998-1999 increased its resources to 13-20 million metric tons (2.6-3.9 Moz) calculated to the depth of 300 m. Approximately 75% of the gold resources are in the ore bodies no. 1 and no. 10. About 25% of it could be mined by open-pit operation. Resources of oxide ore for heap-leach processing are one million metric tons grading 4 g/t.

Geochemical surveys in 1998-1999 over a 35 km^2 area around the Veduga deposit outlined six new gold-arsenic-stibium halos with values similar to if not better than for Veduga itself. For this reason, the inferred gold resources of the deposit could reach about 9-10 Moz.

The Maiskoye Deposit (69°62'N-173°44'E)

The Maiskoye deposit is located in the Chaunsk District of the Chukotka Autonomous Region (Russia), 150 km southeast of Pevek Harbor. The ore field includes a few smaller veinlets-disseminated gold deposits, as well as vein gold-silver and silver-tin occurrences. It is situated in the accretionary fold belt of northeastern Russia at the flank of the Mesozoic Okhotsk-Chukotka volcano-plutonic belt (Sidorov et al. 1984, Bortnikov et al. 2004). The Maiskoye deposit was discovered during geological mapping in 1972 and explored in 1977-1986.

All the deposits and ore showings of the Maiskoye ore field are located in a synclinorium of Triassic sandstone and shales, which are uncomfortably overlain at its southern and eastern end by Early Cretaceous continental sediments and Cretaceous andesite-dacite, rhyolite, tuff-lava, and tuff.

Veinlet-disseminated mineralization is hosted by the Middle-Late Triassic sediments, 1,500 m to 2,000 m thick. The Triassic sediments consist of flyschlike siltstones, calcareous sandstone alternating with carbonaceous shales containing syngenetic pyrite, and siderite concretions. The sedimentary rocks are rich in primary dispersed carbon, which is redistributed in gold-bearing shear zones as graphite and shungite. The carbon contents in such zones reach 1-2%. Carbonaceous matter in a form of vitrinite also occurs as microscopic-size (0.01-0.1 mm) particles disseminated along bedding planes.

The Triassic sediments are folded into large open folds of NNW strike and intruded (Volkov et al. 2002) by (1) stocklike body of biotite granite, granodiorite, and quartz monzonite (111-84 Ma); (2) subvolcanic andesite-dacite bodies; and (3) dikes of granodiorite, granite and granite syenite porphyry (118-107 Ma), lamprophyre (111-106 Ma), and rhyolite porphyry (115-97 Ma).

A system of NW and NE fault zones, up to a few kilometers wide, is related to the development of the Okhotsk-Chukotka volcanic belt. Their intersections control the location of domal risings with granitoid stocks at the core parts and often control gold mineralization.

One such dome complex, which consists of a mosaic of blocks, hosts the Maiskoye deposit. At its core, the dome contains the Middle Triassic sediments while on the periphery—Late Triassic more brittle sediments (Fig. 16). Ore mineralization is found within a horstlike block, 3.5 km long and about 2.0 km wide, which is bounded by faults on the north and south and cut by northerly-trending, echelon-like shear zones. These zones dip steeply (75-85°) at the western flank of the deposit and less so (50-65°) on the eastern flank. A large body of an explosive breccia, 0.8 km by 1.5 km in size, is located at the center of this block and consists of larger fragments of different host rocks in a recrystallized fine groundmass.

The dome is penetrated (Novozhilov et al. 1982) by a fanlike swarm of rhyolite and granodiorite porphyry, aplite, and lamprophyre dikes, which diverge toward the surface. The dikes are up to 100 m thick and 2 km long and make up to 25% deposit's total volume. They are surrounded by thin rims of amphibole-biotite-cordierite hornfels. A hornfels aureole a few hundred meters wide is located at the hanging wall of dike swarm. Hydrothermal alteration consists of quartz-sericite, quartz-carbonate-sericite, and kaolinite-hydromica varieties.

Quartz, carbonate-quartz veins, and zones of veinlet-disseminated mineralization form some thirty ore bodies located in and between the

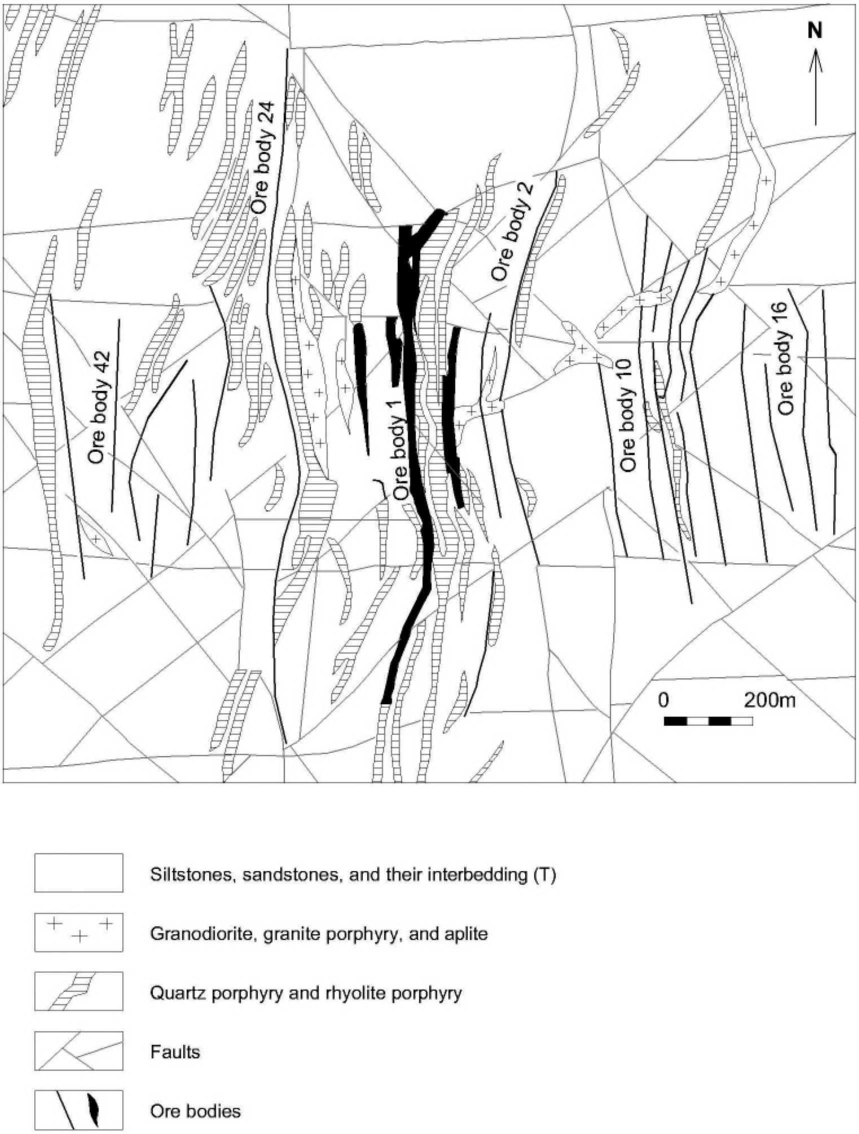


Figure 16. Schematic geologic map of the Maiskoye deposit (after Volkov and Sidorov 2001).

dikes along northerly-trending system of an echelon shear zones, 500 to over 1,500 m long. According to A. V. Volkov, the gently dipping ore zones coincide with both the steeply dipping bedding and the quartz-feldspar porphyry dikes. Linear ore bodies, 2-3 to 25 m thick and 250-400 m long, with relatively sharp boundaries have pinches and swells. The vertical range of the ore zones reaches more than one kilometer from the surface, and their total length is 7-8 km. The largest mineralized zone (ore body 1) is 4.3 m thick and can be traced for 1.5 km along the strike.

Sulfides constitute up to 8 to 12% of ore zones and are developed during three (Bortnikov et al. 2004) stages.

The first stage, quartz-pyrite-arsenopyrite, forms zones of mineralization with finely dispersed gold along northerly-trending tectonic structures and contains the majority of the gold reserves. These zones were formed as a result of metasomatic replacement and consist of quartz, sericite, Fe-dolomite, ankerite, and clay minerals with veinlets and disseminated fine-grained pyrite and arsenopyrite. Arsenopyrite forms typical acicular and elongated prismatic crystals, rarely to 1 mm in size, and contains 33.5-36.3 wt. % iron, 38.7-46.0 wt. % arsenic, and 20-3-24.5 wt. % sulfur with admixture of Ni and Co. The gold content of the arsenopyrite ranges from 182.4 to 1,030.0 g/t. Pyrite in this first association contains up to 6.7 wt. % arsenic and 1.44-42.77 g/t of gold.

The second stage of the gold mineralization at the Maiskoye deposit includes a few mineral associations replacing each other. The earlier, quartz-molybdenite and quartz-wolframite, associations occur mostly in the central part of the deposit. The next mineral association, cassiterite-pyrite-arsenopyrite in quartz veins at the eastern flank of the deposit, contains also loellingite, pyrrhotite, chalcopyrite, tetrahedrite, and tetradymite. Arsenopyrite II of this association forms aggregates of columnar (not acicular) crystals up to 5-7 mm in size. It contains higher amounts of arsenic (43.1-51.4 wt. %) and antimony (up to 1.5 wt. %). Arsenopyrite II also contains about ten times less gold (4.5-117.2 g/t) than the earlier arsenopyrite of stage one. Rare inclusions of native gold up to 5-8 μm are found in the chalcopyrite.

The third, sphalerite-stannite, mineral association, which was deposited after chalcopyrite but earlier than galena and its sulfosalts, occurs in all ore bodies. The last, galena-bournonite-boulangerite, association of this stage includes also sphalerite, tetrahedrite, zinkenite, plagionite, and andorite. The temporary position of the quartz veinlets with pyrrhotite, native bismuth, bismuthinite, galenobismutite, cosalite, and lead-bismuth sulfo-tellurides is not clear.

The third stage, gold-stibnite with native gold, is found spatially close to the auriferous first sulfide stage and occurs as veins and veinlets filling open-space fractures or as cement to quartz-stibnite aggregates in zones of brecciation containing earlier auriferous mineralization. The quartz-stibnite association contains also gray copper ore, chalcostibite, and rarely chalcopyrite. Native gold of 824-923 fineness in this association forms intergrowths with stibnite, chalcostibite, and tetrahedrite-tennantite. Gold contains up to 1.5 wt. % mercury and 1.2 wt. % copper.

The studies of fluid inclusions and oxygen and sulfur isotope distribution (Bortnikov et al. 2004) suggest that mineral deposition occurred from chloride brines with a high NaCl equivalent (37.5-30.2 wt. %) and in the presence of carbon dioxide. Disseminated mineralization of the first auriferous sulfide stage was deposited at 430-238°C and at pressures from 1,240 to 190 bars. Deposition of the second-stage mineralization occurs at 500-200°C and the third, gold-stibnite, stage of mineralization at 230-120°C.

Approximately 80% of gold occurs as submicroscopic particles, mainly in acicular arsenopyrite of the productive stages. The native gold with fineness between 850 and 890 is also concentrated near arsenopyrite crystals. Silver occurs mainly in galena and sphalerite and rarely as argentite, miargyrite, or native silver.

Ore gold grade varies from 3-5 g/t up to 30-40 g/t with an average grade for the deposit at 10 g/t. The gold grade is higher in sediments than in dikes. The silver grade ranges from 1.0 to 15.0 g/t averaging at 3.0 g/t and do not depend on host rock composition. Gold-silver ratios vary from 1.4 to 11.1.

The upper levels of the ore column are marked by strong geochemical halos of Au, As, Ag, Pb, and Hg; the middle levels by Au, As, and Sb; and the lower levels by halos of W, Vi, Sn, and Be. The vertical zoning is also demonstrated by the presence of native arsenic at the upper levels, native antimony at the center, and bismuth at the lower levels of the deposit.

According to Volkov and Sidorov (2001), the Maiskoye deposit was formed during the postaccretionary stage of the fold belt and is related to the volcano-plutonic magmatism of the Okhotsk-Chukotka belt. Such relations with magmatism are not found in all provinces containing gold (arsenic)-sulfide deposits and could be coincidental. Bortnikov et al. (2004) suggests that conditions of mineral deposition are changed from mesoabyssal and compression for auriferous sulfide stage through shallow depth (the second stage) and subsurficial strain environment for the latest gold-stibnite stage. Thus, the Maiskoye deposit is a typical example of polychronous and polygenic mineralization with only the late stages of which could relate to volcanics of the Okhotsk-Chukotka belt.

Resources of the Maiskoye deposit by Soviet data are 23,000,000 tons of ore grading 12 g/t, i.e., 8.9 Moz or 277 t of gold. The JORC resource of the deposit (at a 5 g/t catoff) is about 7.3 Moz (C. Hinde in *Mining Magazine*, November 2007) while a mineable resource, according to the Highland Gold PLC, are 9,950,000 tonnes of ore grading 11.5 g/t, i.e., 3.68 Moz or 114 t of gold.

Similar gold (arsenic)-sulfide veinlets-disseminated mineralization is found mainly in the northwest Sichuan and southwest Guizhou provinces of China (Wang and Zhang 2001; Zhang et al. 2001) and southwestern Alaska (Goldfarb et al. 2004).

Veinlet-disseminated gold mineralization in both China provinces is located in sedimentary, mainly Triassic, host rocks of intercontinental troughs. Submicronic in size, particles of gold are associated with arsenopyrite and arsenical pyrite. Late mineral associations contain stibnite ± cinnabar, realgar, and orpiment. These late associations are found in late quartz veins and do not contain significant amount of gold, antimony, or mercury typical for the Carlin-type deposits, with which the authors are trying to compare it. Similarity of geotectonic setting for veinlet-disseminated gold (arsenic)-sulfide deposits in the CIS and the People's Republic of China includes intercontinental troughs, accretionary complexes, and troughs along passive continental margins as the most potential structures for this type of the deposits that defined their distribution mainly in the Eurasian and possible African continents containing such tectonic structures.

The Donlin Creek deposit of Alaska, similar by its geological, geochemical, and mineralogical characteristics to the gold (arsenic)-sulfide deposits of the CIS, is located at the active continental margin of the North American Cordillera. Such location noticeably broadens possible potential structures for exploration of this deposit type requiring much-smaller flysch basins bordered by consolidated basement rocks, i.e., miniature intercontinental structures.

4.1.2.2 Gold-Mercury-Quartz (Carlin Type) Deposits

The best-known example of sedimentary-hosted gold-mercury-quartz mineralization is the Carlin-type deposits in Western United States. Extensive lists of publications on geology, mineralogy, geochemistry, sources of ore components, and possible genesis of Carlin-type mineralization (Roberts et al. 1971; Radtke and Dickinson 1974; Radtke 1981 and 1985; Bonham 1985 and 1989; Percival et al. 1988; Cunningham 1988; Emsbo et al. 2003; Theodore et al. 2003; and many others) identified main features of this type deposits.

Disseminated gold mineralization forms large commonly relatively low-grade deposits hosted by thin-bedded Paleozoic and Mesozoic sedimentary rocks. Tabular, stratabound or irregular, low-grade ore bodies containing high-grade feeder structures are located along moderately to steeply dipping faults and fracturing zones.

Decalcification, silicification, and argillization represent main types of hydrothermal alteration. Intensive silicification forms massive jasperoid-like rocks. Sulfide minerals include fine-grained pyrite and arsenical pyrite in association with marcasite, arsenopyrite, realgar, orpiment, stibnite, and cinnabar. In contrast to gold (arsenic)-sulfide deposits, arsenopyrite of this group of deposits does not always form acicular crystals. Main trace elements are Au, As, Hg, Sb, Ag, Ba, and Tl. The presence of thallium in geochemical halos is one of the distinguishing features of the Carlin-type deposits.

Micron- and submicron-size gold particles in such ore are associated with arsenical pyrite or arsenopyrite and are deposited on the rims of these minerals or rarely form inclusions in them. Gold is also associated with organic carbon and forms discrete grains and solid solution in realgar and native arsenic. Fine-grained gold particles may be encapsulated often in silica. Gold to silver ratio varies from 1:1 to 10:1 and more.

Most of the Carlin-type deposits do not have obvious association with proximal magmatism and are viewed as some type of replacement mineralization formed in response to deep-seated crustal extension, faulting, and high heat flow, which supports mobilization of ore components from Paleozoic sedimentary rocks by hydrothermal solutions and heated meteoric water.

The Carlin-type gold deposits located in the Great Basin are noted for having the total resources exceeding 4-5 thousand tons, the gold production from low-grade ore by heap leaching, and unique concentration in relatively small area. Attempts to find large concentrations of similar deposits outside of the Western U.S. have not been successful until recently. Russian geologists, for example, discovered similar gold mineralization only during the 1980s in the northern part of Sakha (Yakutiya) Republic, near the Arctic Ocean. Small similar deposits also have been found in southern China.

Comparison of regional geological and geophysical information for the western United Sates and northeastern Russia (Berson et al. 1989) suggests that gold-mercury mineralization in both regions has quite specific tectonic setting.

Extensive NNE-trending belt of Carlin-type deposits including Getchell trend of the same direction, as well as Carlin and Cortez trends of northwest direction, was formed during Tertiary tectonic and magmatic activity in the region, which is marked by a thin crust and high heat flow. This section of the North American continent does not have deep-sea trenches along its coast and deep earthquake centers that are typical for other parts of the North and South American western coast.

Interpretation of satellite images for the Gulf of California area (Puscharovsky et al. 1980) shows that the rift system of the Eastern Pacific Ridge continues northward into the continent (Fig. 17). Typical continental rift sediments (Ueda 1980) and accompanying basalt volcanism exist here. However, main rift valley has not been formed because of permanent sliding of the North American continent to the west (Kuchay and Vesson 1980) or low-angle underthrusting of the oceanic plate beneath western North America (Berger and Bonham 1990). The Basin and Range region has an anomalous shallow position of the stressed mantle surface located only 3-4 km below sea level instead of 5-6 km. Such position is comparable to the depth of mantle surface in the rift zones and is related likely to local rising of the lithosphere over hot zone in mantle. Raising the lithosphere in the western part of the U.S. and in the middle-ocean ridges corresponds to an abnormally low density of the upper mantle (less than 8.0 km/sec) and therefore has a corresponding high heat flow (Thompson and Talmani 1964; Thompson 1965).

Combination of such unique conditions as continuation of the Eastern Pacific midocean rift system under the North American continent, presence

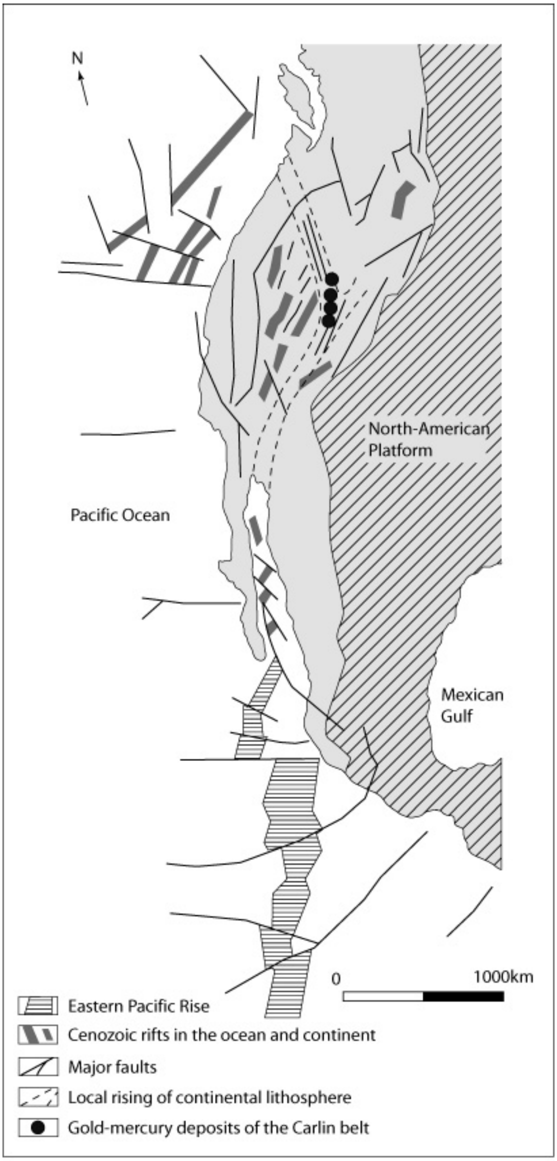


Figure 17. Geological setting of gold-mercury mineralization in the Western United States (after Berson et al. 1989).

of continental rifts, and a thin lithosphere over a mantle hot zone with high heat flow is thought to be responsible for specific geotectonic setting of these unique gold deposits with their characteristic Hg, As, and Tl-rich mineralogy.

Analysis of spatial distribution of contemporaneous midocean ridges and gold-mercury deposits reveals analogous belt of gold-mercury mineralization in the eastern Yakutia (northeast part of Russia). In this region, to the east of the Lena River estuary, the Hackel midocean ridge comes up against the northeastern coast of the Asian continent. The trenchlike basins of Cenozoic sediments, which are located on the extension of this structure to the shelf and further to the interior of the continent, form the Momsky rift (Grachev 1987). Geological-geophysical data trace this structure to the southeast for more than 1,500 km along the southern boundary of the Kolyma terrain (microcontinent) toward the Okhotsk Sea (Fig. 18).

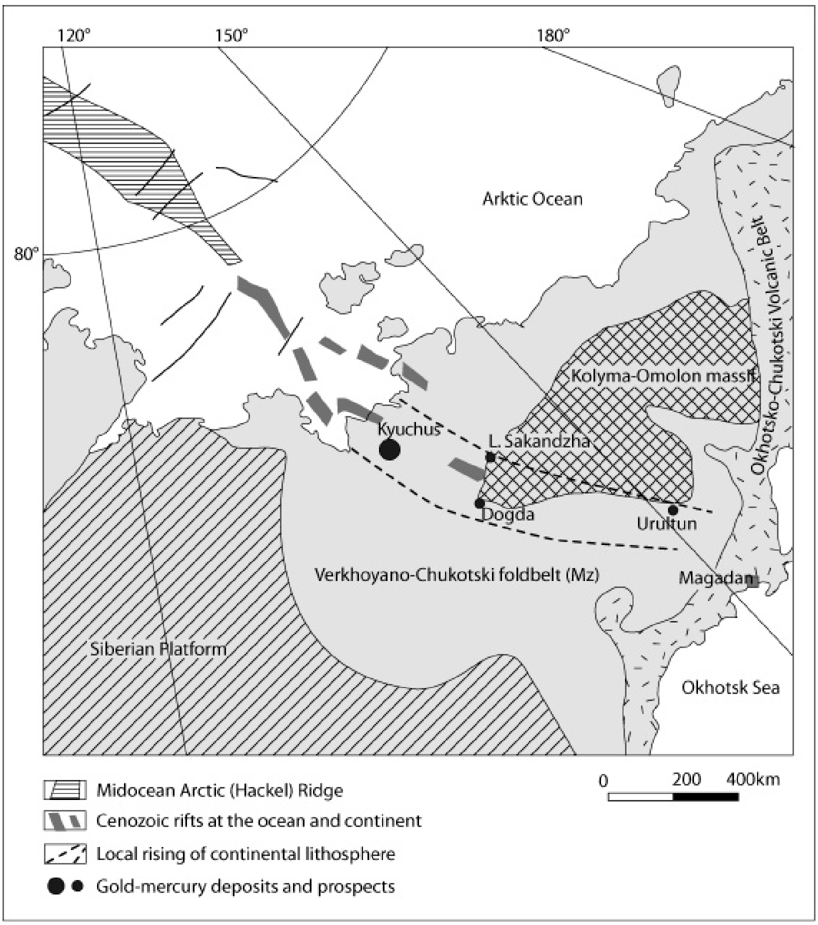


Figure 18. Principal tectonic elements of the northeastern Russia and location of gold-mercury deposits and prospects.

The Kyuchus gold-mercury-quartz deposit and similar occurrences of this type (Levo Sakandzha, Dogdy, Urultin) as well as mercury (Zvezdochka and smaller) and gold-antimony deposits (Sarylakh, Sentachan) are located in this beltlike structure similar to the Carlin belt.

Other locations of gold-mercury-quartz mineralization in connections with contemporaneous net of midocean ridges are not known though it is possible to find such combination with paleo-midocean ridges and rift structures. The Vorontsovka gold deposit, which is located on the extension of the Timan rift structure of east European (Russian) platform under passive margin of the Uralian continent, is one possible example.

The Kyuchus Deposit (69°48’N-134°45’E)

The Kyuchus deposit is in the north part of the Sakha (Yakutiya) Republic approximately 1,000 km north from the city of Yakutsk, on the Yana River’s left bank, about 200 km to the south from its outfall to the Arctic Ocean. It is in the Momsky rift system and is controlled by northeast-striking branch of the deep fault zone (Moskvitin 1997). Displacement along the fault comes up to a few thousand meters.

Middle Triassic sedimentary host rocks consist of flyschlike sequence of shelf-type siltstones, sandstones, and calcareous shales forming syncline fold complicated by smaller folds and faults. Carbon-rich sediments (C_{org} up to 0.95%) contain up to 5% of pelitomorphic carbonate in the groundmass. Isolated lamprophyre and diabase porphyry dikes mark the location of a major thrust that borders the Kyuchus deposit on the NW. The nearest granite outcrop is tens of kilometers to the northwest.

The ore-bearing zone (Stepanov and Moiseenko 1993) is a system of parallel mylonite zones 2-3 to 40 m thick dipping 60-70° to the NW (Fig. 19). This zone is traced for 3,000 m along strike and 500-550 m downdip by drilling and underground workings. Sulfide mineralization is widespread within the crushed and mylonitic zones, but ore bodies with feasible gold grades are located commonly at the hanging wall of the structure. They are represented by disseminated and veinlet-disseminated sulfide mineralization with quartz-stibnite-cinnabar core veins.

The ore bodies are band—and lenslike with irregular distribution of gold that forms ore shoots at the bulges of ore lenses. Ore shoots are dip

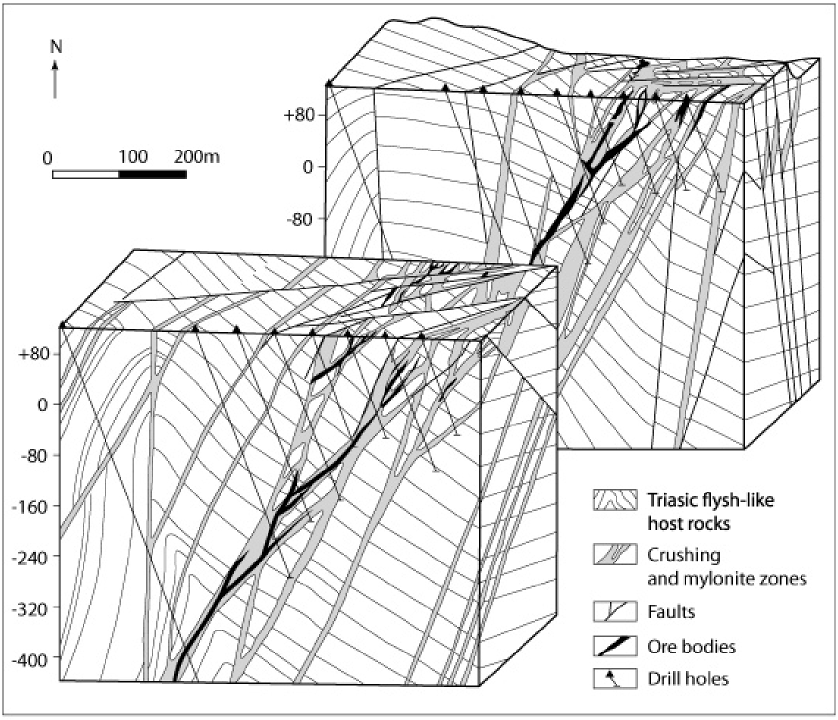


Figure 19. Three-dimensional model of the Kyuchus deposit (after V. Konyshev in: Stepanov and Moiseenko 1993).

gently (10-15°) in the northeast direction and are distributed at an almost regular interval of 50-60 m. The largest one with gold grade of 10-12 g/t is located in the northeast flank of the main ore body and is also enriched in mercury (0.01-0.03% and higher), antimony (0.1-0.3%), and arsenic (0.9-1.0%).

Gold, mercury, antimony, and arsenic have a zonal distribution. The mercury aureole with more than 3 ppm Hg coincides with the general gold mineralization while grades of more than 100 ppm Hg are localized within gold ore shoots. An antimony halo is typical for upper and above-ore levels of the deposit and high grade of arsenic (>1%) more usual for the lower levels of mineralization and often does not coincide with ore shoots. The hanging part of the main ore body is rich in mercury and kaolinite-carbonate veinlets. Carbonate-quartz with stibnite, cinnabar, and native gold vein and veinlet-type mineralization is concentrated at the core part of the ore body, while the footwall contains disseminated pyrite and arsenopyrite.

Ore mineralogy of the Kyuchus deposit is relatively simple with a prevalence of pyrite, arsenopyrite, stibnite, cinnabar, and lead sulfosalts. Native gold, metallic mercury, native sulfur, realgar, orpiment, galena, sphalerite, pyrrhotite, and chalcopyrite are also found but at much lower ends. The amount of arsenopyrite in the deposit is slightly higher than in Carlin-type deposits.

The oxide zone of the Kyuchus deposit is 60-80 m thick and contains remnants of sulfide minerals, limonite, jarosite, and antimony ochre. Arsenopyrite usually is leached from the oxide zone, but the amount of native gold is increased. Associated gangue minerals of the oxide zone are different generations of quartz, dolomite, calcite, dickite and kaolinite, sericite, and gypsum.

The ore consists of brecciated and crushed host rocks with argillic alteration and contains 1-3 to almost 10% thin impregnation and veinlets of sulfides. The three types of ore (Moskvitin 1997; Berson et al. 1999) are (1) massive quartz metasomatite with powderlike impregnation of early pyrite and arsenopyrite; (2) massive quartz veins/veinlets with nests and impregnation of late stibnite, cinnabar, gold, and pyrite; and (3) quartz-carbonate breccia with pyrite, stibnite, realgar, and cinnabar. Sulfide impregnation distributed for a few meters from contacts of quartz and quartz-carbonate vein/veinlets. Gold grade depends mostly not on the amount of sulfides but on the level of veinlet mineralization and is higher in the zone's increased veining.

Pyrite-arsenopyrite disseminated mineral association is developed in altered host rocks containing metasomatic quartz, magnesia-rich siderite, and sericite. Prismatic and acicular crystals of arsenopyrite I vary from 0.05 to 0.3 mm and contain 34.7-37.9 wt. % iron, 42.4 to 46.6% arsenic, and 18.9 to 22.7% sulfur with stibium and nickel as admixtures (0.3 to 0.4%). Gold grades in arsenopyrite I (28 to 1,125 g/t) decrease from the early mineral associations to the later. Pyrite I forms small (0.02-0.06 mm) isometric cube-octahedral crystals and is arsenic-rich (2.0-7.6 mass %) and gold-low.

The stibnite-quartz association consists of arsenopyrite, pyrite II, sphalerite, chalcopyrite, tennantite, tetrahedrite, chalcostibite, and stibnite. It fills open shear fractures, cements brecciated metasomatite with disseminated arsenopyrite-pyrite mineralization, and forms nestlike aggregates in carbonate-quartz veins, lenses, and veinlets or as rims along the vein selvages. This mineral association is concluded by deposition of the allotriomorphic native gold of 960-970 fineness that forms inclusions in stibnite.

The final gold-bearing mineral association, cinnabar-metacinnabar-kaolinite, coincides with quartz-stibnite as a carbonate-dickite veinlets and lenses with dissemination of cinnabar, metacinnabar, and native mercury. It contains also mercury—(up to 15 wt. % of Hg) and silver-rich varieties of tennantite and tetrahedrite, realgar, and orpiment. A tennantite-tetrahedrite assemblage contains also microinclusions of aktashite—a rare mineral typical for telethermal antimony-mercury deposits (Bryzgalov et al. 1999).

Native gold of this association has (Berson et al. 1999) clumpy particles up to 1-2 mm, high in mercury (16.5-22.79 wt. %) and silver (up to 12 wt. %). The gold concentration is low in realgar (0.75-6.0 g/t), cinnabar (0.3-2.15 g/t), and sulphosalts. Impregnation of cinnabar and rarely native mercury can be traced to depths of 600 m and is concentrated commonly at the hanging walls of ore bodies together with the post-ore kaolinite-carbonate veinlets.

Stepanov and Moiseenko (1993) distinguished only two gold-bearing mineral associations: pyrite-arsenopyrite-quartz and realgar-orpiment-cinnabar-stibnite. The late, barren in gold kaolinite-carbonate association, forms rims around vein-type mineralization and takes part in argillization and carbonatization of host rocks altered previously by sulfidization and silicification.

Argillic alteration of the carbonaceous sedimentary host rocks resulted in the deposition of kaolinite, dickite, and hydromica mostly in the rock groundmass. Intense silicification and carbonatization of the host rocks did not result in the typical jasperoid alteration usual for Carlin-type deposits due to the primary shales versus limestone composition of the host rocks.

The majority of the gold at the Kyuchus deposit is related to the ore bodies with veinlet-disseminated mineralization. Geological resources of the Kyuchus deposit (C_1+C_2+P_1) estimated after its exploration are about 23,000,000 tonnes of ore grading 9.3 g/t, i.e., 6.9 Moz or 214 t of gold including approximately 5.0 Moz of proven reserves. Hove International Ltd. of the United Kingdom at the end of 1990s confirmed the probable reserve as 12,145,140 tons grading 8.82 g/t (4.44 Moz) using 5 g/t cutoff grade and inferred resources as 6,278,559 tons of ore grading 9.03 g/t (2.24

Moz) for some 6.64 Moz (205.8 t) of western-approved gold resources of the deposit.

The deposit remains open along strike and to the depth. Since exploration was concentrated mainly on the deposit itself, the area remains underexplored, and the possibility that further works will lead to discovery in this region new trend of gold-mercury deposits similar by its scale to the Carlin trend is high. Such possibility is underlined not only by similarity of the Kyuchus deposit geotectonic setting and mineralogical-geochemical features with Carlin trend deposits but also by the presence in this region of other similar gold deposits that have been explored much less thoroughly than Kyuchus.

The best example of such deposits is the Levo (Left) Sakandzha ore field (Supletsov 1997). This ore field is located to the southeast of the Kyuchus deposit on the extension of the midocean Hackel Ridge under the Eurasian continent. It contains a few gold-mercury-quartz deposits and prospects and belongs to a belt of mercury, which occurs within a major fault zone situated along the northwestern rim of the Kolyma rigid massif (see figure 18). This fault zone consists of a series of thrusts, by which allochthonous blocks of Paleozoic carbonates have been thrust over autochthonous Mesozoic sedimentary sequences.

The main structure of the Levo Sakandzha ore field is anticline, which bifurcates to the north. Host rocks are Middle Ordovician-Silurian dolomite and limestone containing different amount of natural bitumen. Pre-ore diabase porphyry, gabbro diabase, essexite, camptonite, and lamprophyre dikes are common in the ore field. The largest gold-mercury-antimony deposit in this ore field, Gal-Khaya, consists of thick zones of jasperoid and lenslike bodies of gold-bearing quartz-fluorite-mercury breccia. The ore is hosted by carbonaceous limestone and is accompanied by strong thallium geochemical halos containing up to hundreds of grams per ton of thallium. The new thallium sulfide "galkhaite" discovered here in 1972 was later found at the Carlin deposit (Radtke 1985).

The Gal-Khaya deposit was originally considered as a mercury deposit and contains more than 10,000 tonnes mercury. It was rarely sampled for gold during its exploration in the 1960s. Metallurgical tests of ore from the deposit, however, revealed gold grade of 1.75 g/t, and seven randomly sampled core sections were found to contain up to 5 g/t of gold. Gold resources of the deposit are roughly estimated by V. Supletsov to be at least 60 tons. Another group of stratabound-like gold-mercury prospects and deposits (Arbat, Pologoye, Kryuk, etc.) are located nearby and also was not explored thoroughly for gold.

These two examples illustrate the hypothesis that an extensive belt of gold-mercury-quartz deposits and prospects similar to the deposits of the Carlin belt are present in the northeastern part of the Eurasian continent. Both belts are located on extension of the contemporary midocean ridges under the North American and Eurasian continents and characterized by riftlike basins filled with Tertiary and Cenozoic sediments, anomalous shallow position of mantle surface, and high heat flow. The heat that drives the geothermal systems may be related in both regions not to intrusive activity but to the thinness of the earth crust and the resulting high geothermal gradient, which has been tapped by deep, high-angle faults (Percival et al. 1988). These faults could be responsible not only for heating descending meteoritic water that subsequently mobilizes the necessary ore components from the thick sedimentary section but also for the delivery of some mantle fluids along with the mercury and gold.

The only other midocean ridge that approach continent with developed earth crust is an offshoot of the Carlsberg Ridge of the Indian Ocean that is going through the Gulf of Aden and the Red Sea rift toward the Dead Sea. This region does not contain any known Carlin-type deposits or even prospects, but such possibility cannot be excluded.

There is a possibility of finding other Carlin-type deposits in similar paleotectonic situations when paleorifts are approaching continental margins and are extended under the continent. A possible example of a gold deposit in such a geotectonic setting is the Vorontsovka deposit described below.

The Vorontsovka Deposit (59°26’N-60°00’E)

The deposit was discovered in 1983 and is located in the Krasnotur’insk district of the Ekaterinburg region (Middle Urals, Russia). It is situated on the west side of the Auerbakh iron-copper skarn district, in the Silurian-Devonian volcano-plutonic belt. The belt with island-arc type of magmatism over an ocean basement is located on the eastern outskirts of the Caledonian Tagil synclinorium. Andesitic volcanics and comagmatic stocks are overlay and intrude ophiolites, which thrusted on a rim of microcontinent to the east of this belt.

Such location looks quite unusual for Carlin-type gold deposits, but the Vorontsovka deposit is situated on the extension of the southeast-trending Timan rift of the eastern European platform under the Uralian continental structure. The development of the Devonian-Early Carboniferous Timan paleorift under Proterozoic-Early Paleozoic Middle Urals fold belt can be traced by series of southeasterly faults representing concealed ore-concentrating structure (Fig. 20). According to R. Berson and N. Rindzyunskaya (TsNIGRI, written communication), this structure is traced also by geophysical and geomorphological data. A few other mercury and antimony occurrences are known in this zone that continues to the southeast and marks a bend of the Uralian belt and north border of the Kazakhian continent.

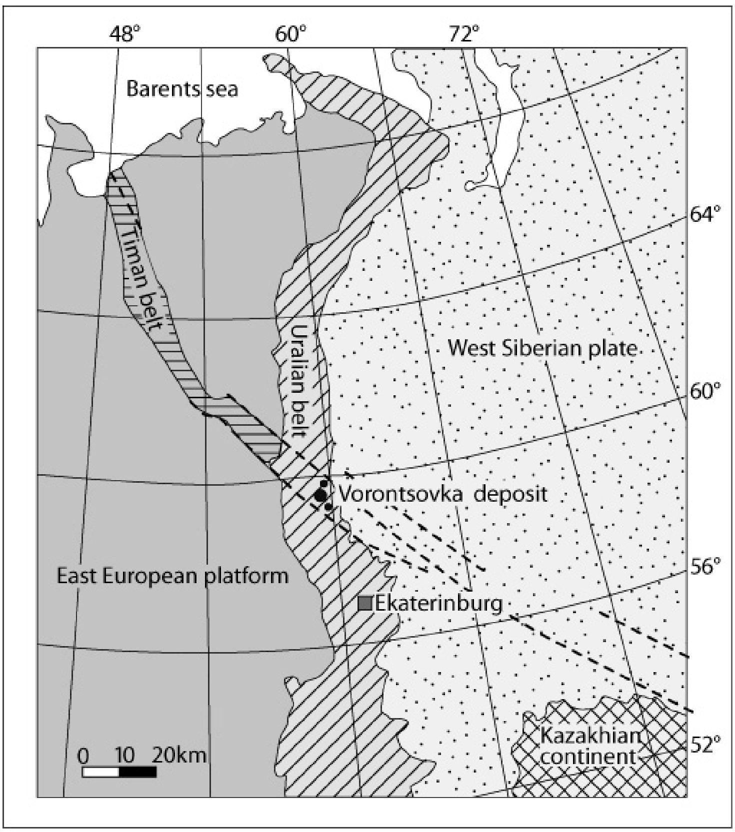


Figure 20. Setting of the Vorontsovka deposit in regional tectonic structures.

The Vorontsovka deposit is situated at the center of a volcano-tectonic depression, 35 km long and 18 km wide, filled by Devonian volcanogenic-sedimentary rocks and intruded by gabbro-granodiorite stocks. The Auerbakh stock, 15 km long and 6 km wide, outcrops 0.6-1.0 km to the east of the deposit and consists of gabbro, diorite porphyry, granodiorite, and potassium-low granite porphyry phases.

The monoclinaly folded Devonian sequence, according to B. Gladkovsky and V. Bobrov who explored this deposit, has a north-south strike and a gentle dip to the west. The lower part of this sequence consists of marbleized limestones, 1.1-1.2 km thick, with interlayers of tuffaceous sandstone and siltstone. The host limestones with skarn alteration along the contact with the intrusive stock are conformably covered by tuffaceous siltstones and sandstone with thin interlayers of limestone, andesite porphyry, and tuff.

The limestone is brecciated along the contact with overlaying volcanic sediments, and this breccia is host to the mine ore body. The first type of breccia (Sazonov et al. 1991) contains rounded rubble of limestone in a matrix of andesitic volcanics. This breccias host large ore bodies in the central part of the deposit. The second type of breccia consists mainly of angular limestone blocks within a matrix of andesite composition. This type is more common on the periphery of the large mineralized zones. Both types of breccia were formed before the intrusion of the gabbro-granodiorite pluton and a series of diabase and diorite porphyry dikes. This fact is illustrated by exhibit of skarn alteration upon breccias caused by intrusive. Some local geologists (V. Bobrov) suggest that the breccia has a tectonic-sedimentary origin while others (B. Gladkovsky, V. Sazonov) are suggesting an eruptive origin in connection with the local volcanic activity. In any case, such breccias are one of the elements of similarity between the Vorontsovka deposit and some Carlin-type deposits, where brecciation is ore controlling. At Vorontsovka, the intersection of N-S thrusting with southeast-trending faults and crush zones is a major control on the distribution of the ore bodies.

Regional propylitic alteration of the volcanics, widespread hornfelsing, and garnet-pyroxene skarns associated with contacts of the intrusive bodies has a regional scale. Feldspathic, wollastonite, and quartz-calcite-sericite-chlorite-pyrite (beresite-listwanite in Russian terminology) alteration is best developed along the faults (Sazonov et al. 1991, 1998).

Wall rock alteration most closely related to gold mineralization at the Vorontsovka deposit includes quartz-sericite and jasperoidal silica. Quartz-sericite, quartz-sericite-albite, and quartz-sericite-chlorite alterations are also developed along fractures and in the volcanogenic cement of the breccias. These alterations are superimposed upon the propylitized rocks and contain sericite, chlorite, epidote, quartz, calcite, and usually pyrite.

Jasperoidal alteration is found in the mineralized limestone breccia. The volcanogenic groundmass of the breccia underwent quartz-sericite alteration with simultaneous deposition of dolomite-ankerite in the limestone. Later jasperoidal alteration developed both along the contact of the gabbro-granodiorite intrusive with limestone as well as inside limestone far away from the contact with granitoids (Sazonov et al. 1998). The small jasperoid bodies are several decimeters thick and 10-15 m long. Chloritization with sulfide mineralization was developed later, mainly along the contacts of the limestone with the quartz-sericite-albite-carbonate altered volcanics.

Erratically distributed argillic alteration that dominates in oxide zone is probable supergene in origin and surrounds the silicification, especially in the tuffaceous rocks. However, V. Bobrov (Korobeinikov et al. 1998) suggests that low-temperature argillic alteration and gold-arsenic-mercury-quartz mineralization are the latest events of the ore process. The argillic association consists of two facies of the acidic leaching stage: (1) hydromica and (2) hydromica-montmorillonite-kaolinite facies in volcanics. The presence of both jasperoid and argillic alteration at the Vorontsovka deposit is another point of similarity between this deposit and Carlin-style mineralization.

Gold mineralization is found along gently west-dipping (10-30°), partly faulted and brecciated contact between the Early Devonian massive limestone and the Middle Devonian volcanics (Fig. 21) where these units have been transected by high-angle feeders filled by later dikes. Stratabound-like ore bodies are traced in north-south direction for about 2.5 km and 276 m down dip. The average thickness of the some twenty-seven outlined ore bodies varies between 1-3 and 30-50 m (up to 95 m in one section), but most of the mineable reserve is concentrated in only three ore bodies.

The largest, carbonate-sulfide, ore body (1,020 m long, 80 to 230 m wide, and 24 m thick) contains 52.9% of the proven gold reserves and is hosted in a carbonate breccia. The tuff-hosted silicate-sulfide ore zone,

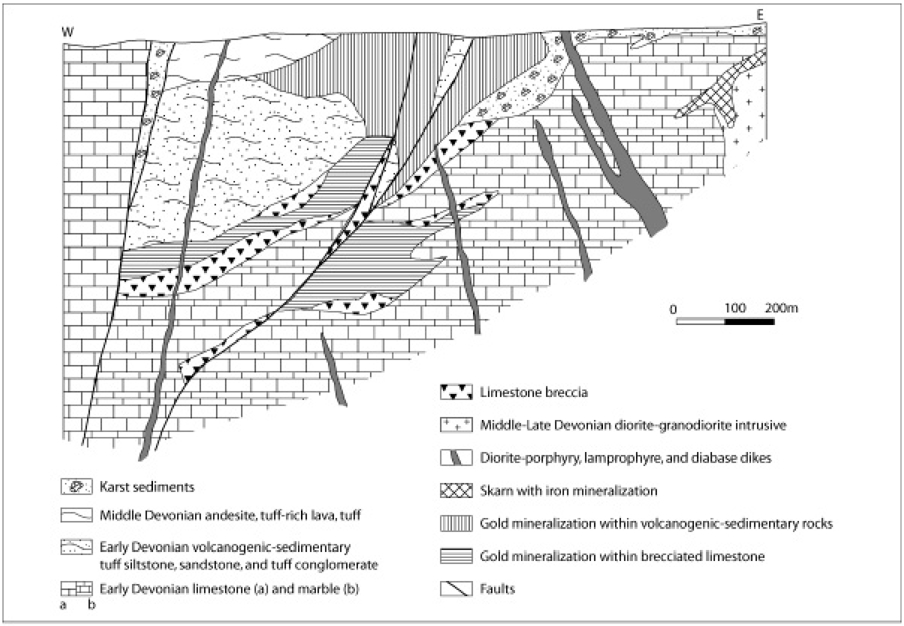


Figure 21. Schematic cross section of the Vorontsovka deposit (simplified after Konstantinov et al. 1993).

which generally lies above the carbonate-sulfide ore body, is 530 m long, from 32 to 252 m wide, and 19.8 m thick. It contains 16.4% of gold reserve. The near surface oxide ore zone that amounts for 22.8% of the gold reserves is traced for some 1,326 m, is 60 to 376 m wide (average—236 m), and 12.3 m thick. The oxide zone outcrops along the southern edge of the Vorontsovka deposit where the sulfide ore is also the shallowest and then gradually plunges to the north. The stratabound character of the ore bodies and their control by the high-angle and low-angle faults is also similar to the Carlin-type deposits.

Two stages of veinlet-disseminated mineralization (Sazonov et al. 1991) related to quartz-sericite alteration include (1) early pyrite-arsenopyrite in propilitized volcanogenic-sedimentary host rocks and (2) productive pyrite-realgar mineralization in limestone breccia. The first stage consists only of pyrite and arsenopyrite and constitutes from 3-5 and up to 30 wt. % of the quartz-sericite altered host rocks. Interestingly, the arsenopyrite, which amounts for 4-6% of this association, does not form thin acicular crystals that are typical for sedimentary-hosted gold (arsenic)-sulfide deposits; the pyrite contains low arsenic and gold values.

The most productive, pyrite-realgar, stage of mineralization in limestone breccia contains the highest gold values and includes three mineral associations. The first one consists of acicular-shaped arsenopyrite II with high arsenic contents, pyrrhotite, chalcopyrite, sphalerite, and native gold (Sazonov et al. 1998). Sphalerite (0.8-2.0 wt. % Fe) was deposited later than pyrrhotite. Gold of 987-998 fineness forms micron-size (1-5 to 20 μm) particles in altered tuff siltstones or in pyrrhotite and pyrite.

The second mineral association, orpiment-realgar, is found in the brecciated limestone at the central part of the Vorontsovka deposit and overprinted earlier pyrite-arsenopyrite and pyrrhotite-arsenopyrite mineral associations. It contains two mineral paragenesises: orpiment-realgar and realgar-stibnite. The first one consists of realgar, mercurial sphalerite (up to 23.1 wt. % Hg), orpiment, rutierite ($TlHgAsS_3$), aktashite [$(Cu, Hg)_2 AsS_3$], cinnabar, native gold, and very rare Tl-As-Sb-S and Pb-Tl-As-Sb-S sulfides. Native gold, 987-995 fineness and up to 0.08 mm in size, contains up to 0.9 wt. % of mercury and forms intergrowths with realgar or fills fractures in early pyrite.

The realgar-stibnite paragenesis also contains zinkenite, sphalerite, silver-bearing Zn-tennantite and Zn-tennantite-tetrahedrite, chalcostibite, minerals of the Tl-Sb-S system, and native gold. Micron-size particles of native gold have lower fineness (910-960) than in the orpiment-realgar paragenesis but also contain 0.3-0.6 wt. % Hg.

The presence of numerous thallium sulfides in the Vorontsovka deposit is another similarity with the Carlin-style mineralization.

The third, arsenic-coloradoite, mineral association in the dolomite-ankerite facie of jasperoid is younger (Sazonov et al. 1991, 1998) than the orpiment-realgar one. It consists of native arsenic, coloradoite, and hessite deposited along fractures in carbonate-realgar aggregates.

A disseminated sulphosalts-polymetal stage of mineralization in brecciated and pyritized limestone and tuffaceous siltstones contains two mineral associations: (1) sphalerite-arsenopyrite-pyrite with pyrrhotite and (2) sulphosalts association with chalcopyrite, sphalerite, plagionite, geochronite, galena, tetrahedrite, and tennantite-tetrahedrite. Most of the gold in this stage is associated with lead sulphosalts and has a fineness of 735-890. The gold has higher (940-950) fineness in the chalcopyrite-sphalerite mineral paragenesis.

Geochemical halos of barium (0.3-0.5%), manganese (0.2-0.7%), arsenic (0.1-0.3%), antimony, molybdenum, lead, and tungsten (all at ranges of 2-3 to 15 ppm) coincide with aureoles of gold (0.5-1.0 g/t) and silver (2-5 g/t). Strong peripheral and late barium, as well as the presence of arsenic and antimony, is also typical for Carlin type of ore.

Gold-arsenic mineralization of the Vorontsovka deposit is not thought to be related to the Auerbakh granitoids (Sazonov et al. 1991, 1998). The high- and low-temperature metasomatic alteration such as the skarn and argillic is present in the same structures at the same erosional levels. K-Ar dating of the granitoids (380 Ma) and gold-bearing quartz-sericite alteration (300 Ma) shows that the early skarn and later auriferous mineralization differs by eighty million years.

The geological resources of the Vorontsovka deposit calculated during the exploration total some 15,420,000 metric tons of ore grading 4.94 g/t gold (76.17 t or 2.45 Moz) and 6.37 g/t silver (98.23 t or 3.17 Moz). Resources of oxide ore are 7,400,000 metric tons grading 4.05 g/t gold and 8.65 g/t silver (0.97 Moz of gold).

The geotectonic setting of the Vorontsovka deposit on the extension of the Timan rift under the Urals and such characteristics as (1) the presence of limestone breccias, which controls stratabound ore bodies, (2) jasperoid and argillic alteration of the host rocks, (3) gold, mercury, antimony, and thallium mineralization; and (4) barium-rich halos are major points of similarity of the Vorontsovka mineralization to the Carlin-type gold deposits. The location of the Vorontsovka deposit nearby gabbro-granodiorite stock and its other features are closest to the Getchell and Pinson deposits of the Getchell trend (Percival et al. 1988).

The presence of the Kyuchus in Yakutia and the Vorontsovka deposit in the Middle Urals, both of which have strong similarities to the Carlin style of mineralization, suggests a good potential for exploration of gold-mercury-quartz mineralization in the CIS. The potential for possible discovery of other such deposits can exist in the structure, which extends from the Hackel Ridge of the Arctic Ocean under the Eurasian continent in less prospected, "Kyuchus trend."

In addition, the example of the Carlin-style Vorontsovka deposit formed on the extension of the paleorift system requires review of other gold provinces of the CIS for such structures and broadens potential for the Carlin-type deposits in unusual geological and geotectonic settings around the world.

4.1.2.3 Gold-Antimony-Quartz Deposits

Gold-stibnite-quartz mineralization is one of the major sources of antimony and a subsidiary source of gold. Such mineralization is known in the Republic of South Africa, Australia, Bolivia, China, France, and other countries (Berger 1993) but does not have a broad development in the CIS.

At the end of 1970s and 1980s, mostly owing to numerous works of Indolev (1975, 1980) and V. Berger (1978, 1981, 1993, etc.), such gold-stibnite deposits were finally outlined as a specific gold model having special geological and geotectonic settings and specific mineralogical-geochemical features.

Gold-antimony deposits of the CIS usually have relatively small resources (400,000-1,000,000 tonnes of ore) and relatively low gold grade (3-6 g/t). At the same time, some of the deposits contain tens of millions tons of ore (Sarylakh—10.6 Mt) and/or very high grades of gold up to 75 g/t and higher (Sentachan).

Many authors from as early as Lindgren (1933) and his followers in the USSR (G. Gamyanin, A. Obolensky, N. Petrovskaya) viewed gold-antimony deposits as combination of mesothermal gold-quartz mineralization overprinted by epithermal antimony mineralization. Emmons (1937), Bilibin (1959), and V. Berger (1978 and others) considered these deposits as the latest member in the low-sulfide gold-quartz vein deposits.

Gold-antimony deposits are developed, according to V. Berger, mostly in intercontinental structures such as Archean greenstone belts (Murchison Range in South Africa), in turbidites along passive continental margins (Yenisey Range, Russia), or in accretionary fold and fault systems (Yano-Kolymsky fold belt, Russia, and the South Tien Shan belt in Central Asia Republics). With exception of Archean greenstone belts, such a geotectonic setting is similar for both the gold-antimony and gold (arsenic)-sulfide deposits.

The most common host rocks for the gold-antimony deposits of the CIS are black shales, turbidites, siltstones, sandstones, and carbonates, which have been metamorphosed to a low greenschist facies. Main ore-controlling structures are shear zones, dragging folds, and compressive deformations.

Two morphological types of mineralization that usually could be found in the same ore zones are (1) stratiform gold-stibnite-sulfide bodies and (2) veins of gold-stibnite-quartz mineralization. The former have broader distribution at the lower levels of the deposits. The vein type has higher antimony and gold grades and has major economical effect in mining of these deposits.

Three typical mineral associations are arsenopyrite-pyrite, sulphosalts-polysulfide, and berthierite-stibnite. Submicroscopic-sized gold particles (800 to 930 fineness) are typical for early mineral association, mostly in arsenopyrite and less in pyrite with positive correlation between gold and arsenic. Larger gold particles (0.01-0.5 mm) in stibnite, berthierite, and quartz are common for the late mineral associations and have higher fineness (940-999).

The major differences between gold-antimony-quartz deposits and epithermal antimony deposits (Berger and Mamonov 1988) are (1) silver grade below 10 g/t with Au : Ag = 15:1 to 5:1 and mercury below 5%; (2) the absence of barite, cinnabar, realgar, and chalcedonic quartz common for epithermal antimony deposits; (3) high fineness (940-999) of gold in later berthierite-stibnite association; and (4) typical quartz-carbonate-sericite-chlorite (beresite) alteration similar to the alteration of related mesothermal gold-quartz vein deposits.

V. Berger described deposition of gold-stibnite-quartz mineralization as a combination of sedimentary, metamorphic, and hydrothermal events with mobilization of ore components from shales host rocks during regional metamorphism.

The Sarylakh Deposit (64°24’N-142°24’E)

The Sarylakh deposit is located at the intersection of the large N-S-trending, 35-40 km wide, Adycha-Taryn fault zone with a concealed regional fault of NE strike (Berger 1978). It is situated within a large, 12 km wide, syncline of Triassic sandstones and shales complicated by smaller folds. The sediments are intruded by a stock of quartz diorite porphyry (120 Ma) located two kilometers north of the deposit, which is intersected by the postmineral quartz-ankerite veins.

The Sarylakh deposit consists of the series of quartz veins. The major one, 2 km long, occurs in shear zone 10 to 20 m wide along a northwest trending and 55-85° NE dipping dextral strike-slip fault (Fig. 22). This “core” vein, up to 17.2 m thick, lies within the fault plane and is accompanied by numerous veinlets of different direction in intensely fractured, sheared, and boudinaged siltstones and sandstone (Volkov et al. 2002). Ore shoots are controlled by the bends in the fault and are traced to significant depth. The uplifted and eroded southeast block of the deposit contains small branching veins with a prevalence of arsenopyrite-pyrite mineralization over stibnite, which is the main one in the northwest block.

The texture of the massive stibnite ore clearly results from granulation and mylonitization within the fault zone. Stibnite grains occur in granulated aggregates up to 5 mm in size, while mylonitic quartz-stibnite ore has a dominated grain size of 0.01-0.1 mm. Main ore minerals are stibnite and quartz. Pyrite, arsenopyrite, berthierite, ankerite, sericite, and graphite constitute up to 10% of the volume, while native gold, silver, stibium, gudmundite, aurostibite, chalcostibite, sphalerite, chalcopyrite, and tetrahedrite are accessory minerals of these quartz-stibnite veins.

A succession of mineral paragenesises includes early and low in gold quartz-pyrite-arsenopyrite association. The arsenopyrite and pyrite impregnation is typical for the shear zones hosting the major vein, especially at its hanging wall. The second association consists of quartz-sulphosalts and appears as single small veinlets and/or inclusions of zinkenite, tetrahedrite, galena, and rare other minerals. The third, quartz-stibnite-berthierite, gold-bearing association is broadly distributed and also includes aurostibite, chalcostibite, and sphalerite. Berthierite in this association is mostly replaced by stibnite and contains inclusions of native antimony and ullmannite (NiSbS).

Gold of this third association is concentrated at the contacts of quartz and stibnite crystals and in quartz. Part of the gold was deposited after stibnite, but most of it appeared at the end of quartz crystallization but before stibnite deposition. According to Indolev (1975), high-fineness gold of the quartz-stibnite-berthierite association is a product of gold remobilization from the earlier pyrite-arsenopyrite association.

Vertical zoning of the Sarylakh deposit results in higher amount of berthierite and arsenopyrite at its deeper levels.

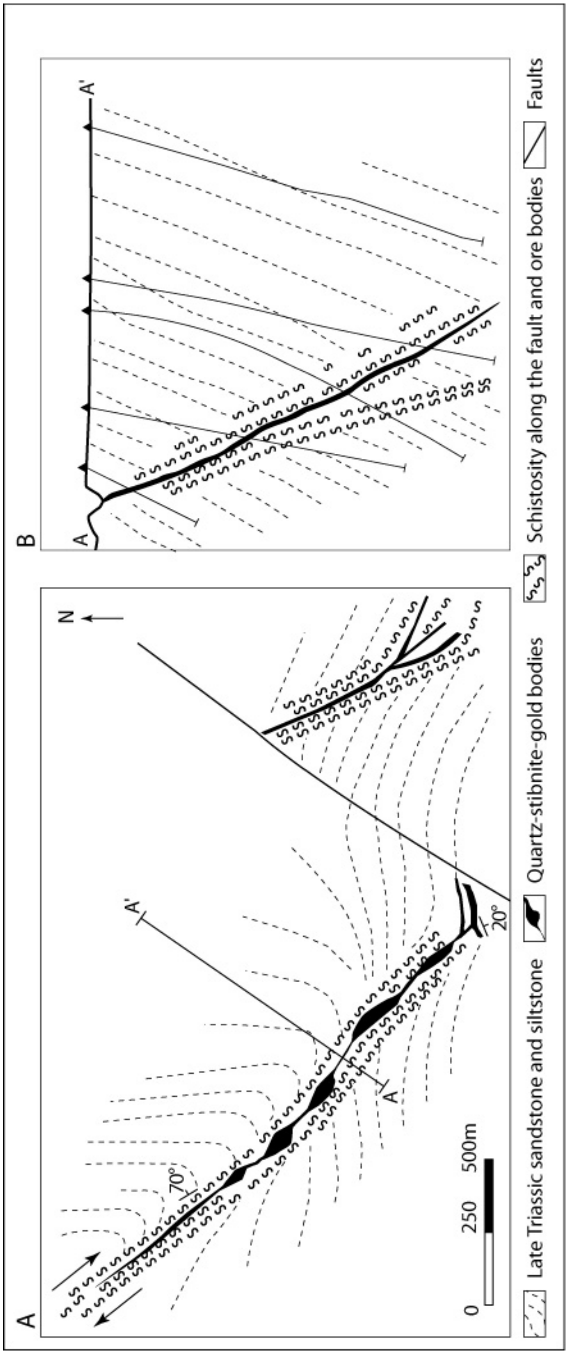


Figure 22. Schematic plan (A) and cross section (B) of the Sarylakh deposit (after V. Berger 1978).

The ore and altered rocks of the Sarylakh deposit and similar deposits of the Yano-Kolyma belt (Sentachan, Maltan, and smaller ones) contain extremely low mercury (1.5-9.0 x 10^{-5}%), much below its common concentration in gold-sulfide deposits.

Gold-stibnite-quartz veins are accompanied by quartz-sericite-ankerite-albite-pyrite (beresite) alteration, which is visible mainly nearby the veins. The gold-bearing stibnite-berthierite association is accompanied by the late micaceous minerals formed as a result of recrystallization and redistribution of early mica. Kaolinite and montmorillonite occur as veinletlike aggregates crosscutting sulfide mineral associations.

Temperature of mineral deposition at the Sarylakh deposit, as shown by study of fluid inclusions in quartz and stibnite, decreases from the early mineral association (380-280°C) to the last one (180-130°C) at the pressure ranges from 600 to 1,600 bar.

Resources of the Sarylakh deposit are 10,600,000 metric tons of ore grading 6% antimony and 6 g/t gold, i.e., about 2 Moz or 62 t of gold.

The Sentachan Deposit (66°27'N-137°03'E)

The Sentachan deposit is located in the same Adycha-Taryn fault zone, about 350 km to the north-northwest from the Sarylakh deposit. The deposit is located at the dextral offshoot of this zone, named as the Sentachan fault, in monocline bedding sequence of sandstones, siltstones, and shales of Late Triassic age. The main ore bodies (Genkin et al. 2002) are lenseslike lodes 0.2-6.0 m wide and 80-120 m long along and within northwest-striking mylonite zones (Fig. 23).

Massive quartz-stibnite veins occupy the central parts of these ore lodes. Further deformation transforms the massive veins into several separate quartz lenses along the northwest flank of the mineralized shear zone. The main veins are accompanied by numerous quartz-ankerite veinlets and aureoles of disseminated pyrite along the hanging wall and by a halo of fine-grained disseminated pyrite in carbonatized sandstone of footwall. Smaller brecciated quartz veins with quartz fragments cemented by the cataclastic fine-grained quartz-sulfide matrix fill steep-dipping fractures. Gently dipping parts of the fissures contain quartz-stibnite mineralization.

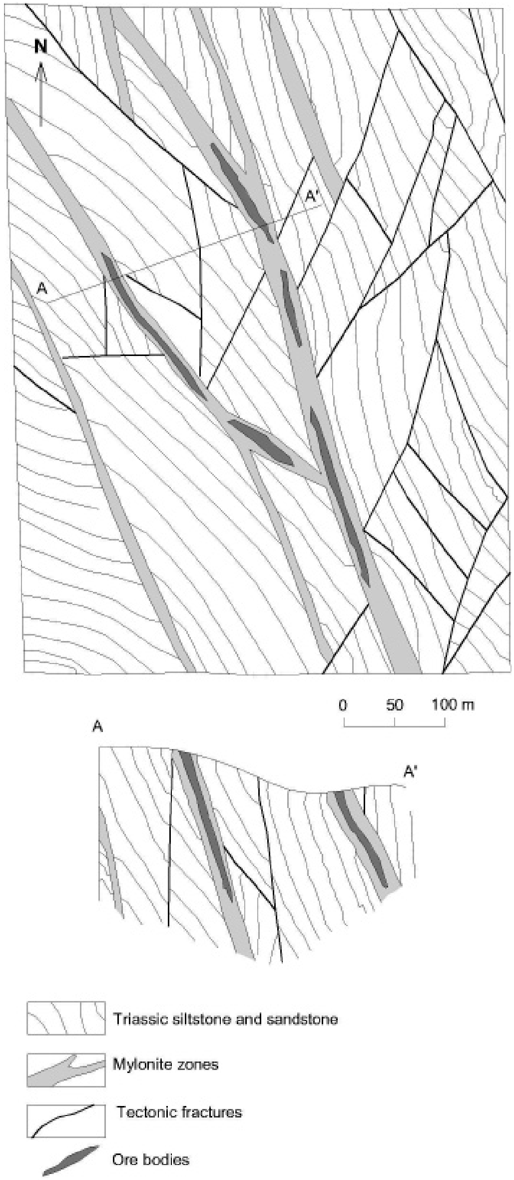


Figure 23. Structure scheme and section of the Sentachan deposit.

Indolev et al. (1980) and Genkin et al. (2002) identified several successive mineral associations. The earliest one consists of cataclastic and brecciated quartz veins that are a precursor to the ore process. The next, arsenopyrite-pyrite, association forms disseminations in sheared rocks and quartz-sericite-ankerite veinlets, surrounding main stibnite-quartz veins. The amount of arsenopyrite decreases rapidly at a distance of 5-7 cm from vein selvages. Quartz-sericite-ankerite veinlets with arsenopyrite and pyrite crosscut the brecciated quartz veins of the early association. Arsenopyrite I occurs frequently along the contacts of siltstone fragments in the quartz veins and is rarely associated with pyrite I replacing it. Pyrite I is widespread in the foliated cataclastic zones where it has been crystallized simultaneously with metasomatic quartz. The quartz, arsenopyrite, and pyrite of this association do not contain even microscopic inclusions of gold.

The third, galena-sphalerite-sulfosalts, mineral association fills secondary fissures within the main fractures, which contain quartz veins with rare fine grains of arsenopyrite II. Aggregates of this third association replaced ankerite, arsenopyrite and pyrite of the early association and are restricted to areas of quartz recrystallization. Native gold of this mineral assemblage is a primarily associate with tetrahedrite and sphalerite. The gold sometimes is replaced by stibnite but commonly occurs at the corroded contacts of quartz and stibnite grains.

Quartz-stibnite-berthierite is the youngest mineral association and contains arsenopyrite III and the main amount of gold. Native gold sometimes replaces arsenopyrite III. Genkin et al. (2002) noted that enrichment of this association with gold is typical where stibnite mineralization replaces the early arsenopyrite-pyrite association.

The original resources of the Sentachan deposit were about 1.5-1.7 million metric tons of ore grading 25% antimony, 37 g/t gold, and 13 g/t silver; but high-grade ore contains 38% antimony and 75 g/t gold. Remaining resources of the deposit at the second half of the 1990s were 14.1 t of gold, 5.7 t of silver, and 87.8 thousand tonnes of antimony.

Except for a broader distribution of the galena-sphalerite-sulfosalt association along with some native gold and a much higher grade of antimony and gold, the Sentachan deposit is similar to Sarylakh and many other gold-antimony deposits of the Yano-Kolyma belt. A different type of gold-antimony mineralization in Proterozoic sediments of the Yenisey Range is described below.

The Uderey Deposit (58°50'N-94°15'E)

The Uderey deposit is in the Late Precambrian (Baikalian) trough of the Yenisey Range along the passive margin of the Siberian continent containing the previously described Sovetskoye, Olimpiada, and Veduga, gold deposits. The Uderey deposit is located (Berger 1981, 1990) at the southern part of this gold belt. It is situated within the Ishimbinsk shear zone and is hosted by the Middle-Late Proterozoic micaceous phyllite (chlorite-sericite, sericite-carbonate, mica-graphite, and mica-clay schists), which are enriched in carbon. This sequence contains, besides the dominant sandstones and siltstones, a chlorite-sericite (silky) shales derived from pelitic to ultrapelitic sediments. The ultrapelitic rocks host interlayers, lenses, and concretions of sulfides (mainly pyrite) up to 15 cm thick and conformal to bedding. The mineralized zone of the Uderey deposit, 15 km long and 1-5 km wide, is enriched with porphyroblasts of siderite and ferrous dolomite.

An average grade of antimony in the different facies of the host rocks (Berger and Neklyudov 1991) varies from 1.33 g/t for psammite siltstones to 28.62 g/t for ultrapelite and is much higher than in similar rocks of other regions. An average gold grade has opposite trend—0.13 g/t in psammite siltstones and 0.08-0.09 g/t in pelite and ultrapelite facies.

The Uderey deposit is located at the T-shaped junction of northeast- and northwest-trending shear zones. The northeastern zone contains a series of quartz-stibnite veins near the intersection of this schistose zone with a series of westerly-trending faults. Ore veins are conformable to the schistosity that is intensified along the vein contacts. At the central part of the deposit, which is about 600-700 m long, veins have a complex shape with branches and accompanied by small quartz veinlets (Fig. 24), while at the flanks they have lenslike shape.

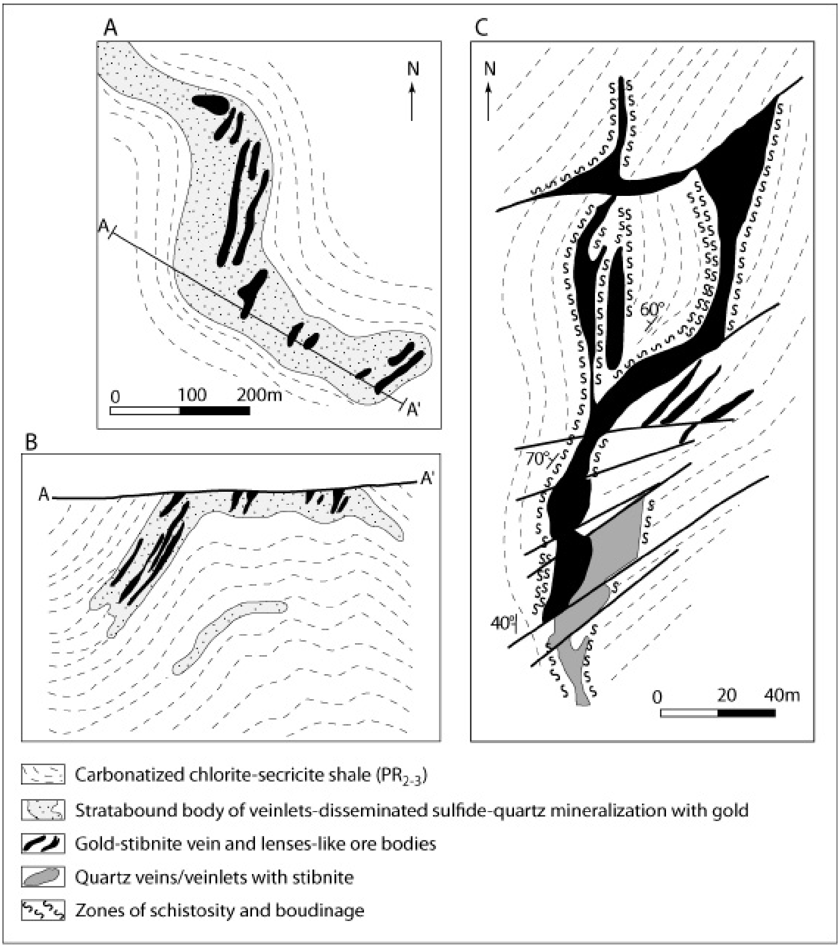


Figure 24. Principal plan (A), cross section (B), and detailed plan of the branched ore body (C) of the Uderey deposit (after V. Berger 1981, 1990).

The ore veins consist mostly of quartz, stibnite, and berthierite that make up to 95% of their volume. Arsenopyrite, pyrite, gold, siderite, sericite, and hydromica are also present in small amounts, while chalcopyrite, sphalerite, jamesonite, chalcostibite, cobaltite, and native stibium are rare. These minerals form two main mineral associations: an early quartz-arsenopyrite-pyrite and a later quartz-berthierite-stibnite. The first one, veinlet-disseminated mineralization of pyrite and arsenopyrite, forms a tabular ore body conformable to the rock layering in a local domelike fold (see figure 24). The acicular arsenopyrite of this mineral association is similar to that found in gold (arsenic)-sulfide deposits such as Olimpiada. Mainly submicroscopic native gold is concentrated within arsenopyrite and pyrite and has a positive correlation with arsenic. The average gold grade of this association is 1-2 g/t.

Sulfides of the younger, berthierite-stibnite, association occur primarily as massive aggregates in veins and only rarely as disseminations in altered wall rock. Berthierite is partially replaced by stibnite and contains inclusions of jamesonite, gray copper ore, and other minerals. Gold grade of these quartz-stibnite ore bodies averages at about 3 g/t.

A final minor stage of mineralization includes quartz-carbonate-hydromica-stibnite, association with fluorite and disseminated stibnite, cleiophane, and pentagonal crystals of pyrite. It forms veinlets 0.5-2.0 cm wide and 3-7 m long that cut all other mineral associations.

The quartz-berthierite-stibnite veinlike bodies are found (Berger and Neklyudov 1991) along the cleavage planes within the early stratabound veinlet-disseminated gold-sulfide mineralization.

Sericitization, carbonatization, sulfidization, and minor silicification of the metasedimentary host rocks, which accompany the earliest mineral association, are clearly visible only in nearby (0.5-1.5 m) of ore veins and are not recognizable in relation to the late stages of mineralization.

Temperatures of the early mineral association vary over a range of 300-200°C at 1,100-300 bar pressure and 5-60% CO_2 in solution. The second mineral association was formed at the temperatures 180-120°C with 20% CO_2 and about 30% NaCl in solution (Berger and Neklyudov 1991).

V. Berger suggests that the Uderey deposit mineralization, most likely, is a product of an early hydrothermal-sedimentary event with later remobilization and dynamometamorphic transformation. The K-Ar age of the hydromica in the latest association is 670 Ma, which is the upper limit of the age of ore deposition.

Resources of the Uderey deposit are about 700,000 tonnes of ore grading 7.0% antimony and 3 g/t gold or approximately 0.68 Moz or 21 t of gold. These resources are much less than those of the Sarylakh and Sentachan deposits, but presence of much larger similar deposits in other parts of the world justifies its description.

The similarity between the Uderey and Olimpiada deposit with gold (arsenic)-sulfide mineralization is only partial. The former does not contain an early quartz-scheelite mineral association while Olimpiada does not have the latest quartz-carbonate-hydromica-stibnite mineral association found at Uderey. The main productive, quartz-stibnite-berthierite-carbonate, stage at Uderey forms large vein—and lens-shaped bodies with average gold grades 3 g/t. A similar association is found at the Olimpiada deposit and occurs as tiny veinlets sporadically containing gold but does not have any real role in the total gold balance in comparison with earlier quartz-pyrrhotite-arsenopyrite-pyrite mineral association. Generally, the late quartz-antimonite association, found at the gold (arsenic)-sulfide deposits, is developed at the end of the ore deposition and never has any significant role as a source of gold.

The Sarylakh, Sentachan, and Uderey deposits are similar in development of the mineable gold-antimony mineralization. Most likely, they represent two subtypes of this deposit type. Early pyrite-arsenopyrite mineral association of the Sarylakh and Sentachan deposits is hydrothermal-metamorphic in origin and does not have stratiform character typical for the sedimentary-hydrothermal mineralization of the Uderey deposit.

V. Berger is possibly right in classifying Mesozoic gold-antimony deposits of the Yano-Kolymsky belt as utmost member of the postbatholith, shear-related gold-quartz mineralization, but the Uderey and other deposits of the Yenisey Ridge (Razdol'ninskoye, etc.) are different. The permanent presence of gold-antimony mineralization at the last stages of gold (arsenic)-sulfide deposits and their similar geotectonic setting can suggest that these two types of mineralization are closer as it had thought earlier, and the Uderey type of mineralization is an utmost member of the gold (arsenic)-sulfide deposits.

4.1.3 Stockworks and Zones of Veinlet-Disseminated Gold-Silver Mineralization in Sedimentary and Carbonate-Sedimentary Formations

Starting with V. Lindgren (1933), it was taken for granted that epithermal gold and gold-silver deposits are associated with Mesozoic and Cenozoic volcanic belts. The discovery of the Paleozoic epithermal deposits in

Hercynian Dzhungaro-Balkhach and Kurama-Fergana volcanic belts of Kazakhstan and Uzbekistan, respectively, has significantly broadened exploration potential for this type of deposits. However, all of epithermal gold and gold-silver deposits anyway were associated with volcano-plutonic belts. The possibility that such deposits could occur in sedimentary black-shales sequences containing commonly veinlet-disseminated gold (arsenic)-sulfide mineralization becomes clear only during the last 25-30 years when gold-silver deposits such as Vysokovol'tnoye, Kosmanachi, and Okzhetpes were explored in the Cambrian-Silurian carbon-bearing sedimentary formations at the western part of the South Tien Shan accretionary zone in Uzbekistan. Similar mineralization, for example at Sopka Rudnaya (Ore Hill in English), was found later in Mesozoic sediments of the Verkhoyano-Chukotski terrain of the Russian Northeast.

Ore-hosting sediments consist usually of interstratifying layers of carbonaceous shales, siltstones, and sandstone metamorphosed at the low-temperature greenschist facies. Sometimes, gold-silver mineralization is in sedimentary-carbonate sequences, as it is at the Okzhetpes deposit in western Uzbekistan.

Such mineralization is usually concentrated in zones of brecciation and silicification, which are complicated fold structures and contains echelon-like series of ore-bearing fractures with differently oriented quartz veinlets and single quartz veins. Gold-silver mineralization is not only known in quartz veins and veinlets but also disseminated in the altered host rocks. The argillic alteration of the host rocks is major one and is represented by deposition of quartz, carbonate, hydromica, kaolinite, dickite, and alunite minerals. Ore bodies have lenseslike or platelike shapes.

Ore mineralization of these deposits is rich in silver with gold-silver ratio from 1:50 up to 1:500, and specific value of mined silver versus gold is usually over 50% (Vysokovol'tnoye, Sopka Rudnaya) sometimes reaching 90% (Kosmanachi deposit). A high content of tellurium and selenium in the ores hosted by carbonaceous sediments has resulted in admixture of these elements in sulfide minerals and in the presence of selenium-rich galena and tellurobismuthite.

Epithermal gold-silver mineralization is often located on the periphery of ore fields with veinlet-disseminated gold (arsenic)-sulfide mineralization. Examples of such localization are the Vysokovol'tnoye deposit nearby

Daugyztau or the Okzhetpes deposit to the south from Kokpatas in the Kyzyl Kum gold province (Uzbekistan), as well as the Sopka Rudnaya deposit of the Maiskoye ore field in Chukotka (NE Russia). At the same time, the Kosmanachi deposit is on the periphery of the Muruntau deposit with gold-feldspar-carbonate-quartz mineralization. However, location of all Uzbekian deposits in Cambrian-Silurian sedimentary formations of the Kyzyl Kum gold province without clear relation to the volcanic magmatism justifies their description as an independent geological-geochemical type.

4.1.3.1 Gold-Silver-Quartz-Sulfide Deposits

The Vysokovol'tnoye Deposit (41°10'57"N-63°58'50"E)

This epithermal deposit is located approximately 7 km to the south-southwest of the Daugyztau deposit with veinlet-disseminated gold (arsenic)-sulfide mineralization (see pp. 95-99) and actually is the flank of the Daugyztau mineralization (Zverev et al. 1999). Its geotectonic setting in the Kyzyl Kum-Nuratau district of Hercynian South Tien Shan accretionary zone is similar to Daugyztau. It is situated at the intersection of steeply dipping northerly- and westerly-trending faults. Host rocks belong to upper parts of the Ordovician-Silurian Besapan series and consist of alternation of carbonaceous oligomictic and polymictic sandstones, siltstones, and shales of turbidite formation that is covered by Devonian limestone (Arifulov 1979).

The deposit is controlled by north-northwest striking anticline fold intersected by north-northeast and westerly-trending faults containing two zones of vein and veinlet-disseminated mineralization up to 100 m thick, traced for 800-1,000 m along strike. The zones are represented by a series of close-by, echelon-like fractures. Lenses—and platelike ore bodies of 0.8-40 m wide are traced along strike for up to 500 m and along dip for more than 400 m. Unfortunately, no map for the deposit was found.

Four stages of mineralization (Arifulov 1979) are chlorite-quartz, quartz-gold-sulfide, gold-telluride, and carbonate. Pre-ore chlorite-quartz stage consists of quartz-chlorite-dolomite-graphite-cubic pyrite-albite mineral association. Quartz forms veins, lenseslike bodies, and veinlets along faults and is the dominant mineral in this association. According to Yu. Paramonov (quoted in Konstantinov et al. 2003), this association could rather be named as scheelite-quartz due to the presence of scheelite not detected by earlier study.

The quartz-gold-sulfide stage has three mineral associations: arsenopyrite-pyrite with gold and silver, sphalerite-gray copper ore, and diaphorite-miargyrite. The main gold-bearing arsenopyrite-pyrite association is accompanied by sericite-carbonate-pyrite alteration and similar to such association at the Daugyztau deposit but distributed only locally. Micron-sized gold is mostly in arsenopyrite and pyrite with its concentration in monomineralic pyrite fraction from 200 up to 800 g/t. Gold grade in mixed pyrite-arsenopyrite fraction is up to 1,700 g/t, while silver grade is lower (180-900 g/t).

Sphalerite-gray copper ore mineral association is high in silver and in addition to sphalerite, tetrahedrite, and freibergite contains bournonite, chalcostibite, chalcopyrite, Se-galena, pyrrhotite, polybasite, native gold, and bornite in carbonate-quartz veins and veinlets (Zverev et al. 1999) inside sericitized rocks and the early arsenopyrite mineralization. Deposition of this association is following arsenopyrite-pyrite one and is not accompanied by some specific alteration.

Main silver productive, diaphorite-miargyrite, mineral association contains in addition clausthalite, boulangerite, stibnite, and argentite, which form intergrowth with tetrahedrite and other minerals of previous association and distributed usually at the striped contacts of pre-ore quartz veins. Monomineral fraction of stibnite with intergrowth of boulangerite has gold grade 4.5-15 g/t and silver grade 607-2,240 g/t. According to Yu. Paramonov, silver mineralization of this association contains also acanthite in association with polybasite, pyrargyrite, and native silver.

Gold-telluride stage of mineralization forms microveinlets cutting all minerals of the quartz-gold-sulfide stage and cementing these minerals in breccia zones. Hessite in this stage associates with dickite, electrum (30-50% Ag), altaite, amalgam of silver, mercurial gold (up to 12% Hg), and intermetallic compounds of Pb-Bi-Sn and Ag-Te-Se-S.

Post-ore, quartz-carbonate, stage contains dolomite, calcite, dickite, hydromica, and barite. Homogenization temperature of fluid inclusions in quartz is from 240°C of arsenopyrite-pyrite association and 230-210°C of sphalerite-gray copper ore association to 110-125°C of quartz-carbonate, post-ore association (Arifulov 1979).

Upper level of mineralization at the Vysokovol'tnoye deposit (Gureikin et al. 1978) is 100-400 m below the Devonian limestone, which services as a barrier to hydrothermal solutions. This distance at the gold (arsenic)-sulfide Daugyztau deposit varies from 300 to 600 m. Vertical amplitude of gold-silver mineralization at the Vysokovol'tnoye deposit is about 250-300 meters or three times less than at Daugyztau.

Average gold grade of 1.0-1.5 g/t at the Vysokovol'tnoye deposit is two to three times less than at the Daugyztau, but silver grade can reach up to 20-30 ounces per ton with average grade ranging at 40-50 g/t. In addition, ore contains up to 14-15 g/t selenium and 15-16 g/t tellurium. The Vysokovol'tnoye deposit has, by rough estimation, about 20.0 million tonnes of ore containing approximately 30-35 Moz of silver and 1-2 Moz of gold. The two top-priority ore bodies of the deposit, according to the Oxus Gold PLC, which started to mine the deposit (Oxus's Web site of January 2006), are ore body no. 7—1,660,000 tonnes of ore grading 127 g/t silver and 2.7 g/t gold (210.8 t of silver and 4.48 t of gold), and ore body no. 4—2,330,000 tonnes of ore grading 27 g/t silver and 1.24 g/t gold (62.9 t of silver and 2.89 t of gold).

The Kosmanachi Deposit (41°32'N-64°32'E)

The Kosmanachi deposit is situated in the same tectonic environment as the Vysokovol'tnoye deposit, i.e., in the Muruntau ore district of the southern Tien Shan, Uzbekistan. The deposit is hosted by variegated part of the Besapan (O-S) formation approximately 1,500 m thick consisting of intercalation of gritstone, sandstone, siltstones, and pelite with thin interlayers of limestone, lenses of chertlike rocks, and dolomite (Paramonov 2001). The host rocks have monocline bedding complicated by interstratal thrustlike deformations dipping to the east-southeast under 5-25° (Fig. 25).

Lenslike, stratified ore bodies have sharp contacts and surrounded by quartz-sericite-chlorite-pyrite (beresite) and argillic alteration. Gentle-dipping ore bodies are traced along strike for more than 1,000 m and have vertical amplitude of more than 350 m. Thickness of the ore bodies increases usually with depth.

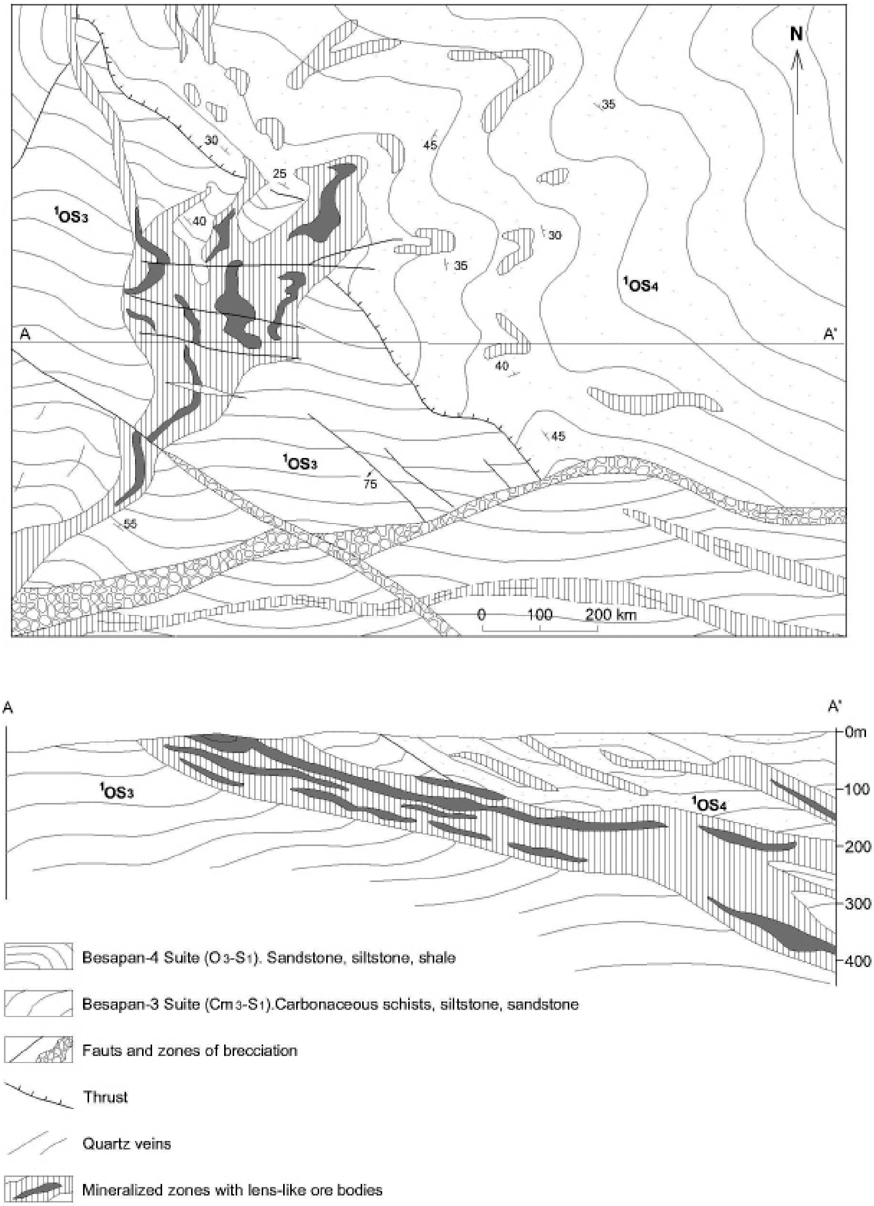


Figure 25. Geologic structure of the Kosmanachi deposit (after Paramonov 2001).

In spite of low amount of ore minerals (in average about 1%), ore bodies contain more than one hundred minerals including sulfides, sulfosalts, tellurides, and native metals. Main ore minerals are pyrite and arsenopyrite, which are present at a ratio 4:1 similar to the Vysokovol'tnoye deposit. Major gangue minerals are quartz and carbonate (mainly ferriferous dolomite). Interchange of quartz and carbonate veins and veinlets with subparallel thin interlayers and lenses of sandstone and siltstones resulted in typical banded structure.

Yu. Paramonov outlined three stages of mineralization: (1) pre-ore, phosphate-quartz mineral association; (2) silver-productive stage with gold-pyrite-arsenopyrite, polymetal, silver-sulfosalts, and quartz-carbonate-stibnite associations; and (3) post-ore stage with quartz-calcite association.

Phosphate-quartz association consists of quartz, carbonate, carbonaceous matter, apatite, and scheelite. The early gold-pyrite-arsenopyrite association of the gold-silver productive stage contains in addition quartz, carbonate, microcline, chalcopyrite, and pyrrhotite. Polymetal association consists of quartz, carbonate, sericite, sphalerite, galena, gray copper ore, pyrite, and chalcopyrite. Silver-sulfosalts association, which is main productive for silver, contains mostly sericite, clay minerals, galena, pyrargyrite, freibergite, hessite, acanthite, polybasite, electrum, native gold, and tetrahedrite. The last association of the productive stage is quartz-carbonate-stibnite with pyrite.

Major silver minerals of the productive stage are native silver, silver-bearing tetrahedrite, and freibergite. Lower level of silver similar to galena, sphalerite, and stibnite is typical for acanthite, pyrargyrite, and polybasite. Tellurides of gold and silver (hessite, sylvanite, calaverite) are rare. Ore contains rare, 0.001-0.0001 mm in size, particles of electrum (450-550 fineness) in quartz. Cerargyrite, iodargyrite, and bromargyrite are main silver minerals in the oxide zone.

Ore of the Kosmanachi deposit is rich in cadmium (up to 3 wt. % in sphalerite) and native silver and is also enriched in selenium (up to 1% in gray copper ore).

Resources of the Kosmanachi deposit, according to Uzbekian data, accounted for about 11,800,000 tonnes of ore grading 105 g/t silver (approximately 40 Moz) and 0.5 g/t gold (270,000 oz). Ore also contains 0.03% tungsten, 0.0012% selenium, and 0.0025% tellurium.

The Okzhetpes Deposit (42°05N-63°45'E)

The Okzhetpes gold-silver deposit is situated at the northwest part of the Kyzyl Kum-Nurata gold province of the west Uzbekistan, about 60 km southwest of the Uchkuduk town. It was discovered in 1974 during geological mapping and explored till 1982. Geotectonic setting of the Okzhetpes deposit within Hercynian accretionary belt of the South Tien Shan is similar to the Kokpatas and Daugyztau deposits except that it is hosted not in the Cambrian-Silurian Besapan formation but in the Devonian-Carboniferous one.

The Okzhetpes ore field is at the southeast plunge of Bukantau anticlinorium and is controlled by northwesterly-trending deep faults (Paramonov 2001). It is confined to the north-south anticline-like rise having tectonic origin at the intersection of the north-northwest and east-west ore-controlling faults. The gold-silver mineralization is hosted by Middle Devonian-Carboniferous carbonate and sedimentary rocks about 2,000 m thick.

The Middle-Early Devonian limestone, dolomite limestone, and marble are developed in the central part of the anticlinorium while Early Carboniferous limestone at the anticlinorium's limbs. The Late Carboniferous intercalation of sandstone, siltstones, clay and calc-clay shales, cherty rocks, and rare limestone in a form of isolated blocks has wide distribution at the northern, western, and southwestern parts of the ore field.

These sedimentary sequences are intruded by the Late Carboniferous stock of granodiorite and quartz diorite in the northern part of the deposit area. Numerous Early Permian (?) dikes of syenite-diorite porphyry, diorite, diorite porphyry, and lamprophyre are known in the area.

The main structure elements of the Okzhetpes deposit are the Northern and Main faults (Fig. 26). The Main, east-northeast (15-20°) direction, fault is dipping 70-75° to south with vertical amplitude of dislocation approximately 300 m. It occurs as a zone of intensive brecciation, silicification, and ferrugination, 20 m up to 100 m wide, with lenses of less disturbed host rocks. This fault is major ore-controlling and ore-hosting structure. Two core quartz veins are explored in the fault zone. The first one containing ore body no. 1 is 8-10 meters wide and traced for more than 1,650 m in the central part of the deposit. The second vein with ore body no. 2 is 190 m long and is located in the western part of the deposit.

Ore body no. 1; 1,240 m along strike and 40-150 m along dip, includes quartz vein at its footwall and veinlets mineralization at hanging wall. Average thickness of this ore body is 10-12 m but increases in some parts up to 20-22 m and pinched out at the deep levels. The ore body no. 2 is confined to the quartz vein and traced 190 m along strike and 45-65 m along dip.

Shear zone of the northern fault of the same east-northeast strike and south dip as the Main fault is 10-30 m wide but does not contain gold-silver ore bodies.

Hydrothermal alteration of sedimentary host rocks and dikes along ore-controlling faults are silicification, albitization, carbonatization, kaolinization, and pyritization. Carbonate sediments are characterized by less intensive silicification and pyritization.

Ore bodies are low (2-3%) in sulfides but contain (Narseev 1991) more than one hundred minerals including native elements, sulfides, tellurides, and sulphosalts. Gangue minerals are mainly quartz and ferriferous dolomite. Prevailing ore minerals (Paramonov 2001) are pyrite, arsenopyrite, and silver sulfosalts, secondary—pyrrhotite, marcasite, chalcopyrite, sphalerite, galena, gray copper ore, sulfosalts of lead and antimony, and cassiterite.

The pre-ore, carbonate-gold-sulfide, stage is composed of calcite, albite, sericite, pyrite, native gold, pyrrhotite, arsenopyrite, marcasite, and cassiterite. The productive, carbonate-gold-silver-sulfide, stage contains three mineral associations: (1) calcite-quartz-gold-pyrite-arsenopyrite with sericite, muscovite, chlorite, and sphalerite; (2) calcite-gold-silver-polymetal (main productive) with arsenopyrite, sphalerite, gray copper ore, chalcopyrite, and argentite; and (3) late calcite-quartz-silver-stibnite with celestine, pyrite, sphalerite, galena, sulfosalts of silver, lead, and antimony, stibnite, and gray copper ore. Post-ore, quartz-calcite, mineral association contains pyrite.

The main amount of silver is concentrated in a native form or in silver-enriched galena, tennantite, tetrahedrite, and sulphosalts. Fine-grained galena contains numerous microinclusions of silver minerals and has a silver grade up to 1,500-1,600 g/t. High in silver tennantite and tetrahedrite (up to 500 g/t in average) are wide spread in the ore. The principal silver minerals are acanthite and polybasite. Pyrargyrite, stromeyerite, sternbergite, stephanite, and miargyrite are forming rare small (0.03-0.1 mm) grains in association with acanthite and polybasite. The prevalent form of silver at the lower level of the Okzhetpes deposit is freibergite. Sulfides and sulphosalts have subordinated role at this level. Hessite forms

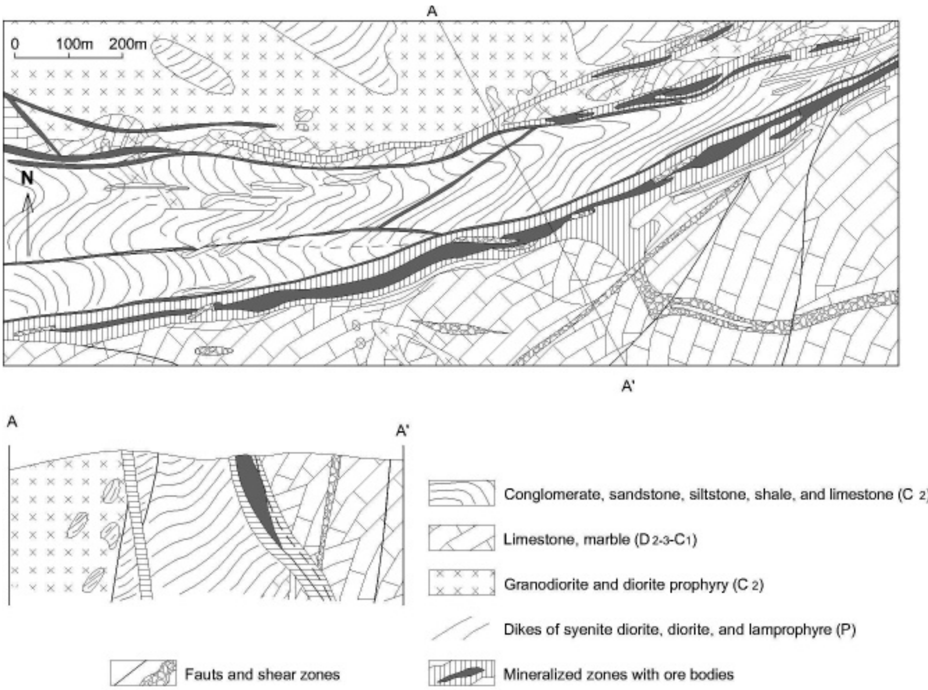


Figure 26. Schematic geologic map of the Okzhetpes deposit (after Paramonov 2001).

intergrowths with galena, pyrite, and boulangerite and also its own small veinlets. Other silver tellurides such as sylvanite and calaverite are rare. Part of silver is concentrated in sphalerite and stibnite. The oxide zone, which is up to 50-70 meters thick, contains cerargyrite and sometimes bromargyrite.

The richest silver mineralization over 1 kg/t is typical for quartz veins. Silver grades in brecciated dikes and host rocks that undergo argillic alteration are up to 700 g/t. Average silver grade in metallurgical samples from the Okzhetpes deposit is varying between 124 and 280 g/t. Gold grades in the same samples are 0.25-0.42 g/t. Ore mineralization at the Okzhetpes deposit is high in cadmium and selenium. The major concentrator for cadmium is sphalerite (3-4 wt. % of Cd) and native silver (1-3%). Selenium contents in acanthite are up to 12 wt. %, in tetrahedrite—1%, and in chalcopyrite—0.2-0.4 wt. %.

The deposit with its five million metric tons of ore resources contains approximately 25 Moz of silver.

Paramonov (2001) suggests that spatial distribution of silver mineralization is controlled by gabbro-syenite-granosyenite dikes of the Early Permian (258 ± 15 Ma) Sautbay series, but genetic relation of the dikes and ore mineralization is not clear.

The major types of gold-silver mineralization of the Vysokovol'tnoye and Kosmanachi deposits in terrigenous sediments are combination of early sulfide veinlet-disseminated gold-bearing mineralization with later quartz-gold-silver-sulfide stage and quartz-silver veins/veinlets mineralization practically without gold. The gold mineralization of the early stages is similar to the typical gold (arsenic)-sulfide deposits like Daugyztau and Kokpatas in the South Tien Shan and Maiskoye deposit at the periphery of the Okhotsko-Chukotski volcanic belt.

The Okzhetpes deposit that is hosted by carbonate sediments does not contain such early stage of veinlet-disseminated gold-bearing mineralization and is more similar to silver-lead deposits in sedimentary and carbonate-sedimentary host rocks such as the Prognoz and Mangazeya in the western part of Verkhoyano-Kolyma province in Yakutiya (Sakha) Republic of Russia.

Gold-silver mineralization of the Kyzyl Kum province of Uzbekistan (Gar'kovets et al. 1979) had developed autonomously to the gold (arsenic)-sulfide and gold-feldspar-carbonate-quartz mineralization and must be defined as an independent gold-silver or silver-antimony-quartz formation. Other specialists (Arifulov 1979; Sidorov et al. 1978; and others) produced convincing-enough facts about connection of gold-silver mineralization in sedimentary rocks with development of gold (arsenic)-sulfide deposits.

All these hypotheses could be acceptable in a case for each specific deposit, but no one can explain the genesis for all known gold-silver deposits in sedimentary formations. Their connection with gold (arsenic)-sulfide deposits cannot explain, for example, the development of almost pure silver mineralization at the Kosmanachi deposit and absence of veinlet-disseminated gold mineralization at the Okzhetpes deposit.

The close relation of gold-silver mineralization with magmatism of the volcanic belts looks logical for Sopka Rudnaya on the periphery of Okhotsko-Chukotski volcanic belt. However, such relation is absent for similar deposits of the South Tien Shan since the nearest Kurama-Fergana volcanic belt is located hundreds of kilometers to the east. It is impossible to solve all the problems for genesis of gold-silver deposits in sedimentary formations on the base of existing quite limited materials.

Known resources of the Vysokovol'tnoye, Okzhetpes, Kosmanachi, and Sopka Rudnaya deposits are too small to justify their development as an independent target. However, Oxus Gold PLC of the United Kingdom started to mine two high-grade ore zones of the Vysokovolt'noye deposit, located near their Amantaytau operations. In 2005, Oxus signed a letter of intent with the Navoi Mine who operates the Muruntau deposit to form a partnership in development of the Kosmanachi deposit.

Presence of such deposits in different age sedimentary formations and their sometimes-close spatial relations with larger gold (arsenic)-sulfide deposits has broadened exploration potential of the sedimentary fold and fault systems.

4.2 INTRUSIVE-RELATED GOLD DEPOSITS OF ISLAND ARCS AND OROGENIC BELTS

Gold deposits with spatial and/or genetic relationships to gabbro—potassium-low granite (plagiogranite in Russian terminology), gabbro-diorite-granodiorite, and granodiorite-quartz monzonite (adamellite) intrusive series, and rarely to alkalic gabbro and syenite series, are broadly distributed in different gold provinces of the CIS. Up until the mid-1960s, those gold deposits were long the major type for exploration and mining.

The largest intrusive-related gold deposits of the CIS have resources of more than 6 million ounces: Beriozovsk (10 Moz), Kochkar (9 Moz), and Natalka (11.29 Moz) in Russia; Vasil'kovskoye (12.26 Moz) in Kazakhstan; and Charmitan (6.77 Moz) in Uzbekistan. Several deposits have gold resources between 2.5 and 5 Moz: Jerooy (Kyrgyzstan), Taror (Tajikistan), Akbakai (Kazakhstan), and Zun Kholba (Russia); but most of intrusive-related deposits have gold resources of less than 2 Moz.

The presence of granitoid plutons and stocks of different ages and in different geological settings (Borodaevsky and Levitan 1974; Levitan 1983) resulted in the development of intrusive-related gold deposits in a very wide range of Late Proterozoic-Phanerozoic tectonic structures and gold provinces. Such deposits are distributed from paleoisland arcs such as the

Caledonian structures of western Siberia and Hercynian arcs and orogenic belts of the Ural province to intercontinental accretionary complexes of the Hercynian South Tien Shan and western Kalba and the Mesozoic Yano-Kolyma region. Intrusive-related gold deposits are known also in regions of Paleozoic magmatic activity of the Late Proterozoic Kokshetau massif in Kazakhstan and of intensive Mesozoic tectonic and magmatic activity in the Archean-Proterozoic Aldan shield and Precambrian-Paleozoic Transbaikal region.

Four main groups of these deposits can be outlined on the basis of the closeness of their relationship to ore-bearing and ore-forming intrusive bodies and the morphological character of gold distribution: (1) stockwork and veinlet-disseminated mineralization (gold-porphyry) within granitoid plutons, (2) lenses and irregular bodies in skarn along and near contacts of intrusive with carbonate or volcanic-sedimentary formations, (3) vein-type mineralization in intrusive bodies and their host rocks, and (4) stockworks in breccia pipes and granitoid stocks.

This classification is very close to the one offered by Sillitoe (1991), except for his attempt to include in it the Muruntau deposit, whose relationship to intrusives is questionable, as discussed previously (see pp. 76-82).

Vein-type deposits in intrusives, which occur widely and have been intensively mined in the CIS, played a significant role in gold production until the late 1960s. These deposits include the Beriozovsk, Kochkar, and numerous smaller deposits of the Urals; the Central, Berikul, and other deposits in the Altai-Sayany region; the Darasun, Klyuchi, and similar deposits in the eastern Transbaikal region; the Bestobe, Akbakai, Aksu, and many other deposits in Kazakhstan; and many smaller ones in all the gold provinces of the CIS. However, many of these deposits are mined out.

Following the exploration of the Vasil'kovskoye stockwork deposit in Kazakhstan and successful mining of the Fort Knox deposit in Alaska, both of which are accessible for open-pit mining, the main role in the exploration of intrusive-related gold deposits must be given to the group of stockwork and veinlet-disseminated mineralization within granitoid bodies. It is especially significant for the CIS, where exploration have been focused on high-grade deposits, but mineralization with gold grades below 3-4 g/t has automatically been viewed as not meriting further exploration.

Known stockworklike deposits in breccia pipes and granitoid stocks (for example, Aksu in north Kazakhstan) have commonly small resources, not broadly distributed within the CIS, and accordingly do not play a significant role in the balance of its gold output.

4.2.1 Stockwork and Veinlet-Disseminated Mineralization in Granitoid Plutons

This geological type of gold deposits contains just one mineralogical variety, described below.

4.2.1.1 Gold-Feldspar-Quartz (Gold-Porphyry) Deposits

The stockwork and veinlet-disseminated type of gold mineralization in intrusive bodies is referred to in the Soviet classifications as the gold-feldspar-quartz or gold-porphyry type (Yevstrakhin and Itsikson 1980; Narseev 1991). Bakke (1995) and Porter (1998) used the term "porphyry" gold deposits for similar stockwork mineralization within granitoid plutons, but these deposits are commonly referred as "intrusive-related" or "plutonic-related" (McCoy et al. 1997).

This type of gold mineralization did not begin to draw attention in the CIS until the late 1960s, following the discovery of the large Vasil'kovskoye deposit suitable for open-pit operations in northern Kazakhstan. Previously known small deposits like the Yubileinoye deposit and the upper part of the Byngi deposits (the Ural province) usually were viewed as a variety of vein-type gold-sulfide-quartz mineralization that often developed in the same ore fields.

V. Yevstrakhin and M. Itsikson showed that the stockwork and veinlet-disseminated gold-feldspar-quartz mineralization in intrusives genetically close to porphyry copper mineralization, because its development coincides in time with the late magmatic stage of productive intrusives and is a product of autometasomatic alteration by the last, water-rich, liquid fraction of intrusive chambers. Two types of such autometasomatic alteration that are typical of stockwork gold mineralization are quartz—K-feldspar and quartz-albite. The first one, potassic alteration, consists of quartz (40-50%), orthoclase (25-50%), muscovite (5-15%), biotite, sphene, apatite, and relics of magnetite. This kind of alteration usually is typical of the late stages of gabbro-diorite-granodiorite intrusive series with elevated alkalinity, as in the Naily and Tyelga deposits in the Miass district of the South Urals, or accompany the process of feldspathization during granite rheomorphism, as at the Vasilkovskoye deposit (northern Kazakhstan). According to a study of fluid inclusions (Korobeinikov 1980), alkaline metasomatic alteration of intrusive rocks occurs at temperatures of 480-300°C, while ore forms at temperatures of 390-250°C.

The quartz-albite alteration is usual for gabbro-granite intrusive series of the sodium type (the Byngi and Yubileinoye deposits of the Urals) or for syenite intrusive series, including nepheline syenite, as in the Ryabinovoye deposit of the Aldan shield. This type of alteration consists of quartz (40-70%), albite (30-40%), which replaces plagioclase, and minor amounts of biotite, muscovite, apatite, and sphene.

The quartz-orthoclase and quartz-albite alteration forms linear or rounded zones in the apical parts of granitoid plutons and stocks. They differ from alteration that associated with porphyry copper mineralization in having (1) a higher temperature of development; (2) a discordant type of distribution with respect to the intrusive bodies, in contrast with the conformable-type concentric-zoning alteration typical of porphyry copper deposits; (3) the prevalence of native free gold particles in the form of intergrowths with quartz, albite, and sulfides, but not refractory gold within sulfides of porphyry copper mineralization; (4) a high (2-9 g/t) average grade of gold, occasionally with anomalously high grades up to 100 g/t or higher; and (5) a low grade of copper.

Another kind of gold porphyry mineralization related to granite intrusives is the Fort Knox deposit, a type still practically unknown in the CIS. The major differences between this deposit and gold-porphyry deposits of the CIS are (1) the granitic composition of the intrusive, (2) the very low (<1%) total-sulfide content with prevalence of bismuth minerals, traces of arsenopyrite, and (3) the presence of local potassic-, albitic-, and phyllic-alteration envelopes 0.5-3 cm thick directly around the quartz-pyrite veins (Bakke 1995; McCoy et al. 1997).

The best-known examples of porphyry gold mineralization in the CIS are the Vasil'kovskoye and Yubileinoye deposits in Kazakhstan and the Jilau deposit in Tajikistan.

The Vasil'kovskoye Deposit (53°21'N-69°15'E)

The Vasil'kovskoye deposit is located 25 km northwest of the city of Kokshetau, the regional center of northern Kazakhstan. It was the first deposit explored within the large Kokshetau rigid massif (microcontinent) during the latter half of the 1960s. Before then, major explorations had been directed toward the southeastern part of the massif, where a group of well-known vein gold-sulfide-quartz deposits (Stepnyak, Bestobe, Aksu, etc.) had been mined since the 1930s.

The Vasil'kovskoye deposit is in the northern part of the Precambrian Kokshetau crystalline massif, which underwent a long period of Caledonian-Hercynian tectonic and magmatic activity. The Late Precambrian metamorphic formations are develop the basement complex in the deposit area, which consists of chloritic shales, quartzite, diabase porphyry, sericite-chert, and coaly shales (Kazhgeldin 1996). The metamorphic sequences are intruded by a multiphase Silurian-Early Devonian pluton that hosts stockwork gold mineralization. The pluton consists of gabbro-diorite, diorite-quartz diorite, and granodiorite-porphyry phases.

The gold mineralization is hosted mainly by altered, intensively fractured, and occasionally brecciated porphyroblastic hornblende granodiorite and gabbro-diorite. The former is typical of the central and southern parts of the deposit. The gabbro-diorite occupies the northern part of the Vasil'kovka ore field and often has transition to the quartz diorite.

Regional propylite alteration is located mainly in the northern part of the deposit within mafic intrusive rocks. The local alteration includes feldspathization and quartz-carbonate-sericite-pyrite mineralization. Pre-ore quartz-feldspar alteration is reflected in the pink color of granodiorite and is typical of the periphery and root part of the deposit. Syn-ore, quartz-carbonate-sericite-chlorite, alteration (gray rocks) is concentrated at the ore level along zones of high fracturing that control the main gold mineralization. The ore zones contain also pre-ore tourmaline and post-ore chlorite, quartz-carbonate, and quartz-fluorite mineralization.

The structure of the Vasil'kovskoye deposit is defined by systems of northwesterly (earlier) and northeasterly faults (Fig. 27). Gentle dipping to horizontal prototectonic fractures also plays an important role in the deposit's structure. The mineralized area of about 1.5 km^2 contains eight gold-bearing linear zones (the main, central, south, southeastern, southwestern, new, potential, and parallel zones), which have been outlined by sampling only. The zones, 8-10 to 100 m wide, are spatially separated at the flanks but form a single conelike main stockwork at the center of the deposit that narrows with depth. The oval-shaped main stockwork zone measuring 400 x 150 m at the surface pinches out at a depth of 1,300-1,500 m (Kazhgeldin 1996).

The stockwork consists of veinlets, veinlet-disseminated, and disseminated quartz, quartz-arsenopyrite, and arsenopyrite mineralization, with most of the gold concentrated in veinlet zones. The veinlet-disseminated ore type is less significant and contains, in addition to veinlets, clusters of arsenopyrite. Disseminated mineralization forms an envelope around the first two types. The veinlet mineralization decreases with depth, but gold grades increase in this direction.

The ore mineralization contains about 90% granoblastic quartz and 3-6% sulfides, including arsenopyrite, pyrite, pyrrhotite, chalcopyrite, sphalerite, galena, tennantite, bismuthinite, native bismuth, tetradymite, loellingite, molybdenite, bornite, and stibnite. Arsenopyrite is the dominant mineral, containing most of the gold. Bismuth and its minerals, which form intergrowths with native gold, chalcopyrite, and tennantite, also are broadly distributed, mainly in areas with high gold grades, and are associated with the arsenopyrite.

The five major mineral complexes outlined by I. Isakovich (in Konstantinov et al. 2000) are the quartz-arsenopyrite and gold-bismuthinite complexes in the central part of the stockwork, the pyrite-arsenopyrite-quartz complex of selvage areas, and the polymetal-stibnite complex of the upper and above-ore levels. Arsenopyrite forms mostly short prismatic crystals from 0.1-0.5 mm to more than 1 mm in size. The arsenic content of the ore averages around 2 wt. % but reaches up to 8 wt. %.

Native gold with a fineness of 840-950 forms micron-sized to 0.06 mm particles and is distributed irregularly, as accretions with quartz, arsenopyrite, pyrite, and bismuthinite; but up to 80% of the gold is free. Relatively large gold particles (0.04-0.12 mm) are more typical of the deep levels of the deposit. High gold content is confined to the arsenopyrite and bismuthinite mineral associations. The gold grade is irregular and varies

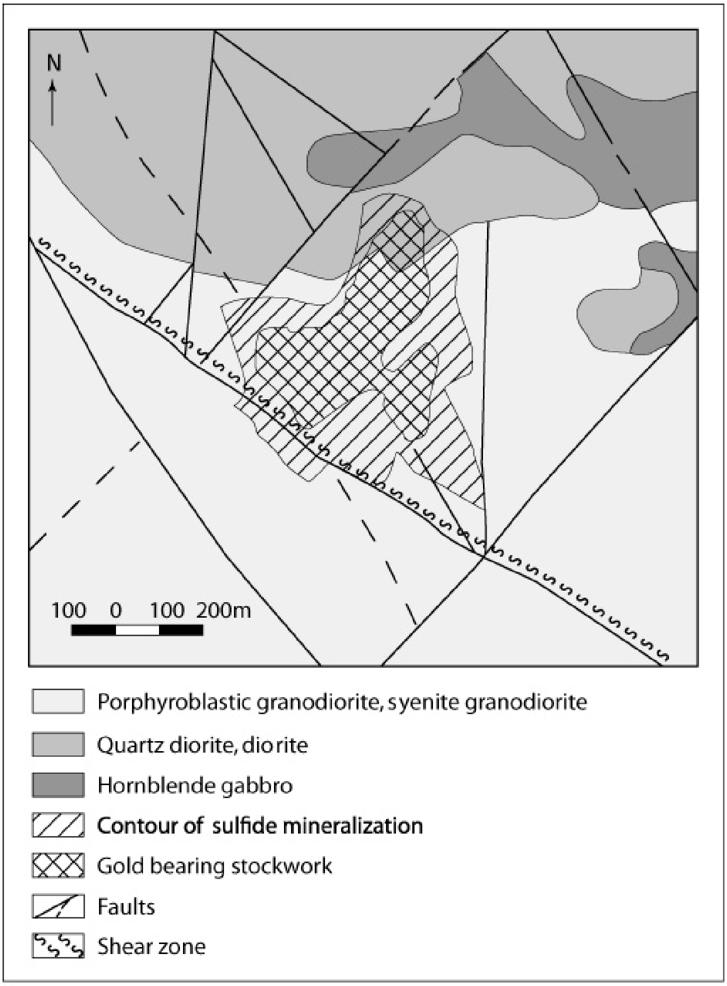


Figure 27. Geologic map of the Vasil'kovskoye deposit (simplified after Kazhgeldin 1996).

from 1.5 to 3.6 g/t, while in ore shoots it may reach 4.5-5 g/t. Several ore shoots, 120-150 m long and 20-40 m wide, are dipped steeply to 400-600 m from the surface. The average gold grade to a depth of 600 m is 2-2.5 g/t, falling to 1.5-1.7 g/t below this level.

According to N. Vargunina (TsNIGRI), the mineralization of the Vasil'kovskoye deposit is located in complex geochemical aureoles of concentric zoning. The aureoles of Au, As, and Bi at the ore level are surrounded by lower intensity aureoles of W, Mo, Pb, and Cu. Vertical geochemical zoning is reflected in increasing Ag, Pb, and Cu contents to the upper levels of the deposit and in decreasing Co, Mo, and W at low ore levels. The gold has a positive correlation with arsenic, bismuth, and silver.

The resources of the Vasil'kovskoye deposit were estimated after exploration as 158,750,000 tonnes of ore grading 2.4 g/t, or 12.3 Moz (381 t) of gold. According to a 2003 estimate by Kazakh geologists, mineable resources in the open-pit contour are 45.4 million tonnes of ore grading 3.65 g/t, or approximately 5.34 Moz (165.5 t). This makes the Vasil'kovskoye deposit the largest gold porphyry deposit of the CIS, with good potential for an increase in its resources by placing under development ore with a gold grade of about 1 g/t, as at the Fort Knox deposit in Alaska.

The Vasil'kovskoye deposit does not have similar scale projects in the CIS, despite the presence of stockwork gold-porphyry mineralization in granodiorite facies of the gabbro-diorite-granodiorite series. Such deposits are encountered in Kazakhstan (Orlovskoe in its northern part, Zholymbet in its central part, and Baladzhal and Sekisovskoye in its eastern part) and in Tajikistan (Jilau, South Tien Shan). All these deposits have typical quartz-carbonate-chlorite-pyrite alteration within the stockwork areas but do not have any traces of the feldspathic alteration wide spread at the Vasil'kovka. All deposits, including Vasil'kovskoye, differ from the Fort Knox deposit above all in the gabbro-diorite-granodiorite instead of granite composition of the hosting intrusives and higher gold grades. At the same time, they are similar in the broad distribution of bismuth mineralization simultaneous with gold deposition. An example of relatively low-gold-grade porphyry mineralization is the Jilau deposit in Tajikistan.

The Jilau Deposit (39°20'N-67°43'E)

The Jilau deposit discovered in 1948 is a quartz-vein stockwork hosted in a granodiorite intrusive near the western border of Tajikistan with Uzbekistan, some 35 km south of the town of Penjikent. Exploration of the deposit was completed in the period 1963-1965, and trial development was undertaken by the Tajik Gold-Mining Agency in the early 1980s. In 1994, Commonwealth and British Minerals PLC, later acquired by the Nelson Gold Corporation, signed a joint-venture agreement with the government of Tajikistan for mining of the Jilau deposit, which began in 1996. The description of the Jilau deposit given here is based on (1) the materials of Serenko and Kordestany (1996) of the Nelson Gold Co., who published a compilation of Soviet data; (2) materials of the Avocet Mining Co., which in 2002 acquired the deposit from Nelson Gold Corp. (Findell 2004); and (3) the results of the deposit study by Cole (2000) and Cole and coauthors (2005).

The deposit area is situated on the north slope of the Zeravshan Range in the South Tien Shan accretionary fold-and-thrust belt, which contains in its western part many world-famous gold deposits such as Muruntau, Daugyztau, Amantaytau, Kokpatas, and Charmitan. The Chinorsai intrusive, which hosts the Jilau deposit, consists mainly of granodiorite and quartz monzonite and forms an elliptically shaped east-southeast pluton about 12 km long and up to 3 km wide (Fig. 28). The intruded Silurian, Devonian, and Lower Carboniferous siliciclastic sedimentary and carbonate rocks are strongly folded and thrusted and contain a hornfelsed aureole several hundred meters wide at the contact with the pluton.

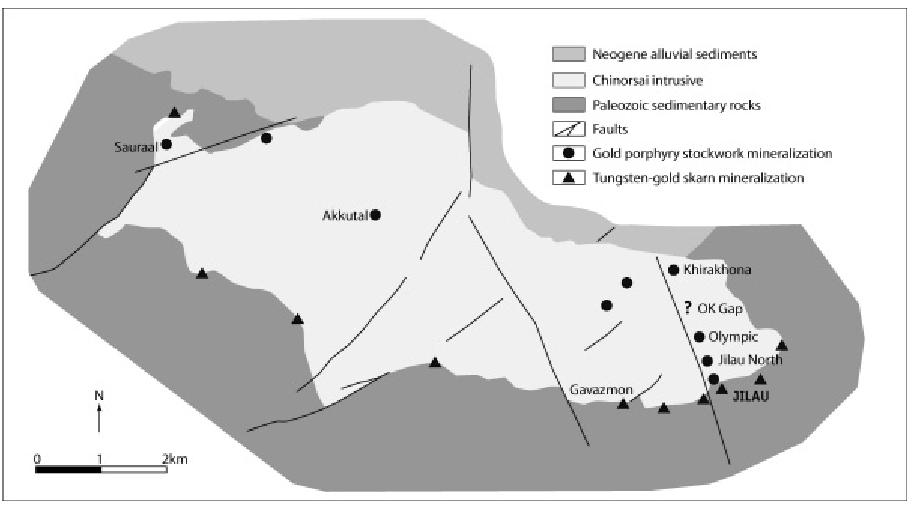


Figure 28. Distribution of gold porphyry and tungsten-gold mineralization at the Chinorsai pluton, Tajikistan (after Findell 2003).

According to Cole and coauthors (2000) and Findell (2003), medium-grained, equigranular biotite-hornblende-plagioclase-quartz granodiorite in the marginal parts of the pluton, transforming into coarse-grained facies at the center, is the dominant phase, with secondary amounts of earlier quartz diorite and quartz monzonite. Northeast-trending dikes of diorite porphyry and lamprophyre cutting through the intrusive are 1-3 km long. Smaller dikes and veins of aplite and pegmatite also are encountered, as are xenoliths of the host rocks.

Stratigraphic relationships indicate the age of intrusion as Middle-Late Carboniferous. This age is supported by K-Ar dating of the intrusive's biotite to 299 ± 9 Ma (Late Carboniferous). Previous Soviet determinations of the absolute age gave 306-319 Ma, which is within the error of the method, and supports the Late Carboniferous emplacement of the pluton. A K-Ar age determination of the biotite from diorite porphyry dikes by Cole (2000) returned 238 ± 7 Ma, corresponding to the Triassic period and placing deposition of the mineralization between 299 and 238 Ma, since the diorite porphyry dikes are definitely post-ore.

Faults, fractures, and shear zones control the stockwork mineralization. The major structures strike to the northeast, northwest, and southwest and mostly dip steeply to the south. They occur in several stages, beginning with the development of the stress pattern formed during cooling of the intrusives. The faults form (Cole et al. 2005) zones of intense fracturing along subparallel and conjugate shear planes associated with foliated fault breccia. The thickness of individual faults ranges from single planar structures to deformation zones up to 25 m wide. They are surrounded by an envelope of subparallel, high-strain shears separated by lower strain zones with a total width of up to 100 m.

Most known gold prospects (Khirshkhona, Olimpic, north Jilau) and the Jilau deposit itself are concentrated at the eastern end of the Chinorsai pluton along a northwesterly ore-controlling shear zone between the Jilau and Andezak faults (see figure 28). The richest part of the lenticular Jilau stockwork is associated with the intersection of this shear zone by the northeasterly Vedushchy (leading) fault and forms a steeply plunging ore shoot in silicified and mineralized granodiorite.

The stockwork consists, according to P. Findell, of quartz veins ranging from discontinuous, irregular quartz veinlets less than 1 cm wide with unaltered margins to straight-walled, throughgoing, sheeted quartz-sulfide veins commonly 2-5 cm and up to 1 m wide. These veins are accompanied by selvages of quartz-sericite-chlorite alteration no wider than the veins themselves. Later quartz-calcite and calcite veins also are encountered within the stockwork.

All veining occurred during the last stages of intrusion. The sheeted quartz veins are not controlled directly by the Jilau fault but fill mainly northwesterly, northerly, and north-northeasterly, steeply dipping fractures, as well as joint planes that dip gently to the south. The high-grade core of the stockwork, with 3 g/t or higher gold grades, forms podlike shoots at the intersections of several fracture-and-joint sets, has north-northeast trend, and is surrounded by broad aureoles of low-grade mineralization. Mineralization extends to the north and northeast for at least 500 m.

The Jilau stockwork contains less than 2 vol. % sulfides. The main ore minerals are scheelite, chalcopyrite, and pyrrhotite (early stage), followed by pyrite, arsenopyrite, gold and silver tellurides, and bismuth minerals. The amount of arsenopyrite increases at the lower levels of mineralization. According to initial Soviet data, the late quartz-calcite veins contain stibnite and cinnabar, but Western geologists have not confirmed this.

Native gold forms fine anhedral grains in quartz vein/veinlets and silicified granodiorite ranging from 500 µm to less than 100 µm. It also forms micron-sized inclusions in arsenopyrite or intergrowths with native bismuth and bismuth tellurides, also in arsenopyrite. According to Soviet data, the gold has fineness from 900 to 600, with an admixture of silver. Silver also is found in native form.

Study of the fluid inclusions in the quartz identified seven types of inclusions, which fall into two compositional groups: carbonic H_2O-CO-CH_4(-N_2)-NaCl inclusions, which occur in earlier quartz types, and H_2O-salt inclusions in later quartz generations (Cole et al. 2005). Gold and gold-bearing arsenopyrite is mainly associated with quartz, which contains carbonic fluid inclusions that generally homogenize at temperatures between 450 and 300°C. The highest gold grades appear to correlate with high CH_4 concentrations in the mineralized fluids.

Isochoric modeling of fluid inclusions by Cole et al. (2005) suggests a fluid pressure of about 220 MPa at a modal temperature of 320°C, indicating an ore deposition depth of 7-10 km.

RTZ Consultants, in an estimate prepared for Nelson Gold in 1996, stated that the Jilau deposit at a cutoff grade of 0.5 g/t has 43.6 million tonnes of ore grading 1.32 g/t of gold (1.85 Moz or 57.35 t) as measured and indicated resources and 61.6 million tonnes of ore grading 0.87 g/t (1.55 Moz or 48 t) as inferred resources. Since early 1996, the deposit has produced 540,000 ounces of gold. In 2006, Avocet Mining PLC, which operates the deposit, announced an increase in the resources of the Jilau deposit to 2.7 Moz or 85.2 t of gold at a cutoff grade of 0.3 g/t.

The Chinorsai pluton contains not only gold but also tungsten. Auriferous scheelite mineralization is in the garnet-pyroxene skarn along the eastern contact of the intrusive and was mined in the period 1953-1973. The presence of scheelite as an ore mineral in the gold stockwork and within the skarn in sedimentary rocks outside the gold zone makes the Jilau deposit remotely similar to the Fort Knox deposit. The absence of feldspar alteration along quartz veins could be explained by the diorite-granodiorite composition of the host intrusive.

Another variety of gold porphyry mineralization is described below through the example of the Yubileinoye deposit hosted by potassium-low granite (plagiogranite in Russian).

The Yubileinoye Deposit (48°35’N-58°45’E)

The Yubileinoye deposit is a good example of gold porphyry mineralization related to island-arc gabbro-granite intrusive series. It was discovered in 1961 and placed in development in 1969. The deposit is located 50 km west of the city of Emba in the western Mugodzhary synclinorium of the Hercynian southern Urals. Silurian and Early Devonian island-arc basalt-andesite-dacite volcanics of the synclinorium are intruded by Middle Devonian gabbro-granite and potassium-low granite stocks, which are comagmatic with the effusive facies.

The ore-bearing granite porphyry stock of the Yubileinoye deposit is situated near the regional northerly-trending western Mugodzhary fault, at the intersection of the northeasterly and northwesterly local faults that caused the development of stockworklike fractures in the intrusive stock. The host rocks for the intrusive are Devonian spilite, diabase porphyry, and diabase that have undergone epidotization and chloritization while granite porphyry underwent silicification and albitization.

Gold-bearing quartz-sulfide veinlets and thin veins 0.1-10 cm wide running in different directions are developed all over the stock area and form zones of stockwork mineralization. Four such zones described as ore bodies at a cutoff grade of 2 g/t (Kazhgeldin 1996) have been identified inside the stock and along its contacts in both intrusive and effusive rocks. The largest and richest one, 4-27 m wide, is located in the central part of the stock and is elongated in a northeasterly direction. Three other ore bodies, 80-240 m long and 9-23 m wide, are located along the northern, western, and southeastern contacts of the intrusive and have been traced by drilling for more than 250 m down dip. Ore deposition was accompanied by quartz-carbonate-sericite-pyrite alteration.

The main ore minerals of the quartz-sulfide veinlets and veins are pyrite, chalcopyrite, arsenopyrite, tetrahedrite, stibnite, and gold; sphalerite, galena, scheelite, molybdenite, and bornite are also present in lesser amounts. The gold is associated with pyrite, arsenopyrite, chalcopyrite, and quartz and forms free particles or intergrowths with these minerals.

The average gold grade ranges from 3.4 g/t to 10-11 g/t. The resources of the Yubileinoye deposit at the cutoff grade of 2 g/t are about 1 Moz of gold. However, the resources may at least be doubled if the low-grade mineralization is included.

A few similar gold porphyry deposits within stocks of gabbro-granite intrusive series are known in the South and Central Urals (Byngi, Naily, Tyelga, etc.) and have the same type of quartz-albite pre-ore and quartz-carbonate-chlorite-pyrite alteration synchronous with introduction of gold ore, but smaller gold resources.

The low level of attention given to the exploration and study of gold porphyry deposits in the CIS precludes a scientifically proven explanation of their origin with the exception of the few general geological facts mentioned above. The only study of the structure, petrogenesis, and fluid control of mineralization was done by Cole (2000) at the Jilau deposit of the south Tien Shan, who suggests that the high-temperature and low-salinity CO_2-CH_4 mineralizing fluid was predominantly magmatic and was derived from magma before or during its cooling.

The low level of attention to exploration for this type of deposits accounts for its high potential and opportunity for new discoveries in the CIS. The broad distribution of gabbro-diorite-granodiorite and gabbro-granite intrusive series within island-arc systems and of granodiorite-granite series of orogenic belts is one factor for success. Another is the old Soviet tradition of exploring deposits with high gold grades and not following up on targets with gold grades below 3 g/t. And the third factor, one of the most important, is the large number of feldspar granite plutons like the Fort Knox pluton of Alaska, which long were considered to be productive only for rare-earth, tin, and tungsten mineralization.

A comparison of a Russian map of Uralian gold-placer deposits made in 1915 (Library of the Colorado School of Mines, Golden, Colorado) with recent geological maps of the same region shows that clusters of gold placers often coincide with the contours of Late Paleozoic granite plutons, but no one has tried to explore these plutons for lode gold. The belief in existing scientific dogmas was so strong that when the author, working in the 1970s, found sulfide mineralization with 5-7 g/t of gold in a pegmatite vein in one Late Paleozoic South Urals granite pluton, he did not explore this pluton further, attributing the presence of gold in the pegmatite to granite-magma contamination from the gold-bearing host rocks of the granodiorite intrusive; and everyone agreed with the explanation.

4.2.2 Vein-Type Gold Deposits in Granitoid Intrusives and Their Host Rocks

This type of gold deposit is widely distributed in all Phanerozoic gold provinces of the CIS and, until the discovery of large disseminated and veinlet-disseminated deposits such as Muruntau (Uzbekistan), Sukhoi Log (Siberia), and Bakyrchik (Kazakhstan) in the 1960s, was one of the major types of gold mines in operation. The resources of deposits of this group range from 10 Moz of gold or more (the Kochkar and Beriozovsk deposits in the Urals, Natalka in the Magadan region of the Russian Northeast) to many smaller deposits of 1 Moz or less.

All deposits of this type have close spatial and temporal connections with productive intrusive bodies, mainly of the gabbro-low potassium granite (plagiogranite in Russian), gabbro-diorite-granodiorite, granodiorite-adamellite series, and/or of the dike series that accompany these intrusives. There are several typical settings of intrusive-related gold veins (Borodaevsky and Levitan 1974): (1) within eroded plutons (Kochkar deposit, S. Urals, Russia); (2) at the periphery of less-eroded plutons with protrusion of some veins into the host rocks (Charmitan deposit, S. Tien Shan, Uzbekistan); and (3) over the apical parts of slightly eroded or concealed intrusive bodies (Natalkinskoye deposit, northeast Russia). One specific subtype of the last is the ladder-type veins in the dikes over the dipping roof of the pluton (Beriozovsk deposit, Central Urals) or competent host-rock horizons (Vasin-Tsezar, South Urals). A recent study by Taylor Wall & Associates of Brisbane, Australia, identified such deposits as the “thermal aureole gold” type generated by a large volume of hydrothermal fluids liberated by magma crystallization and thermal metamorphism during and after pluton emplacement, which focused the fluid flow.

Consistent with the name of this deposit type, the ore bodies are quartz-sulfide veins or groups of veins and veinlet zones that often are complicated by bulges, squeezes, and branching. The thickness and the horizontal and vertical extent of the veins vary from a few centimeters to 20 m in thickness and from a few meters to hundreds of meters, occasionally 1-2 km, in length.

The ore mineralization contains between 1-3 and 10-15% sulfides, with a prevalence of pyrite, arsenopyrite, pyrrhotite, and chalcopyrite in the early stages; galena, sphalerite, and gray copper ore in the middle stages; and bismuthinite, tetradymite, stibnite, tellurides, and native gold and silver in the final stages of mineralization. The most common mineral associations are the pyrite-arsenopyrite, galena-sphalerite, tetrahedrite-bournonite-chalcopyrite with tellurides and sulfosalts of bismuth, bismuthinite-telluride, and pyrite-tourmaline (Timofeevsky 1971;

Berson and Levitan 1981). The gold commonly forms free particles of high fineness from a fraction of a millimeter to 1-1.5 mm or larger. The average gold grade of the ore bodies is 5-15 g/t, but its irregular distribution often produces higher-grade shoots.

Hydrothermal alteration of the host rocks, which precedes or accompanies vein emplacement, is mainly of the linear quartz-carbonate-sericite-chlorite-pyrite type (beresite-listwanite, in Russian terminology) and sometimes are of the higher-temperature quartz-tourmaline (greisenlike) type of alteration.

The two major mineralogical subtypes of intrusive-related vein gold deposits are the gold-quartz and gold-sulfide (arsenic)-quartz subtypes, described below.

4.2.2.1 Gold-Quartz Deposits

Gold-quartz vein deposits with very low sulfide content, mostly 1-2%, are concentrated in sedimentary Phanerozoic gold provinces such as the Mesozoic fold belts of the Yano-Kolyma region in northeast Russia (Natalka) or in the North Tien Shan of Kyrgyzstan (Jerooy). Similar deposits are known in the Hercynian provinces of Australia (Bendigo, Ballart, etc.) and in the Caledonian structures of the Nova Scotia (Canada). These deposits are located within, alongside, or above quartz-diorite-granodiorite plutons intruding into orogenic regions of sedimentary fold-and-fault systems on sialic earth crust. The relationship of some deposits to intrusive magmatism is not always very clear, but its location in hornfels aureoles assumes the presence of a granitoid mass beneath the deposits.

The gold-bearing veins generally consist of 98-99% quartz or less due to the presence of carbonate, albite, and sulfides (Narseyev et al. 1986). Pyrite and/or arsenopyrite of an early mineralogical association, often with scheelite and wolframite, are predominant. Galena, sphalerite, chalcopyrite, pyrrhotite, gray copper ore, and stibnite form individual small grains. The gold is associated with late sulfide associations and forms relatively large isolated grains and thin veinlets. The gold grades are usually 1.5-4 g/t but with a high variability. The highest gold grades are typical of quartz veins with the most complex shape such as sharp bulges, local variation in strike and dip, and the presence of intraore deformations; but many quartz veins contain no gold at all.

The silicification, sericitization, and carbonatization of the host rocks along gold-quartz veins are not intensive. The veins sometimes are accompanied by weak aureoles of sulfidization.

The most typical and best-studied examples of gold-quartz mineralization are the Jerooy deposit of north Tien Shan in Kyrgyzstan and the Shkol'noye and Natalka deposits in northeastern Russia.

The Jerooy Deposit (42°18'N-72°44'E)

The Jerooy ore field is situated in the North Tien Shan province, on the north slope of the Talas Range of northwestern Kyrgyzstan at an elevation of 2,500-3,900 m above sea level. It is approximately 45 km west of the regional center, the town of Talas, and 160 km west-southwest of Bishkek, the capital of Kyrgyzstan. In addition to the Jerooy deposit, the ore field contains numerous small ore showings of gold, copper, and arsenic mineralization concentrated mainly in its southern part. Relatively small vein and stockwork intrusive-related gold deposits such as the Taldybulak, Andash, and Chonur are located to the north of the ore field, along the Kyrgyz Range.

The Jerooy deposit was discovered in 1968 and explored over the next 15 years by adits and drill holes to a depth of more than 600 m. The geological resources (C_1-C_2) of deposit, as calculated during exploration, were 12,523,000 tonnes of ore grading 6.36 g/t, or 2.56 Moz (79.36 t) of gold (Oakes et al. 1998). Inferred gold resources here are about 30 t.

The Jerooy ore field is located in Caledonian structures of North Tien Shan, which are composed of Late Proterozoic sandstones, shales, phyllite, limestone, and rhyolite-dacite effusives intruded by Riphean-Vendian granodiorite, quartz diorite, and quartz monzonite and large Late Cambrian-Early Ordovician granitoid plutons. One such pluton, the Susamyr granitoid batholith, hosts the Jerooy deposit and occupies about 90% of the ore-field area (Fig. 29). Late Proterozoic carbonate-sedimentary sequence outcrops in the northern part of the region, while its southern and southeastern parts contain Cambrian-Ordovician limestone and dolomite, as well as Ordovician-Devonian and Carboniferous sedimentary-volcanogenic continental molasse filling the graben-syncline along the fault within the batholith.

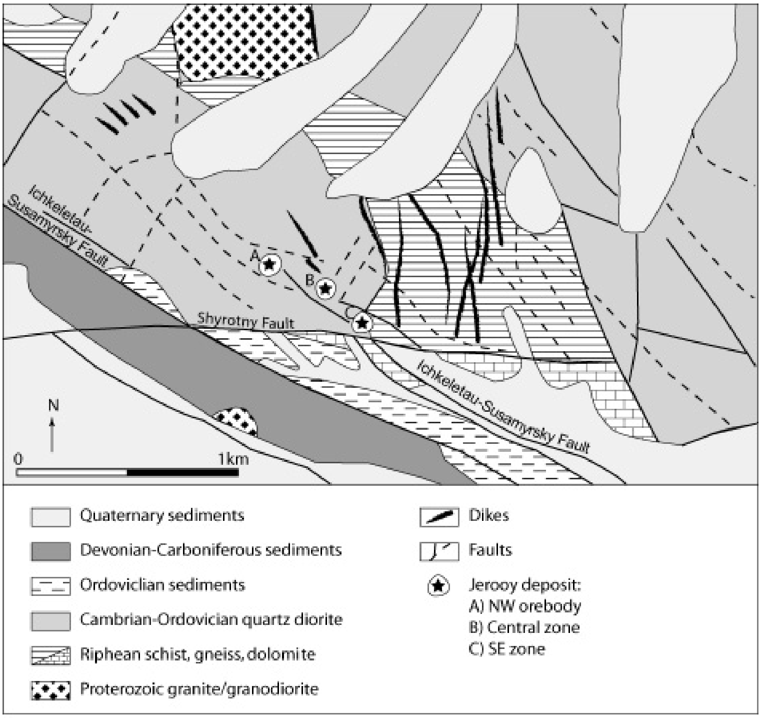


Figure 29. Regional geologic map of the Jerooy deposit area (after Oakes et al. 1998).

Approximately 65% of the Susamyr batholith intrusive rocks are granite and granodiorite, mainly in the central part of it. Diorite and gabbro are located along the periphery of and amidst the pluton's granitoids. Dikes and small stocks of quartz diorite porphyry, granodiorite porphyry, and lamprophyre represent the late stage of the same magma chamber. A few later diabase porphyry dikes may be related to Ordovician volcanics. The concentric distribution of various intrusive-rock varieties and the presence of arclike faults bordering the Jerooy ore field allowed Sorokin and Lomakina (1984) to surmise that the ore field is located on the local domal structure within the pluton.

The structure of the Jerooy ore field is defined by its localization at the large Ichkeletau-Susamyr north-northwest fault along the northern border of the graben-syncline mentioned above. The fault consists of a close series of subparallel fractures dipping to the north-northeast. Three systems of secondary fracture zones running northerly, to the northeast, and northwest are developed at the hanging wall of the main fault. Some of these fractures are filled with dikes and gold-bearing quartz bodies.

Local K-feldspar (adularia) alteration along the quartz-vein selvages and later, more extensive, sericite-carbonate and kaolinite-hydromica-carbonate alteration are the two stages of hydrothermal-metasomatic mineralization that accompanied the ore process. The latest stage is not only encountered in the granitoid pluton but also affected the sedimentary-volcanogenic rocks of the graben-syncline.

A mineralized area in the form of a narrow strip extends in a northwesterly direction along the north flank of the Ichkeletau-Susamyr fault and contains three major ore zones: the northwest, central, and southeast (see figure 29) in fine-grained quartz diorite and to a lesser degree in granitized quartz-mica-amphibole-feldspar schists of large xenoliths in the apical part of the pluton. The ore bodies are a system of steeply dipping northerly-, northwesterly-, and westerly-trending bodies of quartz with a thickness ranging from 1-3 m to 20-50 m, accompanied by a halo of quartz veinlets.

The main ore body of the northwest zone, 270 m long and up to 50 m wide, bends from a westerly to a northerly direction (Fig. 30), with massive echelon-like quartz veining at the core to quartz stockwork and quartz veinlets and stringer zones at its periphery. The dispersed zone of mineralization at its outcrop 3,700 m above sea level changes (Oakes et al. 1998) to a narrower, highly silicified body of quartz about 12 m wide at a depth of 3,240 m. The average gold grade increases in this direction from 6.52 g/t (cutoff grade 2.7 g/t) at the surface to 12.56 g/t at the level of 3,240 m and starts to decrease downward from 3,160 m. The ore body dips 70-80° to the northwest. According to Jenchuraeva and Oakes (2001), the northwest ore body contains 78% of the economic ore and 83.5% of the total gold reserves.

The central ore zone is located 250 m southeast of the northwest zone and contains low-grade gold mineralization hosted by silicified quartz diorite and discontinuous quartz veinlets.

The southeast ore zone, 125 by 100 m in area, crops out at the 3,390-3,450 m above sea level and contains gold mineralization related to 1-2 m thick and short quartz veins of northerly direction and silicified zones.

Silica makes up some 50-80% of the ore bodies, depending on their type, while the amount of sulfides is mostly below 1%, rarely

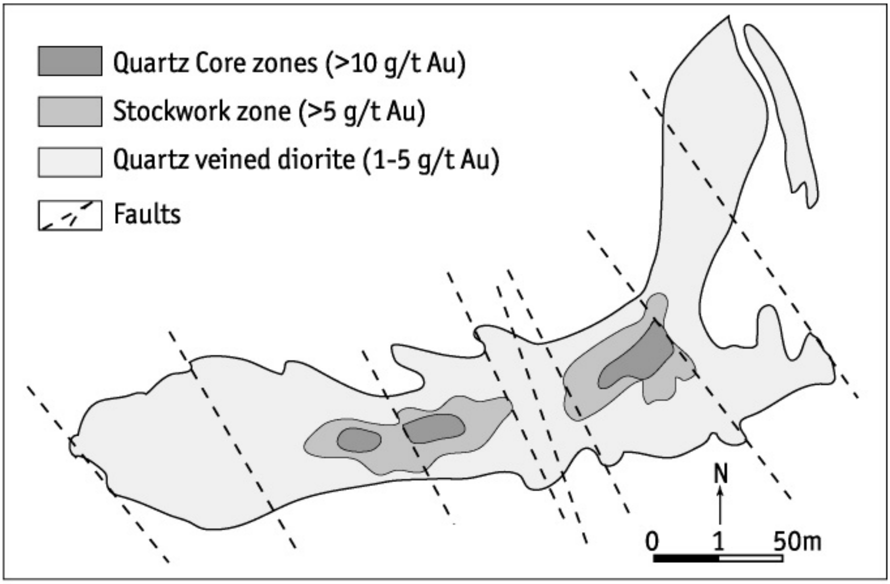


Figure 30. Gold grades distribution at the northwest ore body (after Oakes et al. 1998).

increasing to 2%. Sorokin and Lomakina (1984) outlined six main mineral assemblages. The gold-tetradymite-bismuthinite-quartz mineral association is the major productive one; and in addition to these minerals, it contains pyrite, arsenopyrite, gold tellurides, and native bismuth. The ore minerals form dark stripes, nests, and spots, as well as isolated grains in deformed coarse-grained quartz. The following, scheelite-molybdenite, association is known at the lower levels of the deposit in milky-white quartz veins. Both these associations belong to the early productive stage. Native gold and tellurides of gold forms particles smaller than 0.05 mm in size. The gold fineness varies from 840-900 to nearly 1,000, with a maximum between 950 and 990. The average gold grades are 5-10 g/t, and the gold-silver ratio of this stage is 6 or higher.

The next, polymetallic, stage of mineralization consists of quartz-arsenopyrite-pyrite, quartz-carbonate-chalcopyrite, quartz-carbonate-galena, and quartz boulangerite mineral associations confined to quartz-sulfide and carbonate-sulfide veins and veinlets of fine-grained quartz and carbonate. These veins/veinlets are accompanied by 3-4 m wide aureoles of kaolinite-sericite-carbonate alteration. The gold fineness for this stage varies between 500 and 900. The low average grades of gold (3-5 g/t) and the prevalence of silver (Au/Ag = 0.1) distinguish this polymetallic stage from the early productive gold-bismuthinite one.

Crustified quartz-carbonate veinlets with kaolinite, pyrite, marcasite, and chalcedony complete the ore process and do not contain gold.

The two early productive mineral associations are developed in the period between the formation of quartz diorite porphyry and granodiorite porphyry dikes known in the area of the northwest ore body (Sorokin and Lomakina 1984). The quartz diorite porphyry contains veinlets of deformed quartz with sulfides of the early productive association, K-feldspar alteration, and high gold grades, while the granodiorite porphyry dike intersects the central part of the ore body and contains veinlets of undeformed quartz with impregnation by the late polymetallic mineral association. Such spatial association is strong evidence for a close relationship between the intrusive and ore mineralization.

The zonal distribution of early and late mineral associations (the former only in the ore zones and the latter far outside it) is responsible for the zoning of the geochemical halos. Strong anomalies of Au, Bi, Mo, As, Cu, Pb, Zn, and Ag are typical of the central part of the northwest ore body, while at the periphery of the ore body and outside the deposit a lower intensity halos of As, Cu, Pb, Zn, Ag, and Au are prevalent. Vertical zoning is defined by an increase in the gold-silver ratio from 4.9 at the surface to 6.3 at a depth of 600 m of the surface.

According to the Oxus Gold PLC (Web site 2004) which produced feasibility study of the deposit, the total gold resources of the Jerooy deposit are 25.22 million tonnes of ore grading 3.97 g/t, or 3.22 Moz (99.8 t) of gold, including

- measured resources—3.48 million tonnes grading 6.4 g/t, i.e., 720,000 oz of gold;
- indicated resources—13.79 million tonnes grading 2.67 g/t, i.e., 1,180,000 oz; and
- inferred resources—7.95 million tonnes grading 5.17 g/t, i.e., 1,320,000 oz.

The Jerooy deposit is among the few large gold deposits in the Caledonian granitoid plutons not only in the CIS, and it defines the possibility of similar discoveries in other Caledonian gold provinces of the world.

The Natalka Deposit (61°39'N-147°41'E)

The Natalka deposit, operated by the Matrosov Mine of the Polyus Gold Co., is located just west of the town of Omchak some 650 km northwest of the city of Magadan on the Golden Ring road that connects all major gold-mining sites of the Magadan region to its capital. The deposit was discovered in 1943 and has been worked since 1945. Total production for this period exceeds 2.4 Moz (75 t) of gold and 707,315 ounces of silver (22 t). Proven and probable reserves of the deposit approved by the Russian State Committee of Reserves and currently verified by audit (Mineral.ru of 9/13/07) are 1,125,840,000 tonnes of ore grading in average 1.13 g/t Au (cutoff grade 0.3 g/t) or 1,270.6 t gold (40.8 Moz) including 320.1 t of proven and 950.2 t of probable gold reserves.

The deposit is confined to the southwest flank of the Mesozoic Yano-Kolyma fold-and-fault belt and is located in a synclinal fold at the southwest boundary of the Ayan-Yuryakh anticlinorium. The belt contains a chain of Late Jurassic-Early Cretaceous granodiorite-granite plutons and swarms of granitoid dikes. The mineralized area covers about 40 km^2 and is bounded by faults. The host rocks, more than 2,000 m thick (Volkov et al. 2002), are Late Permian carbonaceous sediments that include tuffaceous shales and less abundant pelitic carbonaceous shales with a rare siltstone-and-sandstone interlayers (Fig. 31). The Permian sediments underwent metamorphism to greenschist facies and are intruded by numerous dikes of Late Jurassic lamprophyre and diorite porphyry, as well as Late Cretaceous quartz-albitite. According to A. Volkov and coauthors, the deposit is confined to the tectonic block of the deep fault zone above the granitoid intrusion. Two granodiorite stocks that outcrop on the periphery of the ore field support this idea.

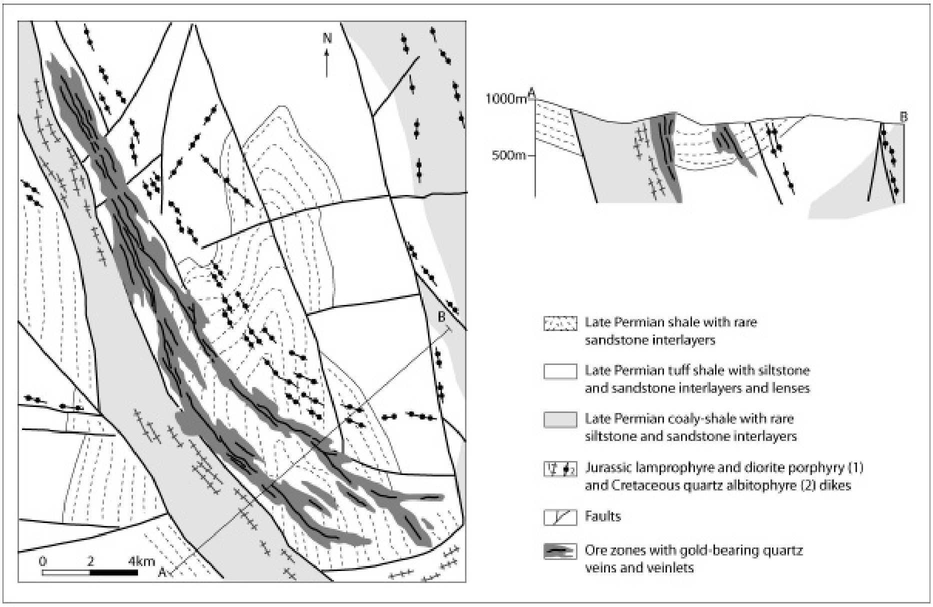


Figure 31. Geologic map and cross section of the Natalka deposit (after Konstantinov and Narseev 1989).

According to A. I. Kalinin (in Konstantinov et al. 1992), pre-ore carbonatization of the host rocks is surrounded by aureoles of chloritization and later sericitization. The syn-ore adularia-arsenopyrite-apatite-magnetite alteration in the central part of the ore zones is accompanied by albite-pyrite-apatite-magnetite mineralization.

The main structural element of the deposit is a northwesterly shear zone 0.3-1.5 km wide at the hanging wall of the regional fault zone, which includes normal, strike-slip faults. The ore mineralization is controlled by steeply dipping shear fractures with mylonite and breccia and forms two linear ore zones up to 25 km of combined length. These zones, from 100-200 m thick in the northern part to 600 m in the southeastern part of the deposit, merge at its northwest flank. They are confined to the southwest limb of the syncline and consist of quartz veinlets, veins, and lenses in silicified, crushed, and banded host rocks. Some of the quartz veins are up to 200 m long and 0.5-3.0 m thick. The quartz veinlets are 1-30 mm thick and often merge into short lenticular quartz veins. At the intersections of the northwest and transverse faults, the veinlets form stockworklike bodies. The thickness of the gold-bearing mineralized zones varies from 1 to 40 m, and the boundaries of the ore bodies are determined by sampling.

Four areas of the deposit with higher gold grades contain steeply dipping ore shoots at the intersections of the main ore trend by cross faults. Most of the ore shoots are confined to bends or bifurcations of the main zone fracture.

The main gangue mineral is quartz with secondary albite, orthoclase, adularia (at the upper levels of mineralization), calcite, and dolomite (Volkov et al. 2002). The amounts of sulfides do not exceed 1-3%, with arsenopyrite, pyrite, native gold, galena, and pyrrhotite as the main ore minerals. Pyrite and arsenopyrite make up 95% of the sulfides, while scheelite, tetrahedrite, boulangerite, sphalerite, chalcopyrite, and electrum are rare.

The two gold-productive mineral assemblages are an early medium-grained quartz with coarse-grained pyrite, arsenopyrite, and finely dispersed gold particles. The younger assemblage includes fine-grained quartz with arsenopyrite, pyrite, galena, and visible gold. Most of the gold was deposited during the second stage together with arsenopyrite and galena. The gold grains of an average fineness of 750-790 vary in size from 0.1 to 2.0 mm and are interstitial, spongy, and dendritic shapes. Sometimes, gold forms emulsion-type inclusions in the sulfides.

The mineralization of the Natalka deposit differs from that of other gold-quartz deposits by presence of disseminated acicular arsenopyrite and arsenical pyrite in sheared and boudinaged host rocks but not in the granitoids. The gold concentration in the arsenopyrite varies from 70 to 220 g/t according to microprobe data or up to 450 g/t according to atomic-absorption analyses (Volkov et al. 2002). However, sulfides account for no more than 20% of the gold in the identified ore bodies. The gold distribution is uneven, with the ore shoots containing 4-5 times higher gold grades than the average grade of 4 g/t in the current run-of-mine ore. The ore shoots have a lenticular shape 10-40 m to 80 m wide and 50-80 m along dip. The gold-quartz aggregates in ore shoots usually have undergone recrystallization, forming large lumpy and crystalline grains in association with sphalerite and galena in sugarlike quartz.

A study of the fluid inclusions in the quartz, carried out by the specialists with the Northeast Institute of the Russian Academy of Sciences in Magadan, revealed a homogenization temperature in a range from 150 to 360°C, with two temperature peaks at 280-320°C and 180-240°C in many samples.

According to Sidorov et al. (1997), Plusnina et al. (2001), and Volkov et al. (2002), the gold ore of the Natalka deposit also contains platinum and palladium mineralization. The platinum and palladium grades analyzed by the ICP-AES technique from 10 samples of altered host rocks, sulfide concentrate, and tailings (Plusnina et al. 2001) vary between 0.28 and 7.22 g/t platinum and from <0.1 to 9.60 g/t palladium, with the maximum concentrations occurring not in sulfide concentrates but in altered host rocks containing sulfide mineralization. However, a study of 10 drill-core samples of the Natalka deposit (Bierlein et al. 2002), submitted for analysis by Placer Dome Exploration Co., showed subeconomic concentrations of platinum (<2-15 ppb), palladium (<2-30 ppb), osmium (<2-10 ppb), and iridium (<2 ppb). Analyses were performed by Ni fire assay, ICP-MS, and INAA and suggest that platinum-group elements do not form native metals, alloys, and tellurobismuthides in these samples. They occur instead as lattice substitutions within unspecified host minerals and/or are concentrated in poorly ordered pyrobitumen and graphite, supporting the possibility of absorption and concentration of PGE during sedimentation and diagenesis.

Current estimates of the Natalka deposit's gold resources are substantially higher (1,270.6 t at 1.3 g/t) than the 250 tonnes of gold approved during the Soviet time. But very low cutoff grade (0.3 g/t) and impossibility of heap-leach processing make these estimates questionable even at the recent level of high gold price.

The Shkol'noye Deposit (61°27'N-148°48'E)

The Shkol'noye gold-quartz deposit is on the southeast trend of the Ten'ka fault of the Ayan-Yuryakh anticlinorium, which also hosts the Natalka deposit. The resources of the Shkol'noye deposit, discovered in the mid-1960s, are much smaller than those of Natalka and amounted to approximately 650,000 ounces of gold and the same amount of silver. The following description of the deposit is based on the data of E. V. Bel'kov and coauthors (Konstantinov et al. 1992), which also have been used by Moiseenko and Eirish (1996) and Volkov (2005).

The main ore-controlling structure of the area is the southern fault zone, which is 0.5-1.5 km wide and consists of a series of subparallel thrusts and strike-slip faults with displacement amplitudes of no more than 100 m. The thickness of the steeply dipping (80° to the NE) crush and fracture zones of the fault reaches 40 m.

The ore bodies of the deposit are hosted by an oval shape granitoid stock, 3 km long and 1 km wide, elongated to the northeast(Fig. 32). The stock was formed in four stages. The earliest stage is gabbro and gabbro diorite, which occur as large xenoliths up to 200 m in diameter in younger rocks. The diorite of the second stage forms two bodies, each up to 1 km^2 in area, in the western and eastern parts of the stock. The granodiorite bodies of the third stage form narrow bands 200-300 m wide in the southern, eastern, and western parts of the stock. The fourth stage is adamellite that is widespread in the central part of the stock and contains most of the ore bodies. Granitoids, 152-146 Ma old, have a normal alkalinity and are surrounded by a zone of hornfels alteration up to 200-300 m wide. The stock's contacts dip 70-90° toward its center.

A large number of basic, intermediate, and felsic dikes (100-90 Ma) conclude the intrusive process. The steeply dipping dikes, up to 2 km long and from less than 1 m to 10-20 m wide, have a mostly east-west strike and are concentrated in the central and northern parts of the ore field. Many of the dikes have undergone hydrothermal alteration and occasionally contain sulfide mineralization.

Host-rock alteration includes greisen, skarn, and argillic types. Pre-ore greisen alteration has limited distribution and is confined mainly to the selvages of the ore bodies, whereas argillic alteration always accompanies and surrounds the ore bodies. Skarnlike mineralization is typical of the deposit flanks in carbonaceous sandstone and siltstones. The ore-hosting crushed zones, 0.5-3.5 m wide, are converted by alteration into sericite-hydromica-quartz rocks and quartzite containing up to 5% pyrite and arsenopyrite. An envelope of weaker alteration up to 20-100 m wide surrounds such zones.

The gold-bearing quartz veins and veinlets form easterly-trending crush/fracture zones, 100-200 m wide and 800-2,000 m long, which intersect regional northwesterly faults. The crush zones consist of sericite-hydromica-quartz assemblage accompanied by silicification carrying

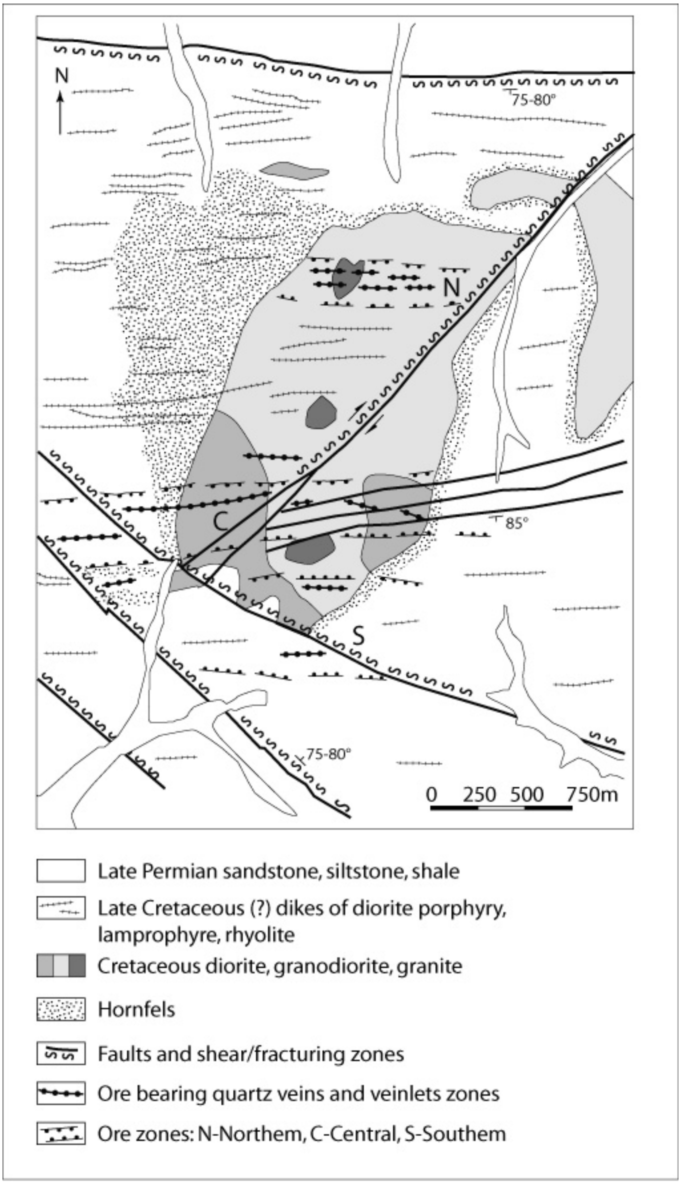


Figure 32. Schematic geologic map of the Shkol'noye deposit (modified after Konstantinov et al. 1992).

disseminated pyrite and arsenopyrite. Three such zones—the northern, central, and southern—have been outlined in the deposit area, but economic gold ore is concentrated only in the central zone. The gold-bearing quartz veins are 20-200 m long and 0.1-1.5 m wide and consist of fine—and medium-grained massive to finely crystalline quartz. Higher, sometimes mineable, gold grades also occur in sericite-hydromica-quartz altered rocks with thin quartz veinlets surrounding veins.

The sulfide mineralization, 1-3% of the vein volume, includes about 60 minerals. The quartz-molybdenite association represents pre-ore stage of mineralization. The ore stage includes (1) the gold-cassiterite-scheelite with bismuth, tetradymite, and rare native gold association; (2) the gold-arsenopyrite-quartz association, and (3) the gold-freibergite-quartz (main productive) association. The gold-arsenopyrite association also contains loellingite, molybdenite, chalcopyrite, pyrite, and galena. The main gold-productive association consists of quartz, freibergite, tetrahedrite, stephanite, jamesonite, boulangerite, polybasite, famatinite, acanthite, electrum, and gold.

The distribution of gold mineralization is extremely uneven, with ore shoots, bonanzas, and nestlike accumulations, 3-45 m in size. The average gold grade in the quartz veins varies from 30 to 50 g/t. Altered rocks along vein selvages host about 25% of the mineable gold with gold grades ranging from 7 to 100 g/t. The high-grade bonanzas, which make up about 10-19% of the ore bodies, contain 50-85% of the gold resources. The gold-silver ratio is 1:1 for the whole deposit but increases in bonanzas.

Native gold of 511-806 fineness (averaging ~730) forms mainly free particles and intergrowths with arsenopyrite, chalcopyrite, freibergite, boulangerite, and polybasite. Gold particles of isometric, lamellar, flaked, and dendritic shape are mostly larger than 0.1 mm, reaching 6-8 mm and up to 20 mm. The gold contains as its main admixtures As and Fe (0.1-0.3%), Hg (0.03-0.1%), and Sn and Pb (0.01-0.03%).

The geochemical field of the Shkol'noye deposit has a concentric structure. Its central part, confined to the granitoid stock, is represented by a complex aureole of Au, As, W, and Bi, while the flanks of the deposit contain a halo of Cu, Pb, Zn, and Ag. The primary geochemical halo directly around the ore bodies contains anomalous grades of gold and silver (up to 5 g/t), arsenic (>1%), tungsten, and antimony.

The geological gold resources of the Shkol'noye deposit are about 902,000 ounces (29 t) grading 39.5 g/t, but this deposit has considerable exploration potential.

Many other gold-quartz deposits such as Karalveem, Utinskoye, Vetrenskoye, and Svetloye are known in the Yano-Kolyma region. Many geologists suggest that these deposits are related to the early orogenic series of independent small intrusions that precede the orogenic granodiorite batholith. An example of the Shkol'noye deposit contradicts this interpretation. The location of most of the gold-quartz deposits of this region along an extended belt of granodiorite plutons and often in between plutons that join, according to geophysical data, at depth suggests their possible relations to the same magma chambers. However, in either interpretation, the gold-quartz deposits of the Yano-Kolyma region are intrusive-related.

Intensive gold exploration during the 1990s following the discovery of the Shkol'noye deposit revealed more than a hundred gold-bearing granitoid stocks in the Magadan and Chukotka regions with gold grades of 3-5 g/t, which need additional exploration.

The described gold-quartz deposits have close (Jerooy, Shkol'noye) or more distant (Natalka) connections to granitoid intrusives and belong in Russian classifications to the so-called medium-temperature deposits of a medium depth. All of these deposits have in common the vein/veinlet type of mineralization with low sulfide content, usually no more than 1-3%, and mainly free gold. All deposits of this type have relatively small alteration aureoles around veins, which are represented mainly by silicification, sericitization, chloritization, and sometimes argillic alteration.

The similar low sulfide content and a prevalence of free gold is typical also for gold-quartz deposits in metamorphic sequences (see pp. 67-71). However, intrusive-hosted gold-quartz deposits have been deposited at much lower temperatures versus those hosted in metamorphic rocks. The quartz of the deposits in the metamorphic host rocks was formed during the process of regional metamorphism at 600°C temperature and 2 kbar pressure (Tomilenko and Gibsher 2001) and accordingly were probably formed at greater depth than the intrusive-related gold-quartz deposits.

4.2.2.2 Gold-Sulfide (Arsenic)-Quartz Deposits

Most of the intrusive-related vein gold deposits mined in the CIS belong to this mineralogical type and contain from 5-7 up to 40-60%

sulfides, commonly with a significant amount of arsenopyrite. They are known mainly in femic metallogenic provinces developed on oceanic-type crust like the Hercynides of the Urals (Kochkar, Beriozovsk, etc.) or the Caledonides of the Altai-Sayany province (Central, Berikul, Komsomol, Kommunar, etc.). Another tectonic setting for such deposits is in the zones and blocks of stable crust that underwent later intensive tectonic and magmatic activity. The continental crust of these regions, which has an originally femic but substantially granitized substratum like some blocks of the Transbaikal region of Russia (Darasun, Itaka, etc.), underwent during such activity a high-degree destruction of the crust.

The gold-sulfide (arsenic)-quartz vein deposits are confined to gabbro-diorite-granodiorite-granite, adamellite—potassium-low granite, and other reasonably felsic granitoid series generated in island-arc and early continental (early orogenic) subduction environment. Relatively small gold deposits of this type are related to the early bimodal intrusive series, which are comagmatic with basalt-andesite-rhyolite and basalt-andesite-basalt island-arc volcanics productive for volcanogenic massive sulfide deposits. However, major gold-sulfide (arsenic)-quartz deposits are related to the adamellite—potassium-low granite series, which, according to Kuznetsov (1964), are associated with the formation of granodiorite batholiths. According to geological and geophysical data, these plutons, tens of square miles in area with a vertical range of at least 5-6 km, formed as a result of palingenesis generated by deep emanations and involving a large mass of rocks in the upper crust. During this process, a large amount of trace gold from the original subducted crust was remobilized, and its subsequent precipitation led to the development of large gold deposits (Levitan and Berson 1977; Levitan et al. 1979; etc.).

Granitoid plutons may play a large role in remobilization of gold from the crustal rocks, but the gold concentration more likely is related to the development of younger magmatic centers responsible for the intrusion of pre-ore dikes of diorite, lamprophyre, and granitoid composition. Such dikes make up a significant volume (up to 40%) of the host intrusives, indicating the prevailing extensional conditions for this stage (Narseev 1991).

A major practical interest in the group of gold-sulfide (arsenic)-quartz deposits belongs to its pyrite-arsenopyrite mineral type containing other sulfides, sulfosalts, sulfobismuthinites, and tellurides (Kochkar, Darasun, Central, etc.), which form the largest gold deposits of this group. Another mineralogical type of large deposits consists of pyrite with sulfides, sulfosalts, and sulfobismuthinites, or without the last of these (Beriozovsk, etc.). The main gold-bearing mineral associations of these deposits are gold-polymetallic (early), gold-telluride, and gold-sulfosalts (late). The mostly free native gold has high fineness (averaging 919) and forms isolated inclusions, clusters, and lenses in quartz and ore minerals. The average gold grades are typically high (10-20 g/t), with even higher grades in ore shoots, up to hundreds of grams per tonne. The gold-sulfide-quartz veins are accompanied by quartz-carbonate-chlorite-sericite-pyrite (beresite-listwanite in Russian terminology) alteration, which form relatively thin zones (from a few centimeters to, rarely, meters) along vein selvages.

Most of the deposits have a concentric mineral zoning with the presence of all mineral associations at the central parts of the deposits or gold-bearing veins. Some associations are disappearing with depth and toward the flanks of deposits in a reverse order of deposition. Vertical zoning is usually less clear than lateral, suggesting a deep vertical distribution of gold-bearing sulfide mineralization up to more than 1,200-1,300 m.

Five of the most intensively studied gold-sulfide (arsenic)-gold deposits (Kochkar, Central, Darasun, Beriozovsk, and Charmitan) are described below.

The Kochkar Deposit (54°30’N-60°30’E)

The Kochkar deposit is located on the outskirts of the city of Plast, 130 km south-southwest of the city of Chelyabinsk, the regional center of the South Urals. The first gold placer was discovered here in 1761 and the first quartz (arsenic)-sulfide vein in 1798, but development of the deposit did not begin until 1845. Approximately 210 tonnes of gold has been mined out of the Kochkar deposit during its more than 160-year history. The Kochkar ore field contains also a large number of smaller gold deposits and ore showings mined by independent prospectors (Okhotnichy, Kosobrodsky, etc.) and large gold placers that have produced more than 100 tonnes of gold. One such placer deposit, the Andrei-Yulievskoe, is still in operation.

The Kochkar ore field is located inside an intensely eroded Early Carboniferous adamellite—potassium-low granite (plagiogranite) pluton confined to a regional north-south fault, which separates a large anticlinorium to the west and a synclinorium to the east. The pluton is elongated northerly for about 50 km, conformably with the regional tectonic setting (Smirnov 1977) and is separated from the Late Paleozoic granite plutons of the anticlinorium by a narrow strip of Precambrian and Early Paleozoic gneiss, amphibolite, and schists. It is bordered to the east by metamorphosed Silurian-Devonian basalt-andesite-dacite volcanics, which fill a riftlike synclinorium within the Ural-Tobol microcontinent of the East Urals. Early Carboniferous volcanogenic and sedimentary formations, which indicate the start of the region's continental stage, have limited distribution (Levitan 1976). According to Sazonov et al. (2001), the intrusion of a plagiogranite pluton is contemporaneous with this stage and is dated at 341 ± 20 Ma.

The pluton has a heterogeneous structure. At the western contact of the pluton, gneiss, crystalline schists, and amphibolite are gradually replaced by foliated granite-gneiss and banded potassium-low granite (plagiogranite). Relatively homogeneous plagiogranite with relics of gneiss occupies the central part of the pluton, while porphyry-like homogeneous variety occurs in the eastern part of the pluton. Yanovsky (1972) explains this distribution in terms of the process of granitization at the roof of the magma chamber. The Kochkar ore field is confined to a relatively uplifted block of the pluton, bounded to the north and south by northwesterly faults that are fragments of a large ore-concentrating structure with the Svetlinskoye gold deposit located on its west flank (Levitan and Kondratov 1972).

Approximately 10-15% of the area is occupied by more than 2,000 steeply dipping dikes up to 20 m wide and 1.5 km long having a radial pattern from east-northeast in the northern part of the pluton to an east-southeast trend in its southern part. N. Borodaevsky, N.

Ershova, and A. Cheremisin (TsNIGRI) have identified four stages of dike intrusion: (1) plagioaplite and plagiopegmatite, which are probably syngenetic with palingenesis; (2) plagiogranite porphyry I and lamprophyre I (pre-ore); plagiogranite porphyry II, felsite, spessartite, and kersantite (post-ore) comagmatic with the plagiogranite pluton; (3) plagioclase-quartz porphyry and quartz porphyry comagmatic with the Visean (Early Carboniferous) effusives; and (4) biotite granite, aplite, pegmatite, and alaskite comagmatic with the Late Paleozoic granite plutons.

Most of the dikes have undergone intensive post-ore recrystallization, biotitization, and K-feldspathization. This process has produced rocks specific to the Kochkar deposit, which gold miners call “tabashki,” or tobacco-like green-brown melanocratic rocks consisting mainly of biotite, amphibole, K-feldspar, epidote, actinolite, quartz, sericite, and carbonates.

The mineralized area of the deposit coincides with a concentration of altered dikes in the western part of the ore-bearing block (Fig. 33). Borodaevsky (1952) outlined three compressed zones of “tabashki” having a northeasterly and east-northeasterly strike. The central parts of these zones contain thick tabashki dikes and adjacent quartz-sulfide veins parallel to the dikes, with relics of primary structure and texture separated by deformed granite into parallel branches and strips. Rare dikes located outside the compressed zones have smaller thickness and lengths. In the southern part of the Kochkar ore field, some dikes have a westerly-northwesterly strike.

Gold-bearing quartz-sulfide veins are grouped into three suites—the northern, central, and southern, which coincide with the compressed zones of dikes. Each suite consists of a series of closely spaced veins positioned usually outside of the dikes or less common in their bodies. The veins form often three or four parallel branches or echelon-like lenses. Yanovsky (1972) outlined four types of ore bodies with different characteristics of distribution, thickness, and gold grade (table 5).

Northwest-striking gold-bearing veins in the southern part of the deposit are accompanied by veinlet-disseminated mineralization in shear zones of the hosting granitoids. Thin dikes usually are accompanied

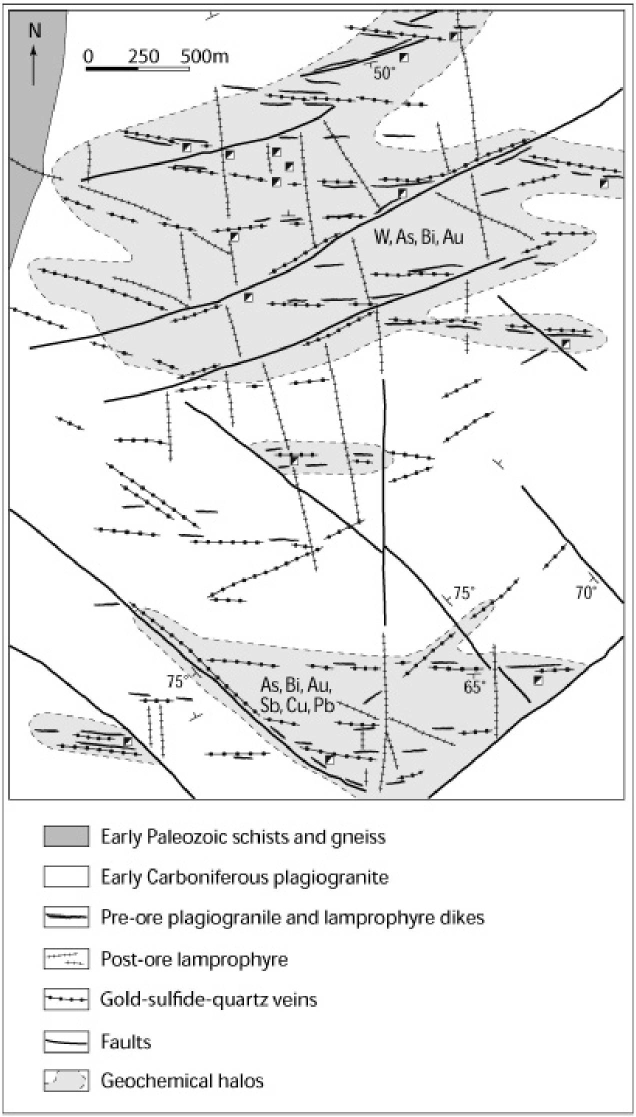


Figure 33. Geologic-structure map of the Kochkar gold deposit (after Konstantinov and Narseev 1989).

by veins along the hanging wall and footwall, with veins forming a series of flat lenses that do not deviate far from the dike contacts. Thick dikes have veins mainly along one of their contacts. The veins may be interrupted by a dike's apophyses and could deviate up to 20-30° from the dike's strike.

TABLE 5
Types of Mineable Ore Bodies of the Kochkar Deposit
(After Yanovsky 1972)

Groups of Ore Bodies	Morphology and Length, m	Thickness, m	Gold Grades, g/t
I) Within ENE faults: azimuth 60-70°, dip to SE 60-85°, rarely dipping steeply to the NW	*En-echelon* lenses 20-50 to 100 m long	0.4-0.7 to 6 (averaging 0.9)	10-25 (averaging 17)
II) Within NW faults: azimuth 290-320°, dip to SW 60-75°	Series of lenses 10-30 m long, chains of lenses	0.5-1.4 (averaging 0.9)	4-30 (averaging 18)
III) Within easterly-trending feather fractures: azimuth 80-100°, dip steeply to S, rarely to the N	Series of lenses 5-40 m long, parallel veins	0.25-0.8 (averaging 0.45)	10-25 (averaging 15)
IV) Within feathering fractures, ENE direction	Shear zones and series of lenses 5-60 m long	0.1-0.7 (averaging 0.5)	8-24 (averaging 20)

The host rocks alteration accompanying the deposition of gold-bearing quartz-sulfide veins is silicification, carbonatization, sericitization, and chloritization, while post-ore alteration includes recrystallization and redistribution of biotite in the tabashki dikes. Hydrothermal alteration forms zones from a few centimeters to tens of centimeters wide around the veins.

The gold grade in quartz-sulfide veins along the main east-northeasterly faults does not change with depth, and the horizontal extension of the veins remains the same. The gold content of the east-west veins often decreases with depth.

Ore shoots with gold grades up to 10-20 times higher than average form in zones of (1) greater fracturing, (2) at vein bends and pinchouts, (3) at points with deposition of different mineral associations. The shoots, up to 50-70 m wide, have a ribbonlike shape and can be traced to a depth of a few hundred meters. The contours of high gold grades in quartz veins are complex and tortuous or straightforward. Smaller ore shoots with highly contrasting gold grades are related, according to Cheremisin (1986), to hydrothermal-metamorphic remobilization of gold at the intersections of ore-bearing veins by post-ore quartz-pyrite-tourmaline-carbonate veins.

Gold-bearing veins are composed mainly of recrystallized quartz with minor amounts of calcite, sericite, biotite, tourmaline, and actinolite (Kolb et al. 2005) and a variable amount of sulfides, which make up 2-7 and as much as 40-50% of the vein volume. L. Mikhailova (in Smirnov 1977) described five successive mineral associations: (1) arsenopyrite-pyrite; (2) quartz-pyrite; (3) chalcopyrite-sphalerite-marcasite with pyrite and gray copper ore; (4) gold-tetradymite with galena, boulangerite, bournonite, and bismuthinite; and (5) post-ore quartz-carbonate-galena.

The second, third, and fourth mineral associations are productive for gold, with gold grades increasing from earlier to later. The ore is high in arsenic, especially in the southern part of the deposit, where arsenic is extracted as a by-product.

Study of the Kochkar ore led to the discovery of a series of new lead-chromium minerals such as crocoite (Leman 1766), phenicophroite (Glocer 1839), embreyite (Williams 1972), well-known aikinite (Hermann 1789), and other new minerals.

The free gold is associated with tetradymite and gray copper ore and is in quartz, pyrite, and arsenopyrite. It forms clumpy and dendritelike grains up to a few millimeters in size. The gold fineness varies from 800 to 970.

The strongest geochemical aureoles around the vein zones in the northern part of the deposit are W, As, Bi, and Au, while in its southern part they are As, Bi, Au, Sb, Cu, and Pb. Changes in the vertical zonation have not been found down to a mining depth 700 m below the surface. Even drill hole intersections of quartz-sulfide veins at a depth of 1,200 m from the surface have the same mineralogical composition and gold grades, as do the upper horizons of the Kochkar deposit.

The close connection of gold-bearing veins to swarms of dikes that are comagmatic with the potassium-low granite intrusion support place of the Kochkar deposit in the intrusive-related group. Kolb and coauthors (2005) showed that a study of oxygen isotopes indicated a magmatic source of ore fluids, but the initial strontium values in the carbonates are incompatible with younger Late Paleozoic granite, as proposed previously by A. Cheremisin.

The current resource estimates for the Kochkar gold deposit calculated to a depth of 700 m (the lowest level of existing capital shafts) is approximately 2.5-3.0 Moz, with an average gold grade of 10-15 g/t. The total resources of the deposit, taking into account the 7 Moz of previous gold output, are about 9.5-10 Moz, or approximately 300 t.

The Central Deposit (55°20'N-87°66'E)

The Central (Tsentralny in Russian) deposit is located in the northern part of the Kuznetsky Alatau region of the Caledonian Altai-Sayany fold-and-fault belt with Early Cambrian folding and later granitoid magmatism. The deposit was discovered in the early 1920s and has been worked since 1929.

The ore field of the Central deposit is in the northern part of a large Late Cambrian-Ordovician granitoid intrusive, which belongs to the Martaiginsk intrusive series. Many other vein gold deposits of this region such as Kommunar, Sarala, Berikul, and Komsomol'sk also have a close relationship to this series. The Central pluton is located to the east of the regional Kuznetsky-Alatau fault and intrudes Cambrian volcanogenic-carbonate island-arc sequences. The pluton has a zonal structure with a central biotite and biotite-amphibole granodiorite, occasionally transitioning to quartz diorite in the core part and gabbro diorite and gabbro at its periphery. The granodiorite contains a large number of melanocratic schlieren that correspond in composition to diorite and gabbro but may be partially altered xenoliths of Cambrian volcanics.

A series of dikes includes pre-ore aplite and aplite pegmatite that forms thin lenticular bodies 0.05-0.1 m thick or swarms of dikes. The dikes of this group are intersected by gold-sulfide-quartz veins and have undergone hydrothermal alteration (Bazhenov and Mityushin 1970). The second group consists of also pre-ore spessartite and diorite porphyry dikes. These steeply dipping dikes fill long fractures of different strikes up to a few kilometers in length. Postdike movements often occur along their contacts, leading to crushing and sometimes complete grinding of the dike body.

The ore-field structure is defined by the north-south-, northwest-, and northeast-trending faults (Fig. 34). The first two are zones of mylonite

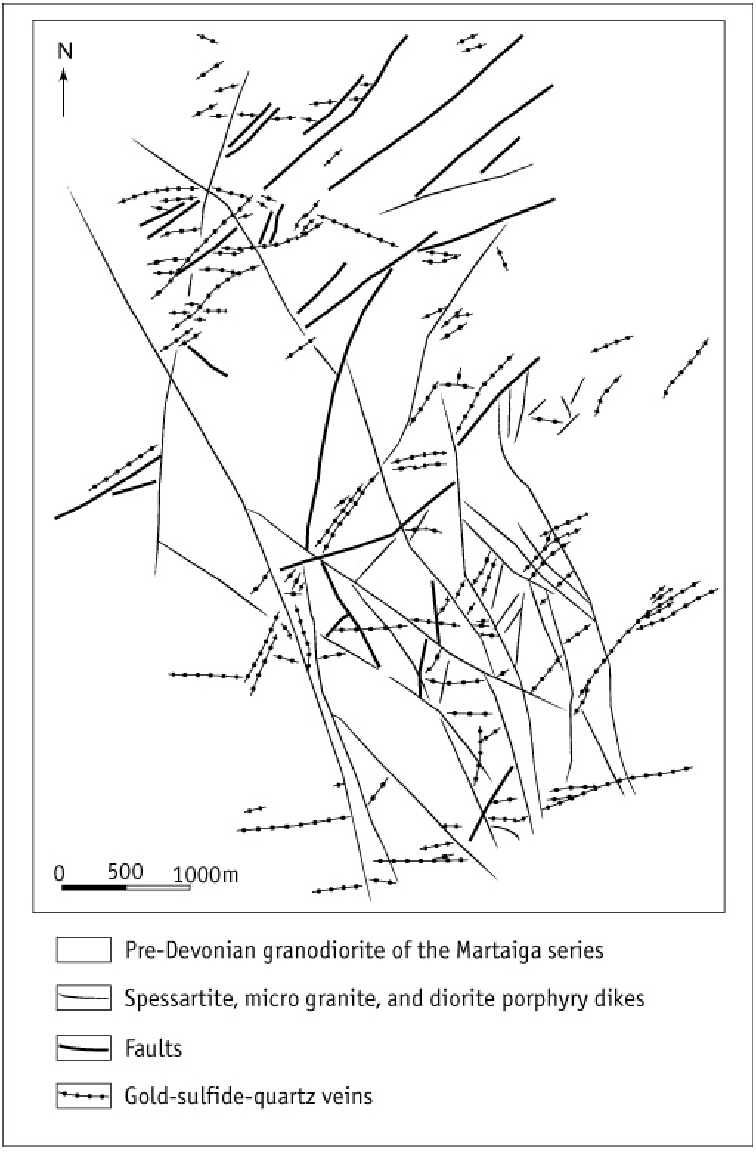


Figure 34. Scheme of the central ore field structure (after Bazhenov and Mityushin 1970).

from 2 to 12 m wide and contain mainly spessartite dikes. The northeast-trending faults usually contain lengthy gold-sulfide-quartz veins, but in the southern part of the ore field they also host diorite porphyry dikes. A widely distributed series of east-west fractures is complementary to the northwest and northeast faults and contains many gold-bearing quartz veins.

Hydrothermal alteration of the host granitoids and pre-ore dikes belongs to the quartz-chlorite-sericite-carbonate-pyrite (beresite) type. The thickness of the alteration envelope varies from 0.5-1.0 mm to 3-4 m (Bazhenov and Kucherenko 1970). The thinnest alteration is developed around gold-sulfide-quartz veins in massive, poorly fractured granodiorite. Altered granodiorite has a granoblastic, lepidoblastic, and sometimes porphyroblastic texture showing complete recrystallization of the host rocks to aggregates of quartz, colorless mica, and calcite. The alteration had several stages: (1) chloritization of mafic minerals and low sericitization of plagioclase; (2) complete decomposition of plagioclase with development of quartz and sericite and intensive replacement of chlorite by muscovite; (3) replacement of K-feldspar by quartz; and (4) silicification, carbonatization, and sulfidization in the form of impregnations of pyrite and arsenopyrite up to 5 vol. %.

The Central ore field contains more than 200 gold-bearing quartz veins. The most complexly shaped veins, a few hundred meters long, with bulges and nicks, are in northeast-striking fractures. They have an *en-echelon* distribution along the strike and numerous apophyses from both the hanging-wall and the footwall sides. East-south veins have shorter lengths of tens and sometimes a few hundred meters, and a simpler shape. All the veins dip steeply at 40-75°. The gold-bearing quartz-sulfide vein zones are concentrated as northeasterly- and westerly-striking, sheeted vein zones. The largest numbers of veins are located at the intersections of the NE and E-W zones. Bazhenov and Mityushin (1970) noted that the highest gold grades in quartz veins are common for such nodes, and outside of them the veins decrease in thickness and gold grade.

According to Bazhenov and Mityushin, the six mineral associations are deposited: (1) pre-ore with dark gray quartz and relics of sericite, muscovite, chlorite, and rutile; (2) quartz-pyrite association with clusters of pyrite; (3) a low in gold quartz-arsenopyrite association with white quartz (mainly in the central and northern parts of deposit); (4) quartz-polysulfide assemblage with pyrite, sphalerite, galena, chalcopyrite, marcasite, cubanite, enargite, bismuthinite, argentite, and native bismuth, gold, and silver; (5) an early post-ore chlorite veinlets intersecting all previous associations; and (6) a second post-ore, quartz-carbonate, association with opaque quartz, calcite, ankerite, and admixtures of chlorite, epidote, and sometimes tourmaline.

The distribution of mineral associations within the Central ore field has lateral zoning. A polysulfide zone is located on its north flank and contains low-fineness gold associated with pyrite, sphalerite, and galena. The arsenopyrite in the arsenic zone of the central part of the ore field is usually in excess at any galena or zinc sulfides. A copper zone with pyrite, chalcopyrite, scheelite, molybdenite, magnetite, and sphalerite is developed mainly on the southern flank of the ore field and contains larger particles of high-fineness gold associated with sulfides but also with quartz and tourmaline.

The homogenization temperature of the gas-liquid inclusions in the quartz is (Troshin et al. 1999) 360-250°C in the copper zone, compared with 290-160°C in the arsenic zone. The temperature of quartz decrepitation has an analogous distribution. The sulfur isotopic composition in pyrite also supports such zoning. The average value of $\delta^{34}S$ increases from 3.8-6 to 9‰ from the steeper-dipping copper zone to the central arsenic zone and the less eroded polysulfide zone of the north flank.

The Rb-Sr age of the ore mineralization from the quartz-calcite-pyrite and quartz-pyrite-sphalerite veins gives an Ordovician age of 458 ± 4 Ma (I_o = 0.70363 ± 23), which is consistent with the geologic age of the Late Cambrian-Ordovician granitoids of the Martaiginsk intrusive series.

The gold distribution in the sulfide-quartz veins is sharply uneven. The gold-rich part of the veins form large elongated gentle-dipping ore shoots along the vein's plane and are confined to areas of highly fractured granodiorite. Such ore shoots can be traced for a few tens of meters along the strike and up to 100 m down dip. Ore shoots in veins, which are located outside of highly fractured zones, form mostly small nests that stand out against the low-grade background. The average gold grades are 7-10 g/t in ore bodies and up to 25 g/t in ore shoots.

The total resources of the Central deposit, which is almost completely mined out, are about 2 Moz of gold. Practically all of the gold deposits associated with the same Ordovician gabbro-diorite-granodiorite Mariinsk taiga intrusive series have gold resources of 1.5-2.0 Moz (45-60 t); most of these deposits are also mined out.

The Darasun Deposit (52°22'N-115°30'E)

The Darasun deposit is located in the Transbaikal region of Siberia, about 260 km north of its capital, the city of Chita. The first gold placer was found here in 1861, and placer mining led to the discovery of the gold-bearing quartz veins in the late nineteenth century. Development of lode-gold mineralization started in 1905, but intensive exploitation of the deposit did not begin until 1927. Total gold output since then is about 3.0 Moz.

The deposit occurs at the southwestern end of the Darasun-Mogocha metallogenic zone of the Mongolian-Okhotsk fold belt controlled by the suture of the Mesozoic collision of the Siberian and Mongolian-North Chinese plates (Prokofiev et al. 2000; Spiridonov et al. 2001). This zone hosts also in its northern part such gold deposits as the Itaka, Klyuchi, Nasedkino, Amazarkan, and Kulinskoye.

The ore field of the Darasun deposit, approximately 60 km^2 in area, contains numerous gold and silver occurrences and the Teremky and Talatui deposits. A few small molybdenum deposits (Zharchinskoye, Torginskoye, etc.) also occur in the area. This fact supports the existence of the so-called "gold-molybdenum belt" of the Transbaikal region, as outlined by S. Smirnov in the 1930s. This belt is confined to the zone of Mesozoic tectonic and magmatic activity within Paleozoic structures of the Mongolian-Okhotsk fold belt.

The Darasun ore field is situated in the large domal structure (Prokofiev et al. 2000) at the intersection of northeast- and northwest-striking deep faults. These zones reflect the two main structure: one which is parallel to the Mongolian-Okhotsk fold belt (NE) and the transverse (NW), the Baley-Darasun ore-concentrating structure, which was outlined by I. N. Tomson and independently by N. A. Fogelman in the early 1960s.

The oldest rocks of this block are metamorphosed Early Paleozoic gabbroid and amphibolite. They are often feldspathized and preserved from denudation by younger Middle Paleozoic-Early Mesozoic granitoids (quartz diorite, granodiorite, granite, granite syenite). The Jurassic stocks of granodiorite and granite porphyry (170-174 ± 10 Ma, according to D. Timofeevsky, TsNIGRI), accompanied by pipelike explosion breccia bodies and dacite-rhyolite effusives, are intruding an older intrusive complex (Fig. 35). The explosion breccia contains sharply angular clasts, mainly of granodiorite and granite porphyry cemented by smaller-sized

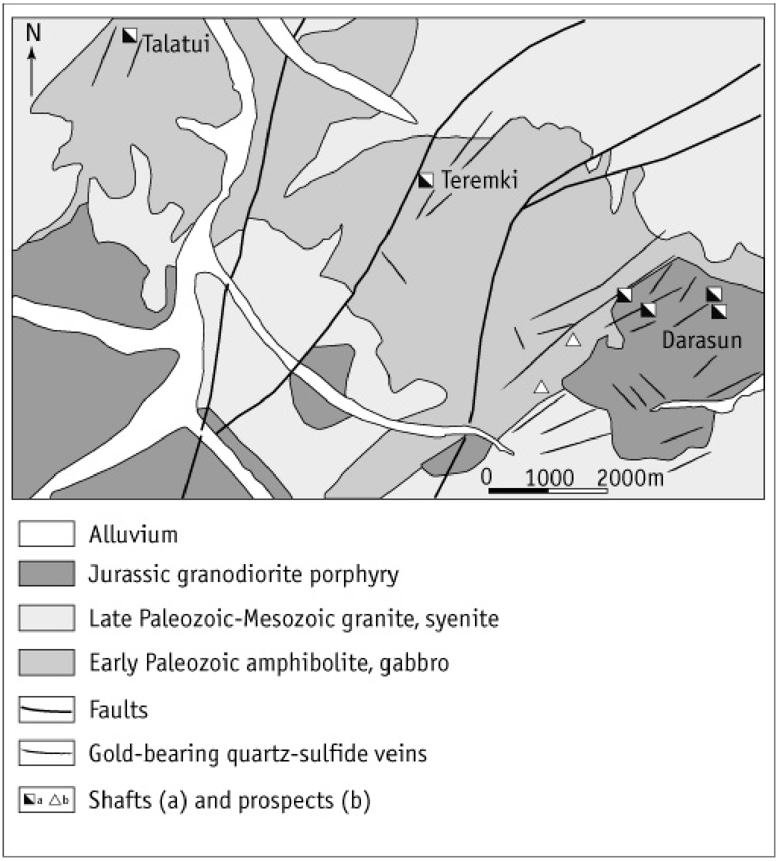


Figure 35. Geologic map of the Darasun deposit (after Highland Gold Web site, 2004).

debris of the same composition, quartz, and often tourmaline. Dikes of diabase and gabbro porphyry, lamprophyre, aplite, and syenite porphyry, all of Jurassic age, are widely distributed in the ore field.

The principal structure of the Darasun deposit was formed during an intrusion of granodiorite porphyry stock that crystallized from high in potassium, calc-alkali magma. The stock has a spiderlike shape with dikes branching out in different directions from its center. The ore bodies are mineralized quartz veins and shear zones concentrated in and around the granodiorite porphyry stock. Some 140 northeast and northwest quartz-sulfide veins have been mapped at the deposit. The thickness of the veins generally varies from 5 to 15 cm, rarely exceeding 30-40 cm. The veins are surrounded by halos of disseminated sulfide mineralization, making the overall thickness of the ore bodies between 0.6 and

1.5 m. All the veins' bulges, pinches, and apophyses are confined to feathering and convergent systems of joints, mutual intersections, and postmineralization displacements. Despite the small thickness of the veins, they can be traced up to 2 km along strike and up to 1.0-1.2 km down dip.

The northeast-trending subvertical veins are predominant in distribution and gold value. They have many southward-dipping ore shoots from 100 to 1,000 m long that are elongated down dip. The northwest-striking veins are steeply dipping to the northeast, are usually shorter than the northeast-trending veins, and, according to Highland Gold's Web site (2005), do not exceed 50 m in length. Figure 36 shows the extensive network of veins present in a northerly-trending cross section of the Darasun deposit (Fig. 36).

Gold-bearing quartz veins are formed by several generations of quartz, carbonates, tourmaline, chlorite, and up to 40-60% sulfides and belong to the sulfide-sulfosalt type of mineralization, with more than a hundred different minerals (Prokofiev et al. 2000). The main ore minerals are pyrite, arsenopyrite, chalcopyrite, pyrrhotite, gray copper ore, bournonite, galena, sphalerite, and native gold. Abundant amounts of Pb, Cu, Sb, Bi, Ag, and As sulfosalts and tellurides accompany the gold and are typical of the deposit. The gold-bearing veins have brecciated, banded, cockade, and crustification structures due to repeated crushing and to the reopening of fractures that host the veins.

The relations between the mineral associations allowed D. Timofeevsky to identify seven mineral associations. The quartz-tourmaline association contains muscovite and perhaps wolframite, in addition to chlorite and a small amount of pyrite. The quartz-pyrite association consists of milky quartz with coarse-grained pyrite and is followed by a pyrite-arsenopyrite association with early iron-rich sphalerite and some gold. The fourth mineral association, galena-sphalerite, contains far more minerals, including quartz, arsenopyrite, tennantite, tetrahedrite, pyrite, chalcopyrite, cubanite, and bournonite. The fifth, pyrrhotite-tetrahedrite-chalcopyrite, mineral association contains bournonite, tennantite, tetrahedrite, pyrrhotite, third-generation arsenopyrite, tellurides of Bi, Au, Ag, Cu, and Pb, electrum, and native gold and silver, is the main productive association for gold. The next (sixth) association consists of ricelike grains of quartz, with carbonates, sulfoantimonite of lead, stibnite, berthierite, realgar, orpiment, and sphalerite. The seventh, quartz-ankerite-calcite-dolomite, association fills fractures in the quartz-sulfide veins and also forms separate veins with chalcedony and a small amount of marcasite.

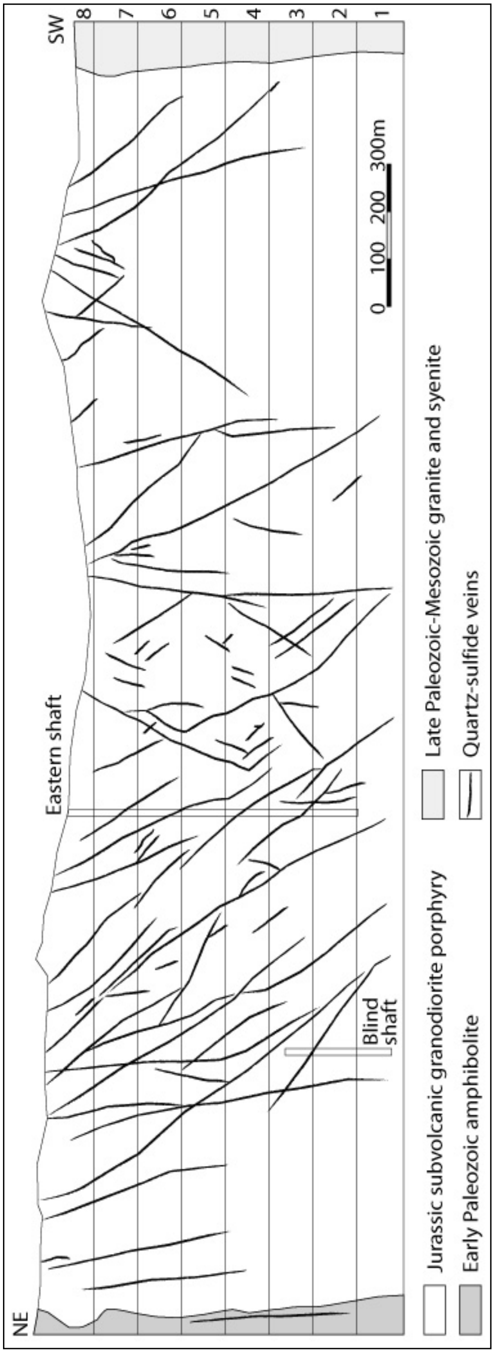


Figure 36. Northerly-trending section of the Darasun deposit (after Highland Gold Web site, 2004).

These seven mineral associations are formed in three stages: (1) an early pneumatolytic-hydrothermal stage, including quartz-tourmaline, quartz-pyrite, and pyrite-arsenopyrite associations; (2) a middle hydrothermal (productive) stage with polymetals, sulfosalts, tellurides, and sulfoantimonite mineral associations; and (3) a post-ore quartz-carbonate stage.

The gold grades of the main productive mineral associations, such as chalcopyrite-gray copper ore and chalcopyrite-pyrrhotite, vary from 20 to 300 g/t. About 30% of the gold is free, ranging in size from a few microns to 250 μm, and it appears in paragenesis with sulfide minerals and sulfosalts. The fineness of the native gold varies from 700 to 920. The finely dispersed gold forms commonly inclusions in arsenopyrite, pyrite, chalcopyrite, pyrrhotite, and gray copper ore.

D. Timofeevsky outlined the concentric zoning of mineral associations around the stock of granodiorite-porphyry: quartz-tourmaline and quartz-pyrite associations are in the immediate vicinity of the stock and are partially overprinted by the pyrite-arsenopyrite association, while the galena-sphalerite, tetrahedrite-chalcopyrite, and sulfostibnite associations are developed in a concentric zone superimposed on the earlier assemblages. Geochemical aureoles of boron, lead, arsenic, as well as the isotherms of homogenization, also have a concentric distribution relative to the stock.

The host rocks underwent pre-ore hornfelsing, K-feldspathization, and high-temperature epidote-actinolite propylite alteration, which was followed by cyclic hydrothermal alteration simultaneous to the deposition of the mineral associations. The main type of hydrothermal alteration of granitoids and gabbroids is chloritization, sericitization, carbonatization, and pyritization (beresite-listwanite type in Russian terminology) that form relatively thin margins along the quartz-sulfide veins.

The total thickness of listwanite alteration around the quartz-sulfide veins in gabbro may reach 10 m. In their outer zones, according to R. Amosov and Kh. Laipanov (TsNIGRI), amphibole is replaced by chlorite, carbonate, and epidote, while plagioclase is replaced by thin aggregates of sericite, calcite, chlorite, and epidote. The inner zones of listwanite, 0.5-0.7 m wide outward from the vein, include carbonate-chlorite, tourmaline-chlorite, and quartz-tourmaline alteration with leucoxene, rutile, and pyrite.

Weak beresite alteration of granite, 0.2 to 2 m wide, is characterized by partial replacement of plagioclase by sericite and ankerite, while microcline is partially replaced by carbonate and quartz. Biotite and hornblende of granitoids are replaced by pseudomorphoses of chlorite, muscovite, ankerite, pyrite, and leucoxene. Full replacement of the original rock by quartz-sericite-carbonate-chlorite aggregates with pyrite is common directly at vein contacts.

The ore mineralization has close spatial and temporal relation to a stock of Jurassic granodiorite porphyry (Prokofiev et al. 2000). The formation of the youngest magmatic and hydrothermally altered rocks was synchronous at about 145 ± 10 Ma. Study of sulfur and strontium isotopes suggests mantle sources for the magma and most of the ore components. The temperature of ore formation varies between 430 and 120°C at a pressure of 1,540-65 bar from fluids with a salt concentration of 42.0-2.2 wt. % NaCl equivalent (Spiridonov et al. 2001).

According to Highland Gold Ltd., which operated the Darasun deposit till 2007, its measured, indicated, and inferred gold resources are 3.74 million tonnes of ore grading 15.1 g/t, i.e., 1.82 Moz or about 58 t. In addition, approximately 4.5 Moz of gold was calculated as the inferred resources of Russian categories P_1 and P_2. The resources of the Teremky deposit in the Darasun ore field are 256,000 tonnes of ore grading 11.8 g/t, or 97,000 ounces of gold; and the resources of the Talatui deposit are 5.46 million tonnes grading 7 g/t, or 1.2 Moz of gold.

The Beriozovsk Deposit (57°51'N-60°44'E)

The Beriozovsk deposit is one of the oldest intrusive-related (dike-related) gold deposits of the CIS, which went into production following its discovery in 1745, and has now been mined for more than two centuries. The Beriozovsk deposit belongs to the relatively rare group of "ladder"—vein-type deposits, where most of the quartz-sulfide veins are nearly perpendicular to the contacts of the hosting dikes. It is located on the outskirts of the city of Ekaterinburg, the capital of the Middle Urals. The ore field also includes the Shartashskoye and Pyshminskoye deposits that have been mined by gold prospectors. Combined placer—and lode-gold production since the first placer discovery near the village of Beriozovsk in 1725 exceeds 400 tonnes.

The most complete description of the Beriozovsk ore field has been given by M. and N. Borodaevsky (1947) and many other Russian geologists since then. This ore field lies in a local grabenlike synclinorium of the Ural-Tobol'sk meganticlinorium of the Ural Mountains. The synclinorium is filled with Paleozoic volcanogenic-sedimentary rocks of oceanic and island-arc formations metamorphosed to greenschist facies and intruded by ultramafic and granitoid bodies. The basement of the synclinorium consists of Precambrian crystalline schists and gneiss that do not outcrop here at the surface.

The base part of the synclinorium's stratigraphic sequence consists (Smirnov 1977*)* of Cambrian-Ordovician diabase with interlayers of tuffite and pyroxene porphyry about 500 m thick. This formation is overlain by 2,500-3,000 m of Ordovician-Early Silurian sequence of quartz-chlorite, quartz-sericite, and coaly chert schists interbedded with tuffite, tuff breccias, sandstone, and limestone. The shales formation is overlain by Late Devonian diabase, basalt porphyry, tuff, and tuff lava, which are overlain by Early Carboniferous tuffite, chert-clay—and chert-carbonaceous shales, and sandstone. The total thickness of the two formations is 600-700 m. The sedimentary and volcanogenic formations are deformed by second-order northeasterly isoclinal folds and by almost east-west strike-slip faults and thrusts.

According to geophysical data, the host rocks of the Beriozovsk ore field are located above the gently dipping roof of the Shartash adamellite pluton (310 ± 10 Ma), which outcrops in the southern part of the area (Fig. 37). The ore field is bordered to the north by a serpentinized Middle Paleozoic gabbro-peridotite confined to an east-west fault zone. A tabular body of serpentinite 400-500 m thick extends from this pluton to the south and thins out at a depth of 600-700 m in the central part of the ore field. Another serpentinite body is in the southern part of the ore field. Several stocks of a Late Devonian gabbro-diorite-granodiorite series comagmatic with the basalt-diabase volcanics are known to the north and south of the Beriozovsk ore field. These stocks host small gold deposits such as Kedrovskoye and Pervomaisko-Zverevskoye.

The most important feature of the ore field is the presence of numerous northerly granitoid dikes, which host most of the gold-bearing quartz-sulfide veins. The dikes are related to the Shartash adamellite pluton and formed in two stages (Ershova and Levitan 1978) separated by the intrusion of the last phase of pluton—a fine-grained adamellite. The first stage contains dikes of lamprophyre (malchite), adamellite porphyry, and microgranite porphyry. The second stage includes lamprophyre II, adamellite porphyry II, aplite, pegmatite, and adamellite porphyry III.

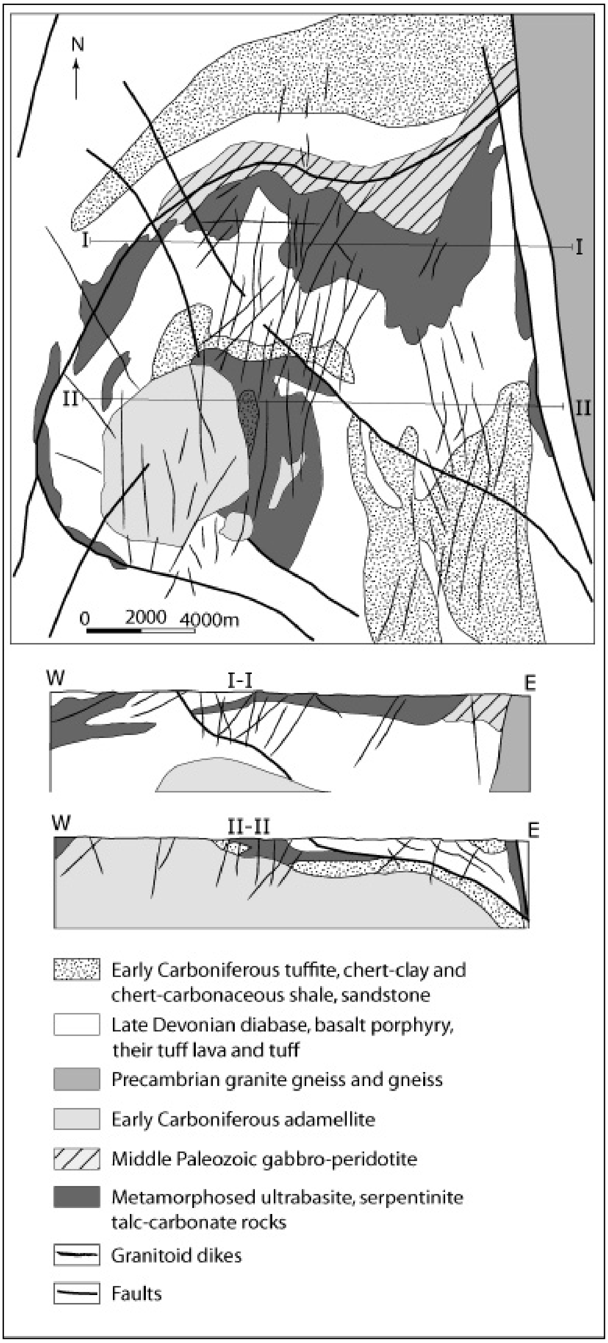


Figure 37. Geologic map and cross sections of the Beriozovsk ore field (simplified after Konstantinov and Narseev 1989).

The Beriozovsk ore field is bordered to the west and east by dipping regional strike-slip faults that divide the synclinorium from the anticlinorial structures and have an amplitude of horizontal displacement of about 10-15 km. Reverse movements along these faults resulted in the S shape of the fault that borders the ore field to the north.

The faults that define the structure of the ore field formed in several stages. The first coincides with the folding of volcanogenic rocks and is responsible for the gentle dip to the west northerly faults. Later movements along the faults, which are bordering the ore field, led to the development of complementary northerly and westerly fracturing that later was filled by dikes. The low-angle faults that accommodated the apophysis of the ultramafic intrusives belong to the same stage. The final stage of faulting took place after the intrusion of adamellite pluton and related dikes. It produced new displacements along faults and formed rupture fractures that host the gold-bearing quartz-sulfide veins both within the dikes and their host rocks.

The ore-hosting dikes form two northerly-trending suites divergent to the north from the exposed part of the Shartash pluton. Each suite includes a few bundles of closely spaced dikes 9-12 m wide and up to 3-5 km long. The distance is 5-10 m between the dikes and 80-100 m between dike bundles. The dike suites dip head-on toward each other at depth.

The main type of hydrothermal alteration is an association of quartz, dolomite, magnesite, and fuchsite (listwanite after Holmes 1928) developed in ultramafic and mafic rocks and quartz-sericite-chlorite-carbonate-pyrite (beresite in Russian terminology) developed upon granitoid rocks. The basic alteration envelope, 0.1-0.4 m to 1.0-1.5 m wide, around the veins at the Beriozovsk deposit, and at other intrusive-related deposits of the vein type, is as follows (Levitan et al. 1984): unaltered rocks→the propylite-albite-chlorite-carbonate subzone→albite-chlorite-sericite-carbonate subzone→quartz-sericite-carbonate subzone→quartz-sericite subzone→ gold-bearing quartz-sulfide vein. The altered rocks around gold-bearing veins contain impregnations of sulfides and have a gold grade of up to 2-3 g/t, which allows them to be mined together with the veins.

The most of gold-bearing quartz-sulfide veins of the Beriozovsk deposit form sets of “ladder” (G. Rose 1842) or “polosovye” (stripes), so named by gold prospectors, veins in the granitoid dikes. These are east-west sets of steeply dipping veins, which are almost perpendicular to the contacts of the northerly-striking dikes. Diagonal and northerly-striking veins are less common. The richest in gold veins are steep-dipping adamellite porphyry dikes hosted by volcanogenic sediments. The length of the veins is limited by the thickness of the dikes, and the vein's thickness varies from a few millimeters to 20-30 cm, rarely more (Fig. 38). The veins are distributed unevenly along the dikes with areas containing 3-5 veins/veinlets per running meter, which alternate with areas of infrequent veinlets.

A rarer kind of gold-bearing quartz-sulfide veins, the "krasichnye" (pigmented) veins, so named by gold prospectors after the ocher richness in the oxide zone, are hosted by volcanogenic sediments or serpentinite. Their length is up to 70-100 m, and their thickness is up to 70-80 cm. The krasichnye veins have a strike and dip similar to ladder veins (an azimuth of 90-110° and a dip of 70-80° to the south) and often directly continue these veins beyond the bounds of dikes (see figure 38). The north zone of such veins is about 2 km wide and is hosted by serpentinite and gabbro in the northern part of ore field. The southern zone, about 1 km wide, is located in the central part of the Beriozovsk ore field.

Two types of gold-sulfide-quartz veins define two types of ore bodies: selectively mined krasichnye veins and stockworklike ladder veins in the dikes. The saturation of the dikes with gold-bearing veins and intensive quartz-sericite-carbonate alteration, also containing gold, makes possible bulk mining of the entire dike body, despite the sharp decrease in average gold grades. The average grade for this type of vein system is just 1.8 g/t, compared with 15-17 g/t to hundreds of grams per tonne for the ladder veins itself. The gold distribution in ladder veins is uneven, depending on the amount and distribution of sulfides. The highest gold grades are mainly in the central parts of the veins and close to the hanging walls of the dikes (Smirnov 1977).

The ladder veins were mined separately up until the late 1940s, but improvement of processing techniques allowed bulk mining of the dikes. Crushed stone generated as a by-product of ore processing was sold as a building material. This byproduct covered about half the operating cost and made it possible for profitably mining the Beriozovsk deposit with the lowest average gold grade in the CIS. The thickness of the dike ore bodies varies from 2-3 to 7-10 m, sometimes up to 20 m, with a length of up to 1.5-3.0 km. The krasichnye veins have 10-17 g/t or even higher gold grades but are already mined out.

According to L. Mikhailova (Smirnov 1977), the mineral composition of krasichnye and ladder veins is practically the same. The main gangue mineral is coarse-grained, druselike quartz with secondary amounts of ankerite, calcite, dolomite, and sometimes muscovite and K-feldspar. The ore minerals account for 2-10% and rarely up to 20% of the vein volume, filling up druse cavities and fractures in quartz. The main ore minerals are pyrite, gray copper ore, galena, aikinite, chalcopyrite, and scheelite. The veins contain also native gold and bismuth, pyrrhotite, sphalerite, gersdorffite, bismuthinite, molybdenite, violarite, tetradymite, cosalite, cassiterite, magnetite, bournonite, and millerite. Three successive mineral associations are (1) the low in gold quartz-pyrite association, (2) the productive tetrahedrite-galena-aikinite association, and (3) the post-ore carbonate association. Oxide ore is developed to a depth of 150-200 m.

Many minerals such as aikinite ($CuPbBiS_3$), crocoite ($PbCrO_4$), pyrophyllite [$Al_2Si_4O_{10}(OH)_2$], phenicophroite $Pb_2(CrO_4)O$, and embreyite

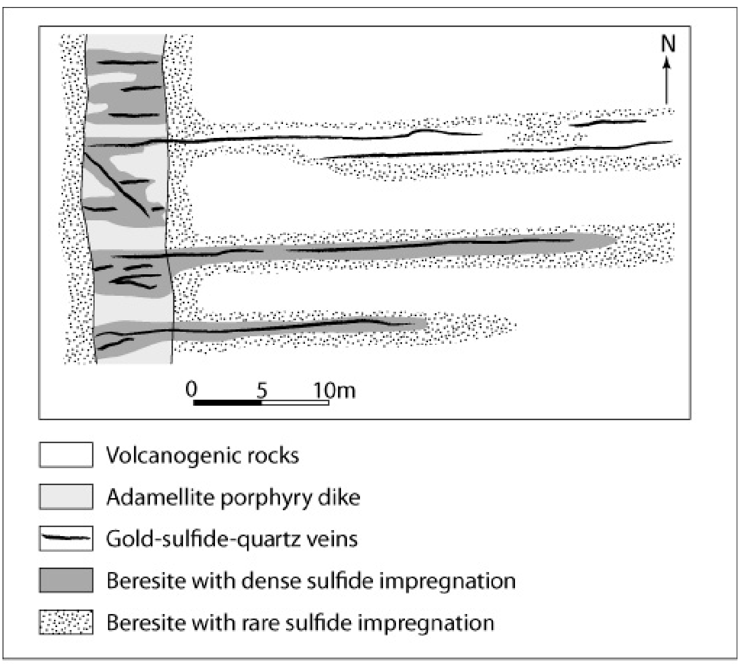


Figure 38. Beriozovsk deposit. Relation between ladder and krasichnye veins (after Konstantinov and Narseev 1989).

$Pb_2(CrO_4)_2(PO_4)_2?H_2O$ were first discovered and described here in the eighteenth through the twentieth centuries (S. Sustavov, *igg.uran. ru/minural_serg*, 2003).

Early dustlike gold particles, mainly in pyrite, are less than 10 μm in size and have 863-984 fineness (Vikentiev and Vikentieva 2000). Later and larger gold II particles, 0.05-0.5 to 1-2 mm in size, were found within druselike caverns and have 729-904 fineness. The gold and silver grades in the pyrite and galena are as follows: for pyrite—0.18-73.5 ppm Au and <0.2-92 ppm Ag; and for galena—0.15-2.96 ppm Au and 0.1-2.51 ppm Ag.

A study of the fluid inclusions and isotopic composition of the ore bodies and host-rock minerals of the Beriozovsk deposit (Bortnikov et al. 1998) showed that the sulfur and carbon are derived mainly from the magma chamber of the Shartash granitoid pluton, with a secondary contribution from the host rocks. The ore and near-vein listwanite-beresite alteration was formed from a two-phase fluid consisting of liquid (H_2O+CO_2) and gas (CO_2) phases. Full homogenization of inclusions occurs at 280-295°C. The solution salinity varied from 7.6 to 18.2 wt. % NaCl equivalent, and the fluid pressure calculated from the isotherm and isochore intersection was 0.9-2.5 kbar.

The vertical zoning of the Beriozovsk deposit is not well developed since the mineral composition of the ore and the ore gold grades remain basically similar to a depth of at least 1,200 m, the deepest interval at which ore has been intersected by drill holes.

The lateral zoning is more distinct and is characterized by smaller amounts of sulfides on the flanks of the ore field, that is, outward from the granitoid pluton, with a simultaneous decrease in gold grade and a change in the same direction in the composition of gray copper ore from high arsenic type near the center of the ore field to high antimony on the flanks.

The age of gold mineralization of the Beriozovsk deposit has not received any special study; however, its close association with the dikes of the Shartash adamellite pluton may indicate the formation of intrusive-related mineralization in the same time span, viz., 310-320 Ma. A study of the gold geochemistry of various rocks of the Shartash pluton showed (Ershova and Levitan 1979) that the gold grade gradually increased from 2.45 ppb in the coarse-grained adamellite of the first stage to 4.0 ppb in the medium-grained adamellite of the second stage and to 4.45 ppb in dikes of adamellite-porphyry I. The accumulation of gold during the emplacement of the pluton is a clear indication that this magmatic system has the potential for gold. The distinctive lateral mineralogical/geochemical zoning outward from the granitoid pluton also supports its close relationship to ore mineralization. Other gold-sulfide-quartz deposits (Kochkar, Dzhetygara, etc.) at the east slope of the Urals are also related to the same early orogenic adamellite—potassium-low granite intrusives of the Early Carboniferous series.

After more than 260 years of production, the Beriozovsk deposit still has significant gold reserves of approximately 5 Moz (150 t) and a total resource base of about 350 t.

The large gold resources make the Beriozovsk deposit a unique example of a deposit type with ladder veins within dikes. A few small, no more than a few tens of tonnes of gold, gold deposits of this type are known in the South Urals (Vasin-Tsezar), Kyrgyzstan (Sultan Sary), and in other CIS gold provinces. Control of gold-bearing veins by local fracture systems in dikes or competent layers of volcanogenic-sedimentary rocks have also been described in other parts of the world, but none of those deposits has gold resources as large as Beriozovsk does.

The Charmitan Gold Deposit (40°20’N-66°44’E)

The Charmitan (in some descriptions “Zarmitan”) gold deposit is located approximately 80 km northwest of the city of Samarkand, the regional center of southern Uzbekistan. It was discovered in 1966 and explored up until 1976.

The deposit is situated (Bortnikov et al. 1996; Paramonov and Akhmedov 2001; Abzalov 2007) in the western part of the South Tien Shan accretion fold-and-fault belt southeast of the Muruntau, Daugyz, and Kokpatas deposits. The Charmitan deposit is confined to the southeast endo- and exocontact of the Late Paleozoic Koshrabad granitoid pluton, which intruded the south limb of the north Nuratau anticlinorium at its intersection with the regional Zirabulak-Koshrabad fault. According to the Rb-Sr isochron method, the age of the intrusive is 306 ± 4 Ma, while the K-Ar age of the granitoids is 269 ± 4.2 Ma, suggesting a Late Carboniferous-Early Permian age (Bortnikov et al. 1996).

The pluton intrudes the Early Silurian Dzhazbulak suite of quartz-micaceous and carbonaceous-micaceous shales, siltstones, and sandstones with lenses of limestone, tuff sandstone and siltstone and rare sill-like bodies of diabase porphyry and gabbro diabase. The sediments are deformed into west-northwest isoclinal folds overturned to the southwest and dipping 60-80° to the north. The Early and Late Hercynian regional metamorphism of phyllite and amphibolite facies affected the sedimentary host rocks, which have also undergone contact metamorphism from the granitoid intrusive. Biotite-feldspar hornfels, marble, and skarn alteration are typical of the pluton's exocontact, while mottled and porphyroblastic andalusite-bearing shales is developed up to 2 km from the contact.

The Koshrabad granitoid pluton is located in the western part of the Charmitan ore field. The four phases of the intrusion are (Gureikin et al. 1979): (1) gabbro syenite, monzonite, and melanocratic syenite-diorite; (2) amphibole syenite; (3) quartz-bearing syenite and granodiorite; and (4) biotite granite. The southeast contact of the intrusive dips about 30° to the east. The dikes related to the Koshrabad pluton include (1) early monzonite, syenite, and syenite diorite porphyry; (2) mesocratic syenite, quartz syenite, and syenite porphyry; and (3) granite, aplite, and granite porphyry.

The Karaulkhana-Charmitan shear zone, several hundred meters wide along the southern contact of the Koshrabad pluton, plays a major role in the localization of gold-bearing quartz veins in the intrusive and sedimentary rocks. This high-angle shear zone is a splay of the northern Nuratau suture fault, which is a part of the south Tien Shan suture (Abzalov 2007). The west-northwest fractures of this fault can be traced for more than 25 km and are subconcordant to the general plan of fold dislocations in the region (Fig. 39). Steeply dipping faults with northeastern and east-northeastern strike, also containing some ore bodies, displace west-northwest structures up to 200-800 m.

About 50 gold-bearing veins, linear stockworks, and slablike ore bodies form four spatially proximal systems. Veins that dip steeply (70-80°) to the northeast are predominant, with average lengths of about 1,200 m and widths of 1-3 m. The veins are parallel to each other or form an echelon structure and often branch out and rejoin. The ore bodies inside the veins are 20 to 450 m long and 0.56-3.7 m wide, and some of them can be traced to a depth of 1,050 m.

The veins and vein zones in the intrusive (mainly granosyenite) are more stable along the strike and often are replaced at depth by systems of linear stockworks up to tens of meters wide. Inside the intensely deformed volcanogenic sedimentary rocks in the eastern part of the Charmitan deposit, the stockworklike ore bodies have a more complex geometry due to the combination of steeply dipping lenticular large veins accompanied by irregular networks of veinlets in cleavage fractures. These ore bodies are concentrated often at the flexurelike bends of a mineralized zone.

The hydrothermal alteration of the host rocks along the ore bodies consists mostly of feldspar-quartz envelopes up to 1-2 m wide with carbonate, sericite, and pyrite mineralization in their outer parts. It is most clearly at selvages of quartz veins in granitoids. Argillic alteration of hydromica and kaolinite, which overprinted earlier feldspar-quartz assemblage, sporadically accompanied veins with abundant sphalerite-galena mineralization on the flanks of the deposit.

Quartz, albite, carbonate, and chlorite are major gangue minerals in the veins of the deposit. Sulfide mineralization constitutes 0.5-15 vol. % of vein and stockwork ore bodies. Low-sulfide content is typical of the veins in the endocontact zone of the intrusive, while moderate amounts of sulfides occur in the sedimentary host rocks at the southeastern exocontact of the pluton. Pyrite, arsenopyrite, scheelite, sulfosalts, and native gold with a sharp prevalence of pyrite and arsenopyrite are the main ore minerals.

The five stages of mineralization identified at the Charmitan deposit (Bortnikov et al. 1996; Abzalov 2007) are (1) quartz-scheelite-feldspar, (2) quartz-gold-telluride, (3) quartz-pyrite-arsenopyrite, (4) quartz-sphalerite-sulfoantimonite, and (5) quartz-carbonate-stibnite.

The early quartz-scheelite-feldspar mineral association forms bands 2-3 cm wide in the selvages of the veins. It contains coarse-grained quartz-scheelite-feldspar aggregates cemented by quartz-pyrite-arsenopyrite aggregates. The gold has a microcrystalline texture and contains up to 0.1-0.3% mercury and bismuth. This association is typical mostly of the lower parts of the ore bodies.

The quartz-gold-telluride association of the second stage is common in the ore bodies and is cut by numerous pyrite-arsenopyrite and quartz-sulfide veinlets. This association contains native gold, aurostibite, maldonite, pyrrhotite, and tellurides of bismuth impregnated into the milky-white

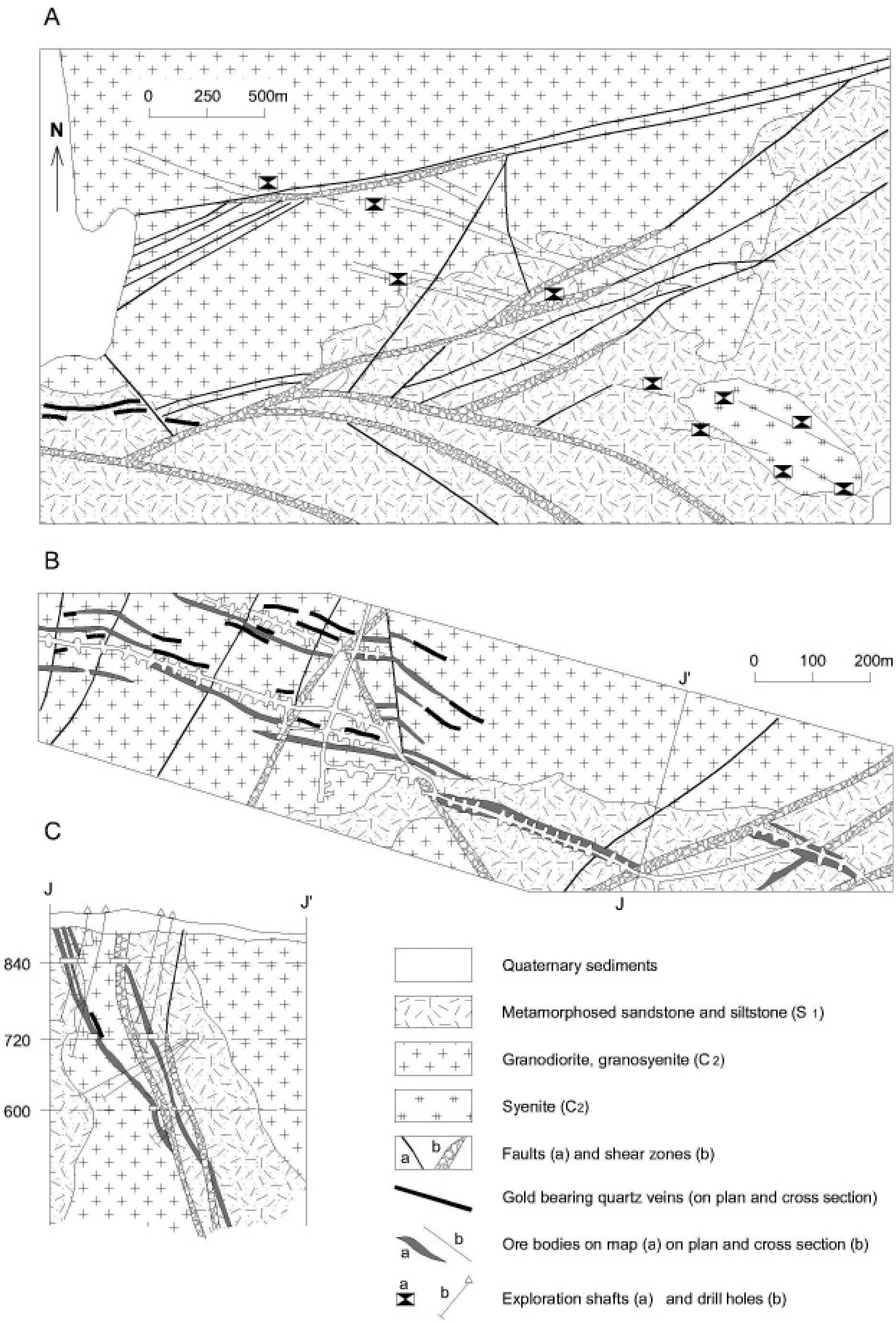


Figure 39. Charmitan deposit: (A) geologic map of the deposit, (B) plan of 840 m horizon, and (C) cross section (after Paramonov and Akhmedov 2001).

quartz. The small (0.0*n*-0.*n* mm) isometric gold particles are associated mostly with pyrrhotite and rimmed by aurostibite and tellurides. High-fineness gold (880-964) contains small amounts of mercury (0.63-0.94 wt. %), bismuth (0.28-0.96 wt. %), selenium (up to 2 wt. %), and tellurium (0.1-0.28 wt. %). The aurostibite contains up to 9 wt. % bismuth and small amounts of silver, selenium, and tellurium.

The pyrite-arsenopyrite mineral association of the stage three is widespread and comprises nests and bands up to several centimeters thick along vein contacts and thin veinlets in altered host rocks. The coarse-grained pyrite and arsenopyrite are mainly euhedral and may have formed at the same time. The native gold II has a fineness of 617 to 937 and contains 0.11-0.71 wt. % mercury. The gold fills cracks in the arsenopyrite, but its concentration in the arsenopyrite (1.2-23 ppm) and pyrite (4.4 ppm) of this stage is relatively low.

The quartz-sphalerite-sulfoantimonite (polysulfide by Paramonov) mineralization of stage four is typical of the upper parts of the bonanza ore bodies and consists of sphalerite, galena, tennantite and tetrahedrite, pyrite, arsenopyrite, bismuthinite, tellurides of gold and silver, bismuth sulfosalts, native gold and bismuth, jamesonite, boulangerite, zinckenite, pyrargyrite, and miargyrite. This association contains several paragenetic mineral assemblages. The earliest is the sphalerite-galena assemblage, with quartz, native gold, and tetrahedrite, followed by the pyrite-arsenopyrite assemblage with electrum and the latest assemblage, consisting of various sulfo-antimonites.

The dendritelike, lamellar, and clumpy gold particles are larger than in previous associations (0.0*n*-3.0 mm) and together with sphalerite fill interstices and fractures in the arsenopyrite. The fineness of gold is 850-950 in association with tellurides, 614-718 in association with galena and sphalerite, and 273-552 in association with sulfosalts.

The youngest quartz-stibnite mineral assemblage, sometimes with pyrite, forms thin veinlets that cross quartz-sphalerite aggregates. It is located mainly at the periphery of the deposit outside the ore bodies. In addition to stibnite, it contains pyrargyrite, owyheeite, miargyrite, gudmundite, berthierite, and native antimony impregnated in quartz.

A microthermometric study of fluid inclusions in quartz (Bortnikov et al. 1996) shows the presence of three compositionally different fluids: (1)

an aqueous fluid with CO_2, CH_4, and Na-Mg chlorides; (2) CO_2 with an admixture of CH_4; and (3) aqueous fluid of moderate salinity, containing Na and Mg chlorides.

The sulfur-isotope composition of sulfides varies from +1.2 to +8.0‰ with $\delta^{34}S$ values that are almost identical in sulfides of different stages. The oxygen-isotope values ($\delta^{18}O$) in feldspar, quartz, and calcite vary over the range from +6.9 to 17.9‰, while the carbon-isotope ($\delta^{13}C$) values in calcite range from -3.1 to -18.4‰.

The mineralization of the Charmitan deposit (Bortnikov et al. 1996) occurred in the temperature range 400-150°C at a pressure of 2.7-0.9 kbar, at pH 5 ± 1, from a primary homogenous fluid of low to moderate salinity composed of H_2O and CO_2 with admixtures of CH_4, H_2S, and probably N_2. The ore-bearing fluid was dominantly magmatic but also contained some components mobilized upon dehydration and decarbonatization of the host rocks during regional metamorphism.

The central part of the deposit is characterized (Abzalov 2007) by higher gold grades and Au/Ag ratios, which are typical for the areas of abundant hydraulic breccias. The higher silver grade, lower Au/Ag ratios, and abundance of pyrite and arsenopyrite are typical for the eastern part of the deposit. It has been noted (Gureikin et al. 1979) that the arsenopyrite in the sediment-hosted ore bodies in this part of the deposit does not contain gold.

According to E. Bertman (in Paramonov and Akhmedov 2001), the vertical mineralogical and geochemical zoning (from bottom to top) is as follows: molybdenite—wolframite-gold paragenesis (Mo-W-Bi-Au1-Ag1) → pyrite-arsenopyrite paragenesis (Co-As-Ag2-Au2) → polysulfide paragenesis (Zn-Pb-Ag3-Au3) → stibnite paragenesis (As-Sb).

The resources of the Charmitan deposit, according to Uzbek data, are 24.2 million tonnes of ore, including 11,344,000 tonnes of measured resources (C_1) grading 10.9 g/t gold (123.4 t or 3.98 Moz) and 9.4 g/t silver (106.6 t). The indicated resources (C_2) of the deposit are 12,863,000 tonnes grading 9.4 g/t gold (120.9 t, or 3.9 Moz) and 12.1 g/t silver (155.6 t).

The wide distribution of intrusive-related gold-sulfide (arsenic)-quartz deposits in the CIS is determined mainly by the geotectonic characteristics of its territory, with many femic-type Phanerozoic metallogenic provinces that contain gold-productive granitoids. Similar intrusive-related deposits in other Phanerozoic gold provinces of the world, such as southern Appalachians and Nova Scotia in North America, the Massif Central in France, Queensland and New South Wales in Australia, and some Chinese provinces, by and large are smaller. One exception is ladder-type vein deposits in dikes such as the Morning Star deposit of the Woods Point ore field in Victoria Province of Australia, with an output of more than 98 t of gold. Another example of a large ladder-type vein deposit is the Alaska-Treadwell deposit (Juneau ore field) in the Canadian Cordillera, which produced about 180 t of gold from the end of nineteenth century through the middle of the twentieth century.

Selective underground mining of gold-sulfide (arsenic)-quartz veins and usually high grade of arsenic in the ore make this type of gold deposits marginally interesting. It is doubtful whether it will be feasible to undertake the development of a new underground mine for such a vein deposit, even with an average gold grade of about 10-15 g/t.

4.2.3 Lenses and Irregular Bodies in Skarn along Intrusive Contacts with Carbonate or Volcanic-Sedimentary Formations

4.2.3.1 Gold-Aluminosilicate (Skarn) Deposits

Gold skarn deposits have a close spatial and temporal relation with granitoid plutons. These deposits because of the relatively small resources (35-60 t of gold) do not currently have a significant role in CIS total gold output. However, high gold grades and the existence of large gold-skarn deposits such as the Phoenix-Fortitude in Nevada (186 t or 6Moz) or the Nickel Plate mine in British Columbia with smaller but higher-grade resources, make this type of intrusive-related gold deposits interesting for future exploration in the CIS.

The best-known gold skarn deposits of the CIS including Sinyukhinskoye, Natal’yevskoye, Lebedskoye, Kaliostrovskoye, and Tardanskoye are situated in the Altai-Sayany province of western Siberia (Russia). Most of these deposits except for Sinyukhinskoye are almost completely mined out. Another region containing gold skarn deposits is Central Asia (the Makmal, Kuru-Tegerek, Bozimchak, Kumbel, and

Akdzhilga deposits in Kyrgyzstan and the Taror, Mosrif, and Jilau deposits in Tajikistan). These deposits are located in orogenic belts of different ages and types (Caledonian in the Altai-Sayany and Hercinian in the Central Tien Shan mountains) but are associate with similar, relatively high alkalinity, late island-arc intrusives of the potassium-sodium gabbro-diorite-granodiorite series.

In all provinces, the productive granitoid intrusions form relatively small stocks with a complex configuration of the contacts with numerous apophyses and satellitic bodies. Many of the intrusives host other types of gold mineralization including gold-porphyry at the Jilau stockwork (Tajikistan) or gold-sulfide-quartz vein occurrences at the Kommunar ore field (Russia).

Ore fields with gold skarn mineralization are located often at the intersections of major faults, but the major factor of ore control is a structure of favorable carbonate and tuffogenic host rocks.

Skarn ore bodies are common (Vakhrushev 1972) at the hanging walls of productive intrusives at points of their sharply discordant contacts with the host rocks or at some distance from intrusives, in zones of bedding breccias. The presence of favorable carbonate or tuff horizons with tectonic fractures function as ore-distribution and ore-controlling structures, and their combination is often necessary to produce viable deposits (Levitan et al. 1984). The ore bodies are either veins, lenses, and irregular nests or tabular, stratiform bodies that are relatively small in comparison with the host replacement skarn mineralization.

According to D. Timofeevsky (in Narseev 1991), gold skarn mineralization is typically the result of the subsequent superposition of three different stages: the pneumatolytic-hydrothermal stage (skarn proper), the hydrothermal stage with gold-bearing mineralization, and the final supergene stage, which forms gold-enriched oxide zones.

Four major mineral and geochemical types of gold-skarn deposits are found in the CIS. The first geochemical type is the iron-cobalt-arsenic with pyrite, arsenopyrite, loellingite, and/or danaite. It is found mainly in Central Asia and is represented by such deposits as Taror and Mosrif (Tajikistan) and Akdzhilga (Kyrgyzstan), which are hosted by sedimentary-carbonate sequences of the Hercynian South Tien Shan accretionary suture. The second, iron-copper with chalcopyrite, type is represented by the Natal'yevskoye deposit of Kuznetsky Alatau (West Siberia, Russia). However, chalcopyrite-rich type also forms more complex varieties of iron-copper gold-skarn deposits such as chalcocite-chalcopyrite-bornite (the Sinyukhinskoye deposit, Gornyi Altai) or pyrite-chalcopyrite-bornite (Lebedskoye, Kuznetsky Alatau, or Tardan deposit, Tuva). All these deposits occur in the Caledonian Altai-Sayany island-arc zones. Less economic and rare is the third, copper-tungsten-gold type with pyrite, chalcopyrite, and scheelite. The fourth and quite exotic geochemical type is the iron-platinum-copper with chalcopyrite, pyrrhotite, troilite, and the platinum group of metals. This type is found only in the Chatkal region of the Central Tien Shan (the Kuru-Tegerek deposit, Kyrgyzstan) and contains high concentrations of gold, platinum, palladium, molybdenum, rhenium, and mercury.

Iron-skarn deposits usually contain economical quantities of gold only in the case of overprinting of the iron mineralization by later gold-sulfide-quartz assemblage as is in the Kaliostrovskoye and Kommunar deposits in the Kuznetsky Alatau, Russia.

The gold of skarn deposits is introduced during the late hydrothermal stage and is accompanied by altaite, tetradymite, tellurobismuthite, melonite, electrum, and native silver and bismuth. The gold commonly forms micron-sized inclusions in sulfides or at their boundaries or is found as rare grains up to a few millimeters in size. Its fineness ranges from 950 in early mineral associations to 470-525 in later ones but is predominantly 800-900. The gold grades of the CIS skarn deposits typically vary between 2 and 15 g/t (average 5-8 g/t) with the gold-to-silver ratio around 1 or lower. This is compatible with worldwide data (Meinert 1989; Theodore 1991).

The Natal'yevskoye Deposit (55°50'N-87°15'E)

The Natal'evskoe gold-skarn deposit was discovered in the mid-1950s in the northern part of the Kuznetsky Alatau (Kemerovo region of Western Siberia, Russia), a region known as Mariinsk Taiga and famous for its placer gold. The following description is based mainly on the published works of B. Vasil'ev (1970 and others).

The Natal'yevskoye deposit lies in the Kiisk uplift or rigid massif. This is a Caledonian age island-arc effusive and granitoid province within the Altai-Sayany region. Its basement consists of Early Proterozoic gneiss-schists overlain by a Late Precambrian subplatform cover of algal limestone and arkosic sandstone, which outcrop only in the northwestern part of the ore field. The Early Cambrian intercalation of marble, basalt-andesite porphyry, and tuff with carbonate-chert shales and limestone has a total thickness of about 1.5 km and forms tight, northeasterly-trending folds. The Precambrian and Early Cambrian sequences are unconformably overlain by Middle Cambrian diabase and labradorite porphyry volcanics, which are deformed into open, northeasterly-trending folds.

The volcano-sedimentary sequences have been intruded by Late Cambrian, gold-bearing diorite-monzonite stocks and by a Devonian gabbro-syenite. The east-west trending dikelike olivine gabbro-norite and gabbro-diabase body of this series intersects a Late Cambrian diorite-monzonite stock (Fig. 40) and contains quartz lenses with gold-bismuth mineralization. The post-ore diabase porphyry dikes are the youngest intrusives in the ore field.

The main role in the structure of the Natal'yevskoye ore field belongs to the granitoid stocks, and, accordingly, the ore field contains two gold-bearing areas—the southern and the northern, which are confined to such stocks.

An elongated (1.3 x 0.25 km) composite stock of quartz diorite, monzonite, and gabbro in the South area intrudes into the eastern limb of the anticline. It has uneven, mostly steep contacts marked by a series of *en-echelon* "embayments" in plan. The contacts are complicated by intrusive apophyses partially parallel to the bedding of an intruded marble. The northern area is distinguished by a smaller (200 x 70 m) stock of quartz diorite-monzonite composition, which intrudes Middle Cambrian andesite porphyry within marble and is itself cut by Devonian gabbro-norite.

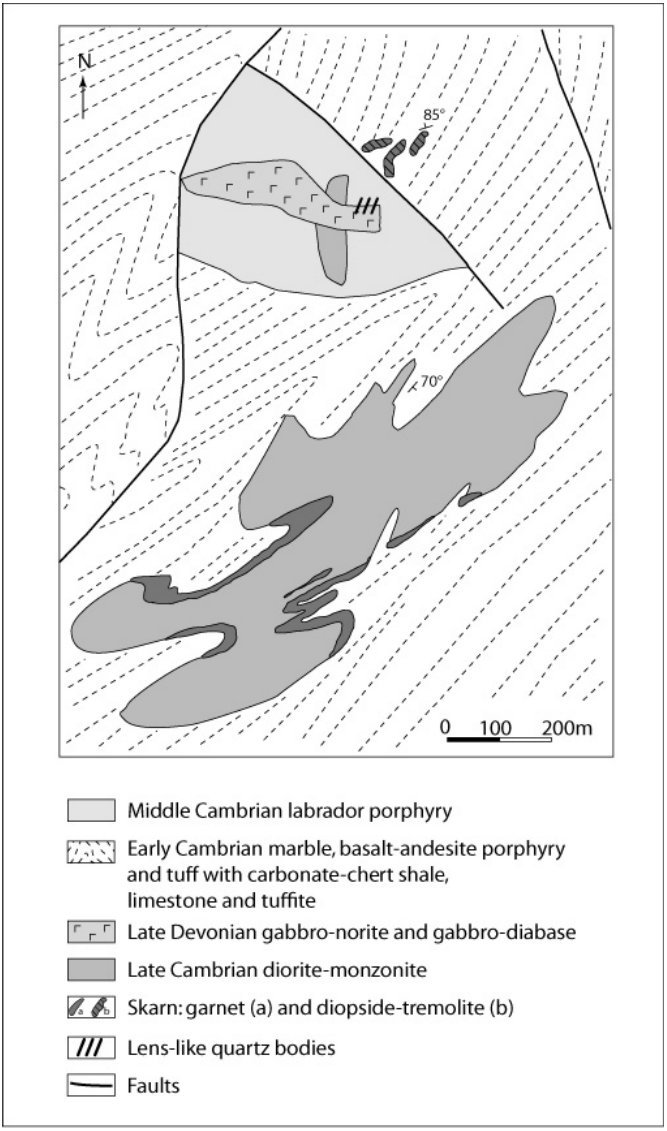


Figure 40. Schematic geologic map of the Natal'yevskoye deposit (after Vasil'yev 1970).

Garnet and garnet-diopside endo- and exoskarn in the southern area are confined to the stock's contact with the marble and to steeply dipping fractures in the stock itself, which are also parallel to its contact with marble (see figure 40). The outer zone of exoskarn consists of marble with grossularite impregnation but is transformed into massive grossularite-andradite-diopside skarn close to the intrusive and to a diopside-enriched endoskarn.

The diopside-tremolite and garnet skarn of the northern area is situated north of the diorite-monzonite stock in carbonate host rocks and north of a fault that divides the carbonate rocks from the andesite porphyry. Garnet skarn is developed exclusively in andesite porphyry. The skarn bodies are controlled by fractures, which cut bedding at a small angle.

In the northern area, the ore bodies 1.5-8 m wide and 30-40 m long contain gold throughout the entire volume of skarn alteration. An envelope of sulfide impregnation often forms around the skarn bodies. The skarn bodies in the southern area are 2-4 m thick, but they can be traced for 300-450 m in strike and dip. Gold mineralization of the southern area forms irregular nestlike and columnar ore bodies in garnet-diopside endoskarn associated with retrograde actinolite, calcite, and quartz.

The main ore minerals of both zones are gold and chalcopyrite. Impregnations of pyrite, molybdenite, bornite, pyrrhotite, arsenopyrite, bismuthinite, cobaltite, hematite, and magnetite are rare. The gold of 900-950 fineness forms grains of lamellar, threadlike, and spongiform particles or crystals along the cleavage planes of calcite or at the border of calcite intergrown with actinolite and garnet. The gold grades are 8-11 g/t.

The mineralogical zoning of the Natal'yevskoye deposit (Korobeinikov 1983) is defined by the presence of an inner garnet-gold-wittichenite-molybdenite-bornite-chalcopyrite zone, an intermediate epidote-actinolite gold-bismuthinite-chalcopyrite-pyrrhotite zone, and an outer quartz-calcite-chlorite-gold-gersdorffite-arsenopyrite-cobaltite zone.

According to Korobeinikov, the hydrocarbonate-chloride-alkaline-calcareous ore fluid was deposited at temperatures of 420 to 240°C.

The gold resources of the Natal'yevskoye deposit, which is mined out, by rough estimate did not exceed 1 Moz and have no further potential.

The Sinyukhinskoye Ore Field (51°92'N-86°68'E)

The Sinyukhinskoye ore field lies in the northeastern part of the Altai Mountains (the "Gornyi Altai," Russia), some 200 km southeast of the town of Gornoaltaisk. The region belongs to the Altai-Sayany gold province of the Western Siberia and is south of the Kuznetsky Alatau region. Gold-skarn mineralization was discovered in 1950 (Vakhrushev 1972), and the Veselyi mine started gold production from the Sinyukhinskoye deposit in the late 1950s by open-pit and underground workings. The underground workings now reach 550 m below the surface.

The Gornyi Altai fold-and-fault belt consists of a series of Paleozoic accretion terrains including a Cambrian-Ordovician island-arc assemblage of basalt-andesite-dacite-rhyolite volcanics, which is intercalated with limestone and sedimentary sequences. These are intruded by stocks comagmatic to volcanics. The terrains were consolidated during the Caledonian (O-S) orogeny and were intruded by the Late Paleozoic granitoid intrusions.

The Sinyukhinskoye ore field is hosted by Early Cambrian diabase, labradorite basalt, andesite, and rhyolite porphyry, and of tuffs intercalated with massive and thin interlayers of limestone and marble (Fig. 41) along the contact of an Ordovician-Early Silurian (445-427 Ma) granitoid pluton intruding. Cambrian-Ordovician flyschlike sediments are widespread to the southwest of the ore field, while red-colored continental Devonian volcanics and sediments occur extensively to the south.

The folded sedimentary and volcanic formations are cut by numerous steeply dipping faults. Early Cambrian quartz porphyry and tuff in the mine area are intercalated with massive limestone beds and are overlain by porphyry basalt with thin limestone lenses, which in turn are overlain by Middle Cambrian porphyrite, tuff, and clastic sediments.

The emplacement of the multiphase Sarakokshinskii granitoid pluton began with hybrid gabbroid and diorite, which are products of the incomplete contamination of the older basic intrusive by the intrusion of biotite and biotite-amphibole granodiorite and granite (Scherbakov 1974). Dikes of diorite porphyry, microdiorite, aplite, and lamprophyre are associated with this phase. This potassium-low granite (plagiogranite) and granodiorite of the second phase has a radiometric age of 360-300 Ma and is accompanied by granite and quartz porphyry dikes. The subalcalic, mostly diorite porphyry dikes, up to 20-40 m wide, occupies more than one-third of the total volume of entire ore field.

The mineralized area is elongated in the east-west direction for about 4 km and is about 2 km wide. It includes eight deposits and several prospects (see figure 41). The principal control of mineralization is the intersections of carbonate layers and lenses, favorable to skarn development, by northerly- and northwest-striking faults. The gold-bearing skarn mineralization is hosted by the quartz porphyry and tuff sequence that contains lenses of massive limestone and is overlain by basalt porphyry with lenses of limestone. However, the skarn ore bodies are typically confined to the limestone lenses and basalt with phenocrysts of labradorite.

Discussions of the Sinyukhinskoye deposit geology by Scherbakov (1974) and Ettlinger and Meinert (1990) differ in their descriptions of skarn mineralization. Scherbakov described large skarn lodes confined principally to the footwall of the carbonate horizon and isolated skarn nests in the middle part of the horizon. The skarn within carbonate horizon consists of wollastonite with secondary amounts of diopside-hedenbergite, grossularite-andradite, magnetite, and actinolite. Near the contact of the carbonate with the andesite-basalt, the skarn is mostly of garnet-pyroxene composition, and all the magnetite bodies are confined to this horizon. The wollastonite at the contact has a secondary role, but its amount increases outward from the effusive, and the outer skarn zone in the limestone consists mostly of wollastonite. In addition, skarn zones, a few centimeters wide, are located along contacts of diorite porphyry dikes with the limestone and consist primarily of epidote in endoskarn and garnet in exoskarn. According to Scherbakov, the epidote deposition in the dikes and their intensive discoloration is a retrograde alteration. Diabase, andesite-basalt effusive, and their tuff under large skarn lodes have similar zones of alteration, up to a few meters wide. All types of skarn here contain minor amounts of retrograde tremolite, prehnite, vesuvianite, epidote, zoisite, quartz, and chlorite.

In contrast, A. Ettlinger and L. Meinert described the main skarn bodies along the margins of diorite porphyry dikes, as endoskarn within the dikes and adjacent basaltic flows, while exoskarn is found in the host carbonate and volcaniclastic rocks. The endoskarn is zoned inward from the dike margin: (1) garnet-pyroxene (garnet being predominant), (2) pyroxene-garnet, and (3) pyroxene.

The altered groundmass of the dikes and basalt contains minor amounts of fine-grained albite, potassium feldspar, scapolite, and clay. These assemblages have locally been affected by retrograde alteration resulting

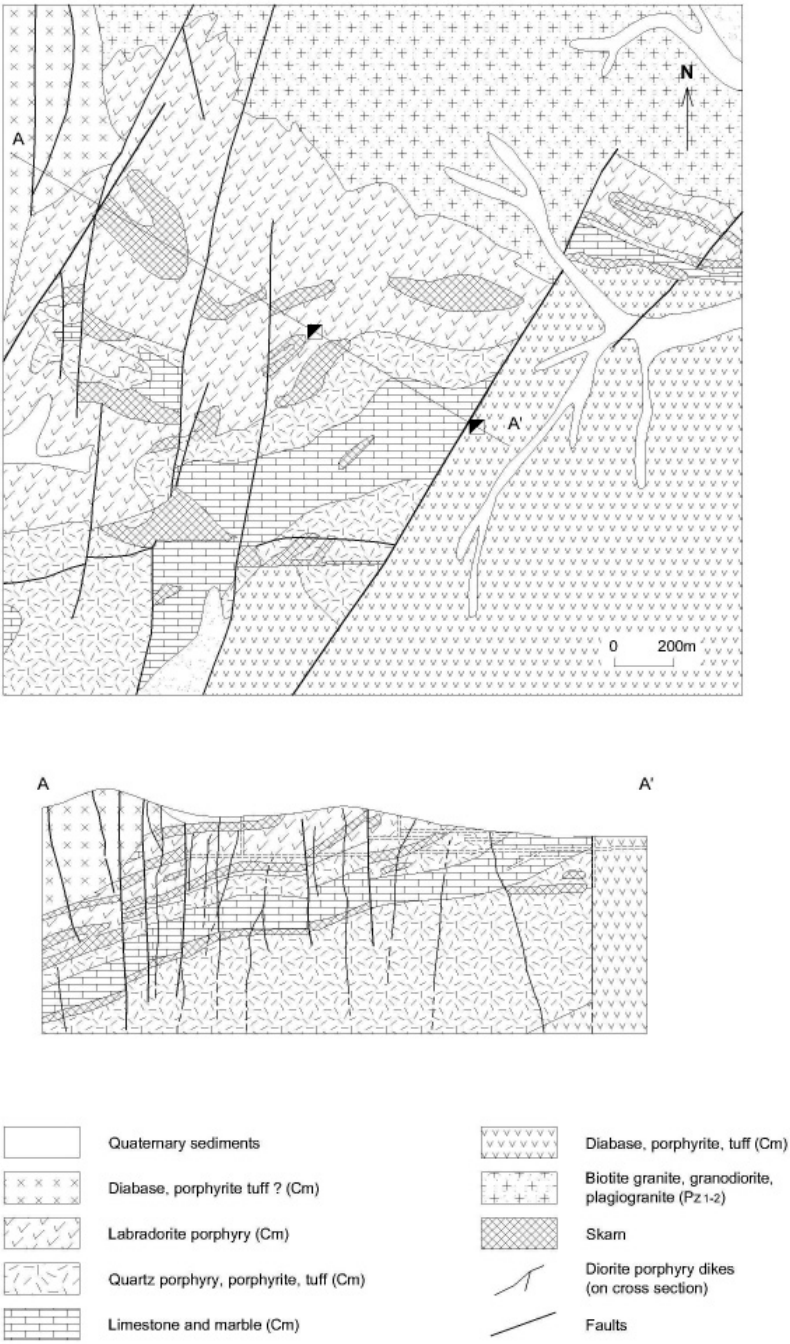


Figure 41. Geologic map and cross section of the Sinyukhinskoye deposit (after Ettlinger and Meinert 1991).

in replacement of the calcite-quartz-chlorite-amphibole association by pyroxene and in the garnet by the calcite-quartz-epidote-orthoclase assemblage.

The composition of the exoskarn depends mainly on the parent rocks: the clastic units are replaced by fine-grained pyroxene hornfels intersected by garnet and pyroxene veins, while calcareous units are replaced by coarse-grained garnet with less pyroxene, and locally abundant wollastonite with prehnite, apatite, quartz, and epidote along the skarn-marble contact. The exoskarn's retrograde alteration consists of quartz and calcite with minor orthoclase, epidote, and actinolite. The wollastonite in the exoskarn appears at a relatively late phase and locally replaces early garnet-pyroxene skarn or forms veins. The pyroxene in both varieties of skarn is iron-poor diopside, while the grossular-andradite garnet is iron-rich, especially in skarn with gold-sulfide mineralization.

The main differences between these descriptions are the role of diorite porphyry dikes in skarn formation and distribution, minor according to Scherbakov (1974) or major according to Ettlinger and Meinert (1990). Another discrepancy is the amount of wollastonite, which according to Scherbakov is predominant over garnet-pyroxene, but which has a lesser role according to Ettlinger and Meinert. Different levels of surface and underground workings accessible for mentioned studies explain these differences: the underground workings were much deeper in the late 1980s than in the late 1960s during Scherbakov's study.

The skarn forms large lodes, 20-60 m thick and up to a few hundred meters down dip, which intersect fold structures and are predominantly near contacts of carbonate rocks with basalt-andesite effusives or diorite porphyry dikes. Disseminated and stockworklike gold ore bodies form irregularly shaped nests, single beds, or chains thereof in the skarn with ore shoots elongated down dip. These shoots are at the intersections of fracturing conformable with the bedding by subsequent, northwest-striking fractures (see figure 41). According to Scherbakov, the gold grades in the ore bodies vary from a few grams to tens and hundreds of grams per tonne. Table 6, which is based on sporadic sampling by Ettlinger and Meinert, gives a more detailed idea of the grades of gold, silver, copper, and other metals in the skarn of the deposit.

TABLE 6
Distribution of Gold, Silver, and Other Metals in Skarn of the Veselyi Mine Working the Sinyukhinskoye Deposit (Simplified After Ettlinger and Meinert 1990)

Element/ Sample No.	Skarn Description	Au (ppb)	Ag (ppm)	Pt (ppb)	Cu (%)	Te (ppm)	As (ppm)
Ga-2	Garnet + epidote endoskarn replacing basalt	50	0.5	50	0.0086	<0.2	106
Ga-5a	Skarn in marble with chalcocite and bornite	3,770	46.1	20	3.37	55.0	56
Ga-5b	Similar to 5a with quartz-calcite-sulfide retrograde alteration	35,897	100.5	<15	10.99	>100	21
Ga-5c	Wollastonite-garnet skarn with chalcocite and bornite	5,390	35.1	25	3.27	95.0	11
Ga-8	Endoskarn in diorite porphyry with bornite and chalcopyrite	860	18.0	15	3.50	5.0	<5
Ga-11	Massive garnet-calcite skarn with epidote, wollastonite, and bornite	2,290	26.2	30	2.16	13.0	54

The ore is formed by veinlets and impregnations of quartz and sulfides (≤ 5-10%) with free gold. Sulfide impregnations sometimes penetrate beyond the skarn bodies into marble, diorite porphyry dikes, effusives, and tuffs. The main ore minerals are bornite, chalcocite, chalcopyrite, magnetite, pyrite, and arsenopyrite that confirm the chalcocite-chalcopyrite mineralogical type of the Sinyukhinskoye deposit. Cubanite, wittichenite, valleriite, tetradymite, altaite, bismuthinite, galena, sphalerite, pyrrhotite, calaverite, melonite, and gold are present in lesser amounts. According to Scherbakov, chalcopyrite, pyrrhotite, pyrite, arsenopyrite, cubanite, and hydrothermal magnetite are prevalent in pyroxenite-magnetite skarn, diabase, and diorite porphyry. The wollastonite skarn in limestone contains mainly bornite, chalcocite, wittichenite, and tellurides. Other ore minerals and gold are present in both skarn types.

The earliest emulsion type of dispersed gold particles (0.01-0.03 mm) is found in bornite, chalcocite, and chalcopyrite. Younger and larger (up to 1 cm) gold particles form lumpy grains in the sulfide fractures. Grains of native gold often occur with almost no sulfides in recrystallized wollastonite and pectolite as wirelike and elongated leaflike particles along facets of radial aggregates. Sometimes gold leaves are located at the tips of wollastonite crystals in drusy openings.

A study by Ettlinger and Meinert of fluid inclusions from skarn minerals of the Sinyukhinskoye deposit showed the evolution of this skarn system to be similar to that of most such systems from early anhydrous calc-silicate minerals formed from saline fluids at relatively high temperature to later hydrous silicate minerals formed at lower temperature from relatively dilute fluids, followed by retrograde assemblage. Most primary fluid inclusions in garnet and pyroxene from the deposit are two-phase and homogenize to a liquid between 300 and 500°C. About 10% of these inclusions contain one or more of daughter minerals such as halite, sylvite, chalcopyrite, and a few unidentified phases. Primary fluid inclusions in wollastonite and epidote are also two-phase but homogenize to a liquid at 140-210°C. Such temperature interval is almost similar to the secondary fluid inclusions in garnet and pyroxene that are homogenized to a liquid at 170-230°C and do not contain daughter minerals.

A previous study of fluid inclusions in skarn minerals outside of hydrothermal alteration (Scherbakov 1974) documented much higher temperatures of homogenization to a liquid between 600 and 880°C; but in the process of wollastonite and garnet recrystallization, as well as in quartz of the gold-sulfide stage, these temperatures vary, according to Scherbakov, between 115 and 380°C.

According to Ettlinger and Meinert, the salinity of two-phase inclusions in garnet and pyroxene varies from 18.2 to 20.6 wt. % NaCl equivalent, while in wollastonite it ranges from 4.1 to 4.9 and in epidote from 0.5 to 2.5 wt. % NaCl equivalent, respectively.

Different authors relate the skarn mineralization of the Sinyukhinskoye deposit to the emplacement of the first stage of the Sarokokshinskii granitoid pluton or to the diorite porphyry of its dike series. Scherbakov noted that skarn mineralization affected the diorite porphyry dikes, but the quartz porphyry and plagiogranite dikes of the pluton's second stage do not contain any traces of skarn mineralization, except that xenoliths of skarn contain gold-sulfide-quartz mineralization.

The Sinyukhinskoye deposit is described in published Russian papers as a typical gold-skarn deposit (Scherbakov 1974; Timofeevsky 1972; Narseev 1991; and others) that produces gold-silver-copper concentrate and gold-silver dore bullion because production is valued mainly by gold. Ettlinger and Meinert (1990), comparing its alteration style and mineralogy with well-documented examples of gold and copper skarn deposit, defined the Sinyukhinskoye deposit as a copper-skarn deposit enriched in gold. The garnet-dominant skarn with iron-rich garnet and iron-poor pyroxene are in sharp contrast, according to these authors, with most gold-skarn deposits. The results given in table 8 for assayed samples also support this point of view, except for the market value of the gold yielded by this deposit, which is much higher than that of copper.

The gold resources of the Sinyukhinskoye deposit have not been published in available sources and may be roughly estimated at the level of 50-60 t of gold. The current exploration (Mineral.ru of 01/28/2008) estimates existing resources of the deposit as 37.5 t of gold grading 8.59-35.39 g/t.

The Makmal Deposit (41°11'N-73°59'E)

The Makmal deposit is located in the Akshiryak Range of central Kyrgyzstan, at the joining of the Central and South Tien Shan structures and directly to the east of the regional Talas-Fergana fault, which divides these structures. The nearest village, Kazarman, is 40 km north of the deposit.

The deposit was discovered in 1967, explored by nine adit horizons during the 1970s, and put in production in 1986. It is now almost completely mined out, having produced about 2 Moz of gold.

The Makmal deposit lies in the western part of the Hercynian Naryn section of Central ("Sredinnyi") Tien Shan, which developed on a rigid Precambrian basement. The basement complex outcrops at the Sary-Dzhaz crystalline massif east of the deposit, which consists of an Archean-Early Proterozoic gneiss, amphibolite, and marble. Early Carboniferous (Tournaisian and Visean) shelf carbonate sediments are widely distributed in the deposit area and are intruded by a Middle Carboniferous diorite (326-303 Ma) and by the Permian (290-277 Ma) Chaartash granite pluton. Bodies of diorite crossed by drill holes and underground workings, according to Jenchuraeva et al. (1999, 2001), are related to the subduction of the Turkestan paleooceanic crust under Kyrgyz-Kazakh microcontinent. Diorite intrusion is accompanied by plagioclase porphyry and lamprophyre dikes. The emplacement of the Chaartash pluton is related (Jenchuraeva et al. 1999) to the Late Carboniferous-Permian collision of the Kyrgyz-Kazakh microcontinent with the Tarim continent.

The Makmal deposit is situated at the southwestern contact of the Chaartash granite pluton with Tournaisian and Visean carbonate sediments (Fig. 42) on the south limb of a large westerly-striking anticlinal fold (Yakovenko and Bogomazov 1985) or monocline (Jenchuraeva et al. 2001). The Tournaisian sediments consist of dolomite, while the Visean sediments are siliceous-carbonate rocks with intercalations of siliceous and predominantly carbonate layers, which include coaly-chert and coaly-clay lenses. The sedimentary rocks of the south anticlinal limb generally strike in nearly east-west direction and dip steeply (75-80°) to the south. The monoclinal bedding is complicated by flexural bends and westerly and northwesterly faults. The faults (Yakovenko and Bogomazov 1985; Jenchuraeva et al. 1999, 2001) are best developed at the exocontact of the pluton in a zone 350-550 m wide that contains most of the ore bodies. The main ore-hosting structures, which contain more than 70% of the ore bodies, are east-west-trending shear and fracture zones of alteration.

Such zones control alteration and often occur at the contacts of dikes and granite apophyses.

Plagioclase porphyry and lamprophyre dikes are one of the most important elements of the Makmal deposit's structure. The former, which consist of oligoclase phenocrysts (30-60 vol. % of the dikes) and rare potassic feldspar phenocrysts in a quartz-feldspar-biotite groundmass, are developed mainly in the central and southern parts of the deposit. These dikes form consistent east-west and northwest-striking bodies up to 10 m wide that dip steeply to the north and south.

Dikes and stocklike bodies of lamprophyre are typical of the northern and central parts of the deposit. These dikes are hundreds of meters long and up to 15-20 m wide.

Jenchuraeva et al. (1999, 2001) described a few types of skarn, which is developed along contacts with diorite bodies and granite pluton. Wollastonite skarn with the less-common garnet, garnet-wollastonite, and scapolite varieties is prevalent at contacts with diorite. This assemblage contains gold-sulfide disseminations and has the following lateral zoning: lamprophyre→garnet skarn with scapolite→garnet-wollastonite skarn→wollastonite skarn→limestone with wollastonite→ limestone or marble.

Magnesian and calcic skarn are widely distributed along the dolomite contact with granite. The magnesian skarn belongs to the magmatic stage and forms relics of forsterite or spinel-forsterite composition in apomagnesian calcic skarn. The latter has a pyroxene-phlogopite, magnetite, and vesuvianite-garnet composition with the following zoning: dolomite→phlogopite-magnetite skarn→phlogopite+pyroxene±vesuv ianite skarn→phlogopite-vesuvianite sometimes with garnet skarn→ vesuvianite±garnet skarn→granite. All these varieties form relatively thin (1-5-10 m) bodies along intrusive contacts with host rocks and can be traced up to 2.5-3 km along these contacts. The garnet-magnetite skarn contains hematite, pyrite, pyrrhotite, and bismutite in association with magnetite.

Strictly calcareous (not apomagnesian) skarn is developed along the southern exocontact of the granite apophyses where it forms a zone 30-100

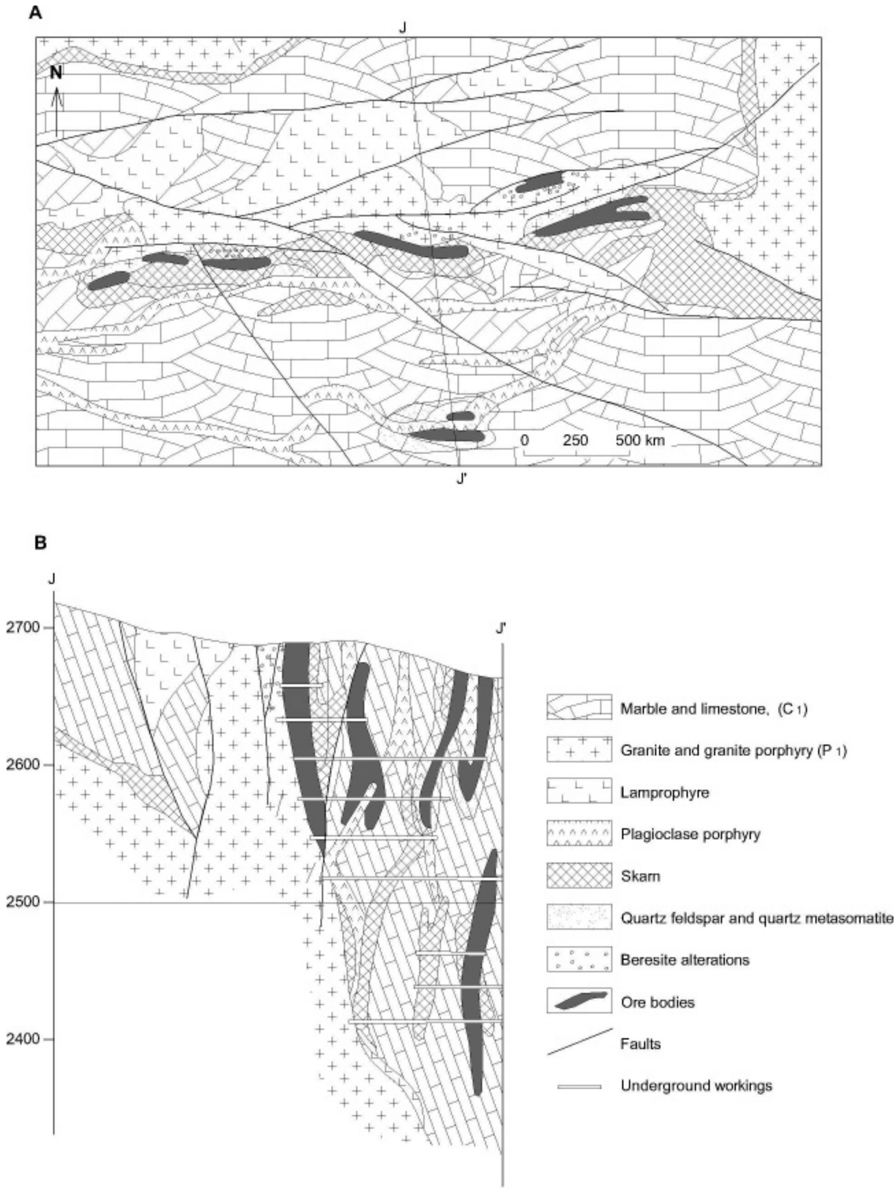


Figure 42. Geologic map (A) and cross section (B) of the Makmal deposit (after Dzhenchurayeva et al. 1999).

m wide and approximately 1 km long. It has practically monomineralic wollastonite composition with less common garnet.

An important role in concentration of gold is playing by the quartz-feldspar alteration of skarn, plagioclase porphyry dikes, and granite. In the central part of the Makmal deposit, such alteration forms a “metasomatic breccia”—brecciated skarn of pyroxene-garnet, garnet, and wollastonite composition that was cemented and then replaced by fine-grained aggregates of quartz and plagioclase.

According to Jenchuraeva et al. (2001), disseminated, low-grade gold-sulfide mineralization in the garnet skarn, which is found at the contacts with a Middle Carboniferous diorite, is related to later silicified zones. The later emplacement of an Early Permian granitic pluton was accompanied by four subsequent types of ore mineralization: (1) magnetite (syngenetic with skarn), (2) massive sulfide in skarn, (3) cassiterite mineralization in greisen, and (4) gold-sulfide (productive) mineralization[7].

Massive sulfide mineralization forms lenses and pockets up to 8-10 by 4-5 m hosted in a garnet-pyroxene skarn and consists mainly of sphalerite and pyrite with subordinate galena, chalcopyrite, arsenopyrite, molybdenite, magnetite and sporadic hessite, petzite, tetradymite, bismuthinite, cosalite, boulangerite, native gold, silver, and bismuth.

Economic gold-sulfide mineralization is controlled by quartz-feldspar altered rocks, areas of silicification, and sometimes by zones of quartz-carbonate-chlorite-pyrite alteration. Pyrite, chalcopyrite, pyrrhotite, sphalerite, galena, molybdenite, bismuthinite, boulangerite, jamesonite, and gold are disseminated unevenly. The ore is low in sulfides (3-5%), with average gold grades of 5-8 g/t. The ore bodies of highest gold grade are confined to the skarn breccia that is cemented by the quartz-feldspar mineral assemblage.

Two generations of gold form relatively large free particles up to 1-2 mm in size but more often have smaller size of 0.02-0.08 mm. The first and predominant generation of gold is associated with quartz-feldspar altered

[7] It is quite unusual for gold-skarn mineralization to accompany leucocratic granite and we do not exclude a possibility that the gold mineralization is related to earlier diorite intrusions.

rocks, while the second is associated with quartz veins that carry larger gold particles. Gold fineness varies from about 890-915 in the quartz veins to 960-995 in quartz-feldspar rocks. The second-generation gold contains more than 0.50% mercury.

The massive sulfide mineralization is rich in tellurides (Jenchuraeva et al. 2001) and contains galenobismuthite and Bi-galena enriched in silver. The economic disseminated gold-sulfide mineralization contains abundant pyrrhotite, which was not detected in the massive sulfide mineralization.

Four large ore bodies (the Contact, Main, Southern, and Dip), which have a flat, lenslike shape and are up to 55-75 m thick, contain gold as the principal economic component. They are traced for 100-600-800 m along the strike and up to 300-400 m down dip.

The ore zone of the Makmal deposit, to a depth of about 600 m (Supambayev and Zakhozhaya 1985), has clear vertical mineralogical and geochemical zoning (from the surface down): mercury sulfosalts (livingstonite rarely), native silver, tennantite and tetrahedrite, sulfosalts of silver (prustite, pyrargyrite), copper (bournonite), and lead (boulangerite, galena-bismuthinite), arsenopyrite, stibnite, sphalerite, pyrrhotite, sulfosalts of bismuth (bismuthinite, rarely tetradymite), native gold, wolframite, cassiterite, scheelite, and molybdenite.

The geochemical zoning is as follows: (1) Ag, Sb, As, Cu, Pb, and Zn at the upper-ore level; (2) Au and Bi are along the entire interval of economic gold mineralization without fluctuations of concentration (ore level); and (3) W, Sn, Cr, Ni, Vo, and Mo beneath the ore level.

The liquid inclusions in quartz of altered rocks and quartz veins (Jenchuraeva et al. 1999) range in size from 0.0003 to 0.02 mm and contain between 8 and 45 vol. % gas phase. The temperature of mineral deposition is in the range 200-520°C. Homogenization occurs at 300-400°C for the quartz-feldspar alteration, 230-350°C for the quartz-carbonate-chlorite-pyrite alteration, and 200-250°C for quartz veins. The predominant components of the gas-liquid inclusions are H_2O (60-97 vol. %) and CO, with lesser amounts of N_2, H_2, and CH_4. The saline composition of the inclusions changes from sulfate-chloride for early quartz-feldspar metasomatite through hydrocarbonate-chloride alteration to hydrocarbonaceous ferruginous in late quartz veins.

The Kuru-Tegerek Deposit (42°33'N-71°27'E)

This copper-gold skarn deposit is located in the Chatkal system of ranges in western Kyrgyzstan approximately 300 km west-southwest of the capital city of Bishkek and 45 km northeast of the village of Kanysh-Kaya—the center of the administrative Chatkal District in the Jalal-Abad region.

The Kuru-Tegerek deposit was discovered in 1963 and was explored from 1967 through 1981 by Soviet geologists and in the period 1998-2001 by the U.S.-Kyrgyz HEMCO-Kyrgyzstan Corp. Eurasian Minerals Inc. of Canada was granted an exploration license for the deposit area in 2004.

The Chatkal region of the Central Tien Shan is a crystalline (rigid) massif with Late Proterozoic-Paleozoic volcano-sedimentary, volcanic, and carbonate rocks deposited on a Proterozoic crystalline basement. The deposit is located in the southeast part of the Sandalash Range, which contains a Late Proterozoic (Riphean-Vendian, in Russian terminology)-Middle Ordovician passive margin and rift sediments, a Late Ordovician-Silurian magmatic arc and an accretionary complex, and Late Devonian-Carboniferous orogenic molasse and bioorganic shelf-type limestones.

Early Carboniferous (Lower Mississippian) limestones and siltstones in the Kuru-Tegerek area form synclinal folds and are intruded by small Permian diorite and quartz diorite porphyry stocks. Pyroxene-garnet skarn with copper, gold, silver, molybdenum, and platinum-group mineralization is developed intermittently at the broken and dislocated contacts of the stocks with limestone. Farther from the contacts, the limestone contains wollastonite skarn without sulfide mineralization.

The copper-gold skarn mineralization of the Kuru-Tegerek deposit forms three separate zones named south, northwest, and northeast (Fig.

43). The south skarn zone contains most of the deposit resources. It occurs in the footwall of a quartz diorite stock, which dips westward under the stock. The zone is 880-1,100 m long on different levels and 30-150 m thick and was traced to 900 m below the surface. The northwest zone, confined to the hanging wall of the same stock, is 800 m long, 10-25 m thick, and can be traced 600 m along its westward dip. The northeast skarn zone is located at the diorite stock northern contact, dips to the northwest (30-45°), and has been traced for 620 m along strike, with a thickness of 15-23 m.

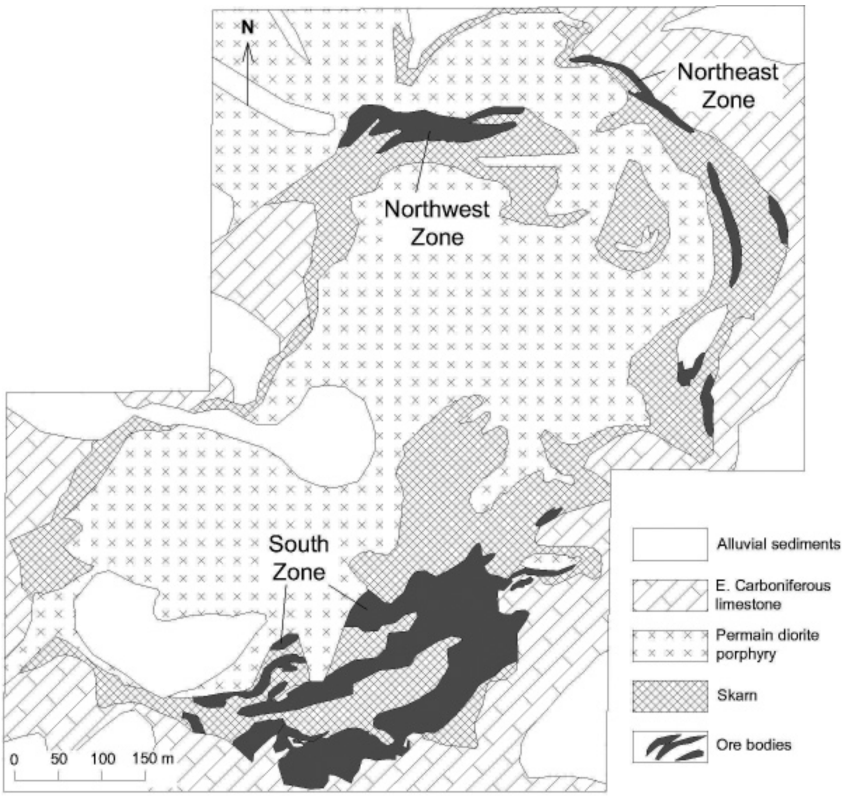


Figure 43. Geological map of the Kuru-Tegerek deposit (after *Eurasian Minerals*, 2005).

Three types of mineralization at the Kuru-Tegerek deposit are (1) gold-copper with platinum-palladium in skarn (the principal productive), (2) molybdenum with rhenium in diorite porphyry, and (3) gold-rich limonite (formerly high sulfide) ore in marble. Gold-rich skarn forms winding ribbons 2-3-25 m wide in gold-copper mineralized zones that also contain lower grades of gold and silver. The typical distribution of gold, silver, and copper is shown in a cross section of the south zone (Fig. 44).

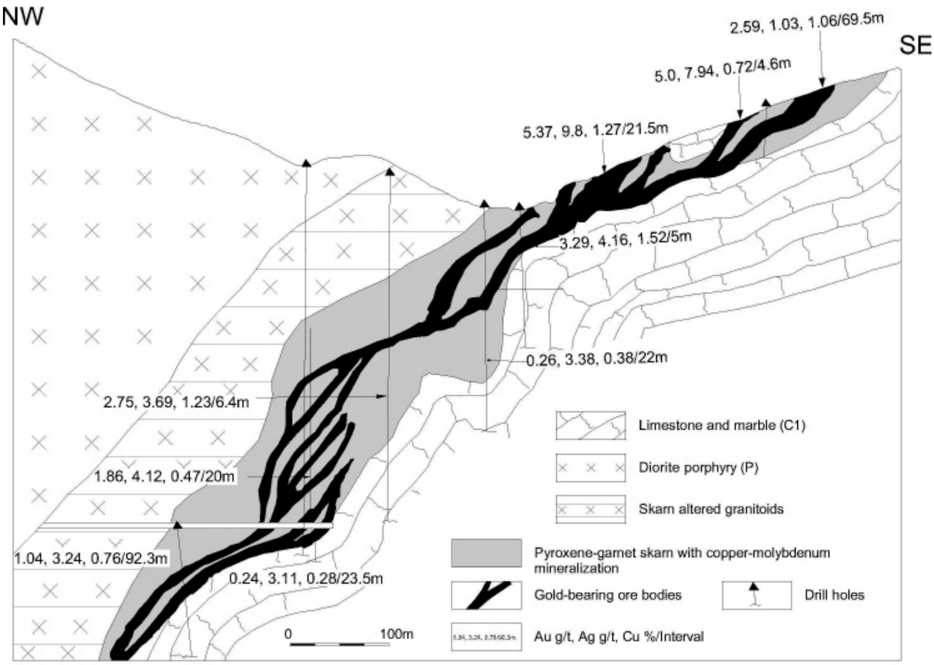


Figure 44. Kuru-Tegerek deposit: Cross section of the south zone (after Soviet exploration in the period 1963-1980).

The garnet-pyroxene skarn is dominantly grossularite, andradite, and diopside in composition with smaller amounts of wollastonite, serpentine, sericite, and chlorite. It contains disseminated oxides and sulfides including magnetite, chalcopyrite, pyrrhotite, pyrite, molybdenite, covellite, sphalerite, and native gold. In addition, the skarn contains platinum and palladium mineralization. Sulfide mineralization appears to be a late phase as it associates with or follows the retrograde stage of the skarn process, as marked by the formation of such minerals as tremolite, anthophyllite, and antigorite.

The oxidized high sulfide zone, with abundant limonite, goethite, malachite, chalcocite, azurite, and native copper and gold, has an average thickness of 104 m and ranges from 20-60 m and up to 180 m in the south zone. The northwest and northeast zones are considerably less oxidized. The transition of the oxide zone to the sulfide zone occurs through a mixed zone of oxide and sulfide minerals.

The geological resources of the Kuru-Tegerek deposit, calculated as the Soviet C_1-C_2 reserves in 1967-1981, are 172,664,000 tonnes of ore grading 0.60% copper, 0.56 g/t gold, and 2.15 g/t silver. These ore resources are equal to 1.023 million tonnes of copper, 97.36 tonnes of gold, and 372 tonnes of silver. Some blocks of the deposit, according to Soviet-era estimates, contain up to 0.83% copper, 1.51 g/t gold, and 4.81 g/t silver. Data on the platinum group and molybdenum mineralization have not been disclosed. According to Eurasian Minerals Inc., however, the measured and indicated resources of the south zone are 9,199,000 tonnes of ore grading 1.56 g/t gold and 0.53% copper (14.35 t of gold and 49,016 t of copper). This amount includes 2,884,000 tonnes of oxide ore grading 2.016 g/t gold; 2,903,200 tonnes of mixed oxide and sulfide ore grading 1.151 g/t gold; and 1,320,200 tonnes of sulfide ore with the lowest gold grade of 0.736 g/t but the highest copper grade of 0.563%.

Several other prospects with similar copper-gold skarn mineralization, with occasionally higher grades of gold and copper, are known in the vicinity of Kuru-Tegerek and in other parts of the Chatkal region (Kichi-Sandyk and Bosymchak).

The Phanerozoic gold and copper-gold skarn deposits of the CIS, as well as the most of similar deposits in other gold provinces of the world, have relatively small gold resources of 1-2 Moz and average gold grades usually not exceeding 5-7 g/t. The rare high gold grades in the McCoy deposit of Nevada, reaching 442 g/t, do not affect its average grades, which vary between 2.06 and 5.29 g/t of gold for different ore bodies (Kuyper 1988).

The possibility of finding new outcropping gold skarn deposits in the Paleozoic and Mesozoic gold provinces of the CIS is relatively low because skarn alteration and high sulfide content make these deposits easy targets for geological and geophysical surveys, which were thoroughly carried out during the Soviet era. There is a somewhat better possibility of finding new concealed gold skarn deposits in the greenstone belts of ancient shields of the East European and Siberian platforms.

As should be clear from the above description of the intrusive-related gold-porphyry (stockwork), quartz-vein, and skarn gold deposits, all of them have close spatial and temporal association with different types of productive intrusives. This pattern becomes even clearer when all three types of the deposits are concentrated in one ore field, as in the Kommunar ore field in the Kuznetsky Alatau of the West Siberia (Korobeinikov 1980; Smirnov 1977). This ore field is situated at the northern exocontact of the Kaliostrovskii granodiorite pluton, which is part of the Solgon granitoid batholith (476 ± 3 Ma) that is intruded into Late Precambrian (Riphean) diabase porphyry and volcanogenic-sedimentary sequences. The gold mineralization forms four different morphological types: (1) lenses of magnetite skarn in the endo- and exocontact zones of granodiorite with limestone, (2) stockwork in amphibolized gabbro-diorite, (3) separate quartz veins, and (4) a combination of gold-bearing quartz veins and stockwork. All deposits and ore showings of the Kommunar ore field (Podlunnyi Golets, Maslovskoye, Feodorovskoye, etc.) are relatively small, and this ore field is mentioned only to highlight the presence of all three types of intrusive-related mineralization in proximity to one intrusive.

4.3 VOLCANIC-RELATED GOLD AND GOLD-SILVER DEPOSITS OF VOLCANO-PLUTONIC BELTS AND CONTINENTAL RIFT ZONES

The most obvious feature of the volcanic-hosted gold and gold-silver deposits is their relationship to the mainly Mesozoic-Cenozoic volcanic and volcano-plutonic associations of island-arc and pericontinental volcanic belts, as well as to orogenic volcanics and zones of Mesozoic tectonic and magmatic activity within Proterozoic and Paleozoic consolidated structures. The most of volcanic-related gold and gold-silver deposits in the CIS are known throughout the eastern part of Russia.

The easternmost gold province with such deposits is confined to the Koryak-Kamchatka accretionary belt of the Kurile-Kamchatka island-arc system (Zonenshain et al. 1990). Mesozoic-Cenozoic volcanic complexes here are progressively younger from west to east and represent former continental-margin volcanic belts. The major deposits of these belts are the Ametistovoe, Aginskoye, Ozernovskoye, Mutnovskoye, Rodnikovoye, Asachinskoye, and Prasolovskoye; but there also are numerous smaller deposits and prospects.

Directly to the west of the Koryak-Kamchatka gold province are located the Okhotsk-Chukotka and Sikhote-Alin Mesozoic volcanic belts containing volcanic-related gold and gold-silver deposits. These belts mark the Cretaceous active continental margin and contain the Kupol, Lunnyi, Dukat, Karamken, Khakandzha, Mnogovershinnoye, Belaya Gora, Salyut, and Primorskoye deposits, as well as numerous gold occurrences.

The next cluster of volcanic-related gold deposits to the west is in the regions of Mesozoic tectonic and magmatic activity of a Precambrian and Paleozoic structures of the Aldan shield (the Kuranakh and Lebedinoye deposits, Yakutia), Proterozoic and Paleozoic structures of the Transbaikal region (Baley-Taseevo), and Late Paleozoic structures of the Mongolian-Okhotsk belt (Pokrovskoye, Prognoz).

The western part of the CIS also contains a few Mesozoic-Cenozoic volcanic-related gold deposits in the Transcarpathian (Beregovskoye, Muzhievo in Ukraine) and Lesser Caucasus (Zod, Megradzor in Armenia).

In contrast to other gold provinces throughout the world, volcanic-related gold and gold-silver deposits have been found not only in Mesozoic-Cenozoic but also in Paleozoic provinces of the CIS. The Kochbulak and Kysylalma deposits are in the Paleozoic Kurama-Chatkal volcanic belt of eastern Uzbekistan-northern Tajikistan. This belt contains also a number of smaller epithermal gold deposits and the Almalyk deposit, one of the largest gold-copper-molybdenum porphyry deposits in the CIS.

Small volcanic-related deposits such as the Arkharly, Naurazbai, North Kaptas, Ushshoky, and others are known in the Paleozoic Balkhash volcanic belt of Central Kazakhstan. Many geologists also assume a Paleozoic age for the large Kubaka epithermal deposit hosted in Devonian volcanics of the Omolon rigid massif of the Magadan region (northeastern Russia).

On the basis of the empirical correlation between the mineralogical and geochemical features of volcanic-related deposits with associated volcanic formations and types of the continental crust, Konstantinov (1984) outlined three geochemical varieties of the CIS gold-silver deposits: the gold-telluride (Au/Ag—10:1-1:1), gold (Au/Ag—1:1-1:20), and gold-silver (Au/Ag—1:20 or less).

The three main geological types of CIS gold-silver deposits, which correspond to their three geochemical types, are (1) vein, stockwork, and ore breccia of *gold-telluride* mineralization related to basalt-andesite volcanics; (2) veins and metasomatic bodies of *gold* mineralization related to andesite-dacite (rhyolite) volcanics; and (3) veins and stockworks of *gold-silver and silver* mineralization related to dacite-rhyolite volcanics. These three geological types are similar in general to the models for volcanic-hosted epithermal gold-silver deposits offered by Bonham (1988): alkalic-related (gold-telluride), high-sulfur or high-sulfidation (gold), and low-sulfur or low-sulfidation (gold-silver deposits). White and Hedenquist (1990) and later Hedenquist and Lowenstern (1994) included gold-telluride deposits in low-sulfidation group together with silver-rich deposits, but relations of these two types with volcanics of different composition are difficult to explain and can cause some mistakes during evaluation of the deposit's potential if it is based solely on alteration mineralogy.

4.3.1 Veins, Stockworks, and Breccia Pipes of Gold Mineralization Associated with Basalt-Andesite-Dacite Volcanics

4.3.1.1 Gold-Telluride-Adularia-Quartz (Alkalic-Related) Deposits

The gold-telluride deposits are related to basalt-andesite-dacite or alkaline trachybasalt-trachydacite volcanics and are developed mostly in volcanic belts of mature island arcs and regions of continental margins with thick continental crust. A good example of a mature island-arc tectonic setting in the CIS is the Neogene-Quaternary Koryak-Central Kamchatka volcanic belt with basalt-andesite-dacite volcanics hosting the Aginskoye deposit.

Gold-telluride deposits in volcanic belts with andesite-dacite volcanics at the continental margins are more widely distributed. Examples of such deposits are the Zod deposit in the Eocene-Miocene Adzhary-Trioletiya arc of the Lesser Caucasus (Armenia), the Mnogovershinnoye deposit of the

Paleogene eastern Sikhote-Alin volcanic belt (Russia), and the Kochbulak deposit of the Late Paleozoic Kurama volcanic belt (Uzbekistan).

The most essential feature of the gold-telluride deposits tectonic setting in all these different volcanic belts is their location over rigid structures with a well-developed granitic crust: the Central Kamchatka massif (Aginskoye deposit), the Dzirula massif of the Lesser Caucasus (Zod), the Kiselevskii block of the northern Sikhote-Alin belt (Mnogovershinnoye), and the Chatkal-Fergana massif of the Central Tien Shan (the Kochbulak deposit). The same volcanic belts outside the rigid massifs contain different types of gold and gold-silver deposits, which will be described later.

Veins, zones of disseminated mineralization, stockworks, and pipelike ore bodies with gold-telluride mineralization are confined to volcanic calderas or their vents within the volcano-plutonic domes or volcano-tectonic grabens.

The gold-telluride deposits of the CIS, despite their age differences, are associated with similar volcanic and volcano-plutonic series, are accompanied by similar quartz-adularia-sericite alteration of the host rocks, and contain a similar set of sulfide minerals, sulfosalts, and tellurides. The gold in all these deposits has high fineness (over 800-850) and is associated with quartz, sulfides, tellurides, and sometimes with gray copper ore and sulfosalts. The gold-silver ratio generally is above 1, varying from 1:1 to 10:1.

In the following description, well-studied examples of gold-telluride deposits are arranged by increasing age of the ore-productive volcanics.

The Aginskoye Deposit (55°30’N-157°52’E)

The Aginskoye deposit is located in the central part of the Sredinnyi (Median) Range of the Kamchatka Peninsula, 436 km west of the city of Petropavlovsk Kamchatskii and 127 km from the town of Mil’kovo. The deposit is one of several situated in the central Kamchatka gold district of the Koryak-Central Kamchatka volcanic belt that belongs (Zonenshain et al. 1990) to a Neogenic island-arc. The Aginskoye deposit was discovered in 1964 and explored in the period 1974-1985.

The basement of the area consists of Precambrian-Mesozoic (?) metamorphic crystalline schists and gneiss overlain by Late Cretaceous volcanogenic-cherty sequences. The latter were folded at the end of

Mesozoic-beginning of Paleogene into a series of northwesterly and northerly folds, which form the Sredinnyi anticlinorium and are intruded by numerous granitoid plutons and small bodies of peridotite, gabbro, and syenite.

The upper stage of the area consists (Schepotiev et al. 1989) of Neogene-Quaternary continental volcanics of an andesite-basalt-andesite-dacite formation overlying the eroded surface of the lower-stage folded structure and accompanied by comagmatic intrusives.

The northeasterly Main Kamchatka fault defines the position of the Koryak-Central Kamchatka volcanic belt. Intersections of this regional fault with subordinate north-northwest and north-south faults control the central-type volcanoes, which play a key role in localizing gold-silver mineralization.

The Aginskoye deposit and numerous gold and mercury ore showings in this ore field are at the center and on the northeast slope of the Neogene-Quaternary Aginskaya volcanic structure formed at the intersection of northwesterly, northeasterly, and northerly concealed faults. The caldera of this stratovolcano, approximately 12 km in diameter, is filled with Miocene-Pliocene rhyolite and andesite tuff, ignimbrite, and lava interbedded with sandstone, siltstones, and minor coal beds in the lower part of the structure (Schepotiev et al. 1989). The middle part of the volcanic sequence consists of psephite tuff of basalt-andesite composition and individual andesite-dacite and dacite lava flows. Basalt and andesite-basalt lava (7.6 Ma) represent the upper part of the sequence mapped at the hypsometrically highest levels. The total thickness of the volcanics exceeds 1,100 m.

The numerous subvolcanic intrusive bodies include stocks and dikes of quartz diorite, diorite porphyry, and andesite (7.4 Ma) and are intersected by later necks and dikes of basalt and dacite. The distribution of the intrusive bodies and dikes emphasizes the oval shape of the stratovolcano structure.

All volcanic and subvolcanic rocks in the caldera and along its periphery have been subject to chlorite-carbonate and zeolite facies of propylite alteration near the surface and epidote-chlorite and prehnite facies in the dipper parts of the volcano. Quartz-adularia and quartz-sericite-hydromica alteration are widely distributed around gold-bearing quartz veins. A quartz-adularia-rectorite zone borders the quartz veins and gives way to a quartz-adularia-corrensite zone, which is replaced farther from the vein by calcite, chlorite, and pyrite association. This alteration sequence is similar to alteration related to the solfataric activity of modern volcanoes, which are abundant on the Kamchatka Peninsula.

The vertical zoning of propylite and syn-ore alteration are expressed in the strong silicification and pyrite-alunite-kaolinite-quartz alteration in the upper part of the metasomatic column (Schepotiev et al. 1989). Below this level, the strong silicification is replaced by quartz-kaolinite, quartz-montmorillonite-hydromica, and quartz-adularia-hydromica facies. The most intensive adularization is developed at the lower level of altered rocks aureole. Barren quartz and quartz-carbonate veinlets are typical of the above-ore level.

The major role in the structure of the Aginskoye ore field belongs to two clusters of northeast-striking shear zones (Aginskaya and V'yun), represented by steeply dipping (45-90°), low-amplitude strike-slip fracture zones up to 10 m wide. These faults host almost all of the dikes and main ore bodies. Northwest-striking curved faults are encountered mainly on the northeastern flank of the deposit and often are post-ore. Westerly and northerly fractures sometimes also host quartz veins.

The gold-bearing veins of the Aginskoye deposit form Aginskoye, Pereval'noye (Divide), and V'yun (Bindweed) clusters. The first two are separate at the surface but merge at a depth of about 100 m. High-grade gold quartz-adularia veins are hosted commonly by faults that dip steeply to the northwest and southeast. The Aginskaya and Surprise zones are the main ore-hosting structures, which form a single conjugate system of shear fractures converging in plan at 10-15° and downward at 40-50°.

Quartz veins commonly occur adjacent to the dikes and form a series of lenticular bodies up to 50-120 m long that often are connected by thin veins/veinlets. Gold-bearing quartz-adularia veins are accompanied by zones of quartz veinlets up to 1 m wide and sharply change thickness along strikes and down dip. The veins often branch and pinch out and have many apophyses. Almost all the ore bodies are in the three main zones of the deposit: Aginskaya, Surprise, and Valerie, which are branches of a unified northeasterly cluster of veins about 4.5 km long and 300-400 m wide that merge at depth (Fig. 45).

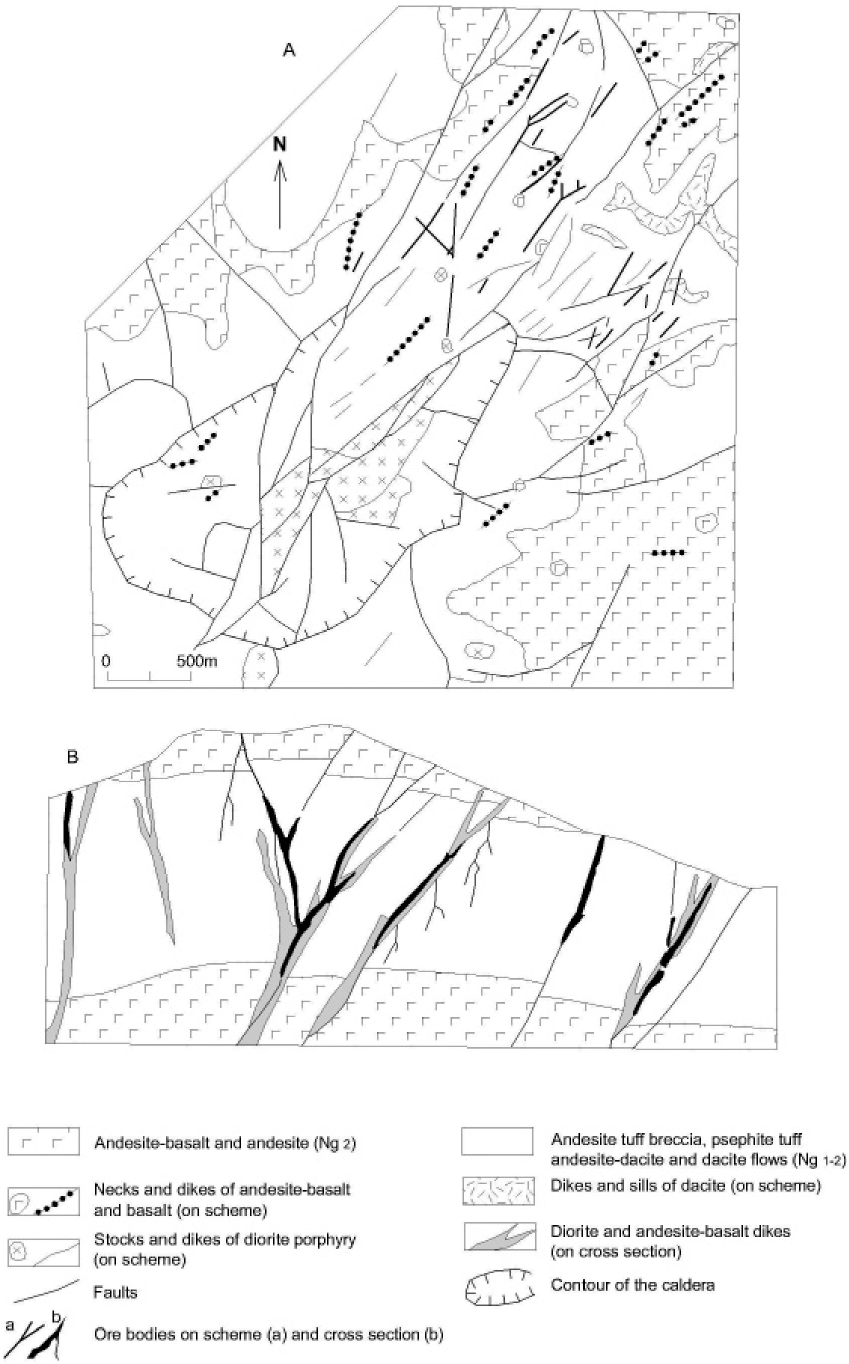


Figure 45. Aginskoye ore field: (A) structure scheme of the ore field and (B) schematic cross section of the Aginskoye deposit (simplified after Schepotiev et al. 1989).

There are two types of ore bodies. The first type, thick veins and vein zones with a complex structure confined to the major shear zones, contains about 90% of the ore reserves. The veins range from 50 to 300 m along the strike and up to 350 m in depth and contain the highest gold grades—up to 11 kg/t. The second type of ore bodies, lenses and splays linked to wide shear zones, occurs only in the central part of the deposit, has plane dimensions of no more than 50 x 50 m, and is 0.2-1.0 m thick. The average gold grades of these ore bodies vary from 12 to 50 g/t.

The quartz-adularia gold-bearing veins have colloform-laminated, breccia, and metacolloidal structures typical of all epithermal deposits and contain between 0.1-0.5 and 2-3% sulfides (pyrite, chalcopyrite, sphalerite, galena, and pyrrhotite), with mostly native gold and tellurides (hessite, altaite, calaverite, petzite, sylvanite, etc.) in gold-bearing associations. In contrast to other gold-silver deposits, the ore contains almost no silver sulfosalts. The bulk gold-silver ratio averages 2:1.

The six mineral assemblages corresponding to the different stages of ore deposition are (1) the quartz-pyrite (pre-ore), (2) the gold-adularia-corrensite-quartz assemblage with three subsequent gold-pyrite mineral associations (gold fineness of 924-968), (3) the gold-adularia-quartz assemblage with gold-zeolite-quartz and adularia quartz associations (gold fineness of 720-952), (4) the gold-calaverite-quartz assemblage with gold-calaverite-sylvanite and gold-calaverite associations (gold fineness of 940-960), (5) the gold-hessite-corrensite-quartz assemblage with gold-hessite and pyrite-chalcopyrite associations (gold fineness of 816-880), and (6) quartz-zeolite-calcite (post-ore).

The size of lumplike and wirelike particles and native gold crystals varies from 0.01 to 0.1 mm, rarely larger. Fine-grained native gold and tellurides form impregnations in nodelike chalcedonic quartz or powderlike films in colloform stripes of quartz-adularia-hydromica veins.

The vertical zoning of mineralization is characterized by an increase in sulfide content at the lower levels of ore bodies and the decrease in the size of gold particles and sulfides toward the upper ore levels. Accordingly, the content of copper, lead, and tellurium also decreases toward the upper levels with a simultaneous increase in the gold-silver ratio from 1-2:1 at the lower levels to 12-88:1 in the upper horizons of the ore bodies. Gold tellurides also are prevalent at the upper levels, while tellurides of silver, particularly hessite, are typical of the lower levels of the ore bodies.

The geological resources of the Aginskoye deposit, as verified by the Russian State Committee for Mineral Reserves, are 806,000 tonnes of ore grading 38.4 g/t gold and 17.4 g/t silver, or 30.9 t (~1 Moz) of gold and 14 t of silver. According to Kinross Gold Co., which for some time held the license to develop this deposit, its mineable proven and probable reserves are smaller: 919,073 tonnes of ore grading 29.6 g/t gold and 13.2 g/t silver, i.e., 27.2 t of gold and 12 t of silver.

The gold distribution is extremely uneven, with ore shoots and bonanzas, which contain up to hundred grams per ton of gold and silver. Up to 85% of the gold resources are concentrated in compact ore shoots. The largest ore shoots of the Surprise zone are 120-220 m along the strike and 12-40 m wide. Flat-lying linear ore shoots with numerous very rich, steeply dipping high-grade gold nests may have been controlled by the intermixing of high-temperature hydrothermal and cold vadose water near the paleosurface at the time of ore deposition.

The Cripple Creek gold-telluride deposit is mineralogically similar to the Aginskoye but is situated in the different tectonic setting of the Rocky Mountains (Colorado). It is related to a Tertiary diatreme of phonolite volcanics and intrusives in the Precambrian basement and is accompanied by alkali adularia and carbonate alteration.

The Zod Deposit (40°13’N-45°65’E)

This deposit is at the watershed of the Zangezur Range of the Lesser Caucasus, 11 km from the town of Zod in the eastern part of the Armenian Republic, near the border with Azerbaijan. The gold deposits of this region have been known since antiquity and were rediscovered in the early 1950s.

The Zod deposit is situated in the west-northwest Sevano-Akera ophiolite zone, the main Mesozoic suture zone associated with the Late Cretaceous continental collision (Zonenshain et al. 1990) of the Arabian and Eurasian plates. The ophiolite zone separates the structures of the Greater and Lesser Caucasus and belongs to a nappe unit broken by subsequent deformation into a number of slabs containing Late Jurassic and Early Cretaceous cherty sediments and turbidites. During this time, west-northwest-trending breccia and shear zones prevailed. After the collision, the newly formed Eocene-Miocene Adzhary-Trioletiya volcanic arc occupied the whole area of the Lesser Caucasus; and during the Pliocene, much of the area was covered by calc-alkaline basalt and andesite.

The deposit is hosted by an ophiolite complex intruded by Miocene (22-20 Ma) quartz porphyry dikes, which are comagmatic with basalt-rhyolite volcanics and are believed to be the initial source of gold-bearing hydrothermal solutions. Subsequent solutions related to Pliocene basalt-andesite volcanics complete the deposition of gold mineralization. As noted by Konstantinov et al. (2000), it is quite rare for an ophiolite zone to host an epithermal gold deposit.

The Zod deposit is located at the intersection of the Sevano-Akera ophiolite zone by the younger, northerly-trending Zangezur fault zone (Konstantinov et al. 2000), which contains subparallel belts of Oligocene-Miocene extrusives and numerous Pliocene-Quaternary volcanic centers. In the Zod deposit area, the Zangezur fault zone becomes apparent as small northeast faults that are accompanied by brecciation and schistosity of an Upper Cretaceous gabbro-peridotite and effusive-sedimentary rocks that is cut by Miocene quartz porphyry (rhyodacite) dikes.

Gold mineralization is found in east-west and northwesterly zones of quartz-talc-carbonate alteration up to a few kilometers long and 12 to 50 m wide, which are concentrated mostly within Late Cretaceous gabbro and along its contacts with lenses of serpentinized peridotite protruding into the gabbro (Fig. 46). Such alteration zones are rare in peridotite and in the effusive-sedimentary sequence.

The altered host rocks are intensely pyritized and contain 15-60% carbonate, up to 40-50% talc, quartz, chalcedony, and magnetite. Alteration developed in two stages. Serpentine-talc-carbonate zones with low silicification and disseminated pyrite impregnation similar to listwanite type of alteration belong to the first stage. This stage coincides with the intrusion of quartz porphyry dikes and often is not accompanied by ore mineralization. The intense silicification, sericitization, and pyritization of the second stage are accompanied by the deposition of quartz and gold-bearing sulfide mineralization. The hydrothermal alteration described above differs somewhat from typical epithermal deposits (Smirnov 1977). This may be explained by the composition of the host rocks and/or by the formation of the deposit in a relatively deeper environment than other near-surface volcanogenic deposits.

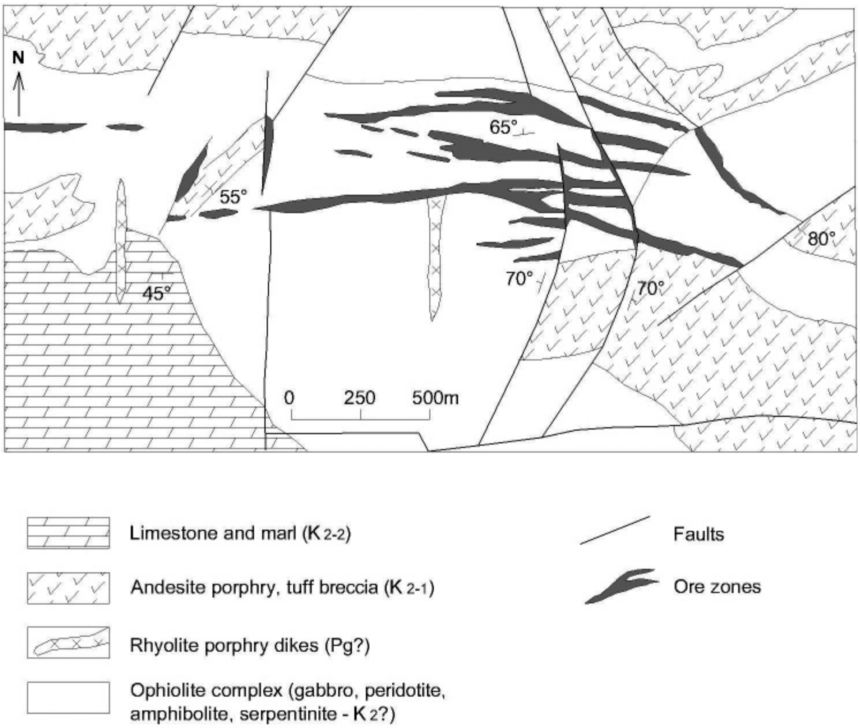


Figure 46. Schematic geologic map of the Zod deposit (simplified after Konstantinov et al. 2000).

The Zod deposit contains more than 30 steeply dipping subparallel ore bodies concentrated mostly in its central part, along the contact between gabbro and peridotite. The six largest ore bodies, 10 to 40 m thick, contain about 80% of the gold resources.

Three different types of ore bodies (Konstantinov et al. 2000) in descending order of importance are (1) vein zones that include quartz veins with lenses, veinlets, and nests of sulfides; (2) veinlet zones of intense sulfide mineralization in quartz porphyry dikes; and (3) zones of dense veinlets in altered host rocks. East-west-, northeast-, and west-northwest-striking quartz-sulfide veins dip steeply (60-70°) to the north or south and have mostly sharp contacts with host rocks defined by fractures with fault gauge. The veins usually have a consistent strike for hundreds of meters, with deviations of up to 15-20° from the strike, and branch near the flanks into fine lenticular veinlets. Vein thickness varies from 3-5 cm to 1.5-2 m, or 6 m in swellings. The vein zones have thicknesses 3 to 12 m, with a distance of 0.3-4 m between individual veins.

Gold-bearing sulfide mineralization is concentrated mostly as bands along the quartz-vein selvages and was deposited on early quartz and/or talc-carbonate rocks along vein contacts.

Veinlet zones of intense sulfide mineralization are localized near or within a westerly dike of quartz-porphyry intersected by underground workings in the central part of the deposit, and along a similar dike of northerly direction. The dikes contain veinlet-disseminated mineralization, while massive sulfide concentrations are found along their contacts. This type of ore bodies can be 40-45 m wide and 50-400 m long.

The third type of ore bodies, zones of dense quartz-carbonate veinlets with sulfide impregnation on weak altered rocks up to 100 m long and 1-5-10 m wide, is mainly in gabbro and serpentinite. The ore bodies are located along large fractures or forms series of veinlets with listwanite-like alteration along quartz veins. They are difficult to correlate and contain very small fraction of the resources.

The quartz-sulfide and quartz-carbonate-sulfide veins and veinlet zones contain from 5 to 30% (15-20% on average) of sulfides. Pyrite, arsenopyrite, marcasite, sphalerite, pyrrhotite, chalcopyrite, gray copper ore, freibergite, stibnite, and gold are the main minerals. Rarely occurring galena, jamesonite, altaite, hessite, melonite, gersdorffite, boulangerite, tetradymite, loellingite, sylvanite, bismuthinite, tellurobismuthite, wehrlite, corinite, chekhanovite ($Bi_2Te_4O_{11}$), ruckidgeite [$(BiPb)_3Te_4$], smirnite (Bi_2TeO_5), and volynskite ($AgBiTe_2$), native tellurium, and antimony are encountered here also.

The main gangue minerals are quartz, breunnerite, ankerite, rhodochrosite, talc, chlorite, sericite, and zeolite. Chalcedony, magnesite, sericite, and barite are rare.

The six stages of ore formation (Konstantinov et al. 2000) include (1) quartz-sericite-pyrite; (2) quartz-breunnerite-sphalerite-pyrite; (3-4) quartz-arsenopyrite and quartz-marcasite-arsenopyrite with sulfoarsenides, sulfosalts, tellurides, sulfo-antimonite, and gold; (5) quartz-carbonate-stibnite; and (6) quartz-carbonate mineral associations. The quartz-carbonate-stibnite association forms often separate veins.

According to studies of fluid inclusions in quartz, hydrothermal solutions with pH 4-6 contained 4-10 wt. % NaCl equivalent and had temperatures from 380-280°C to 240-100°C.

Gold of 875-925 fineness is present as free particles in association with sulfides, in the form of a finely dispersed phase in pyrite, and is included in the composition of some tellurides. The gold particles vary in size from 0.005 to 1-2 mm, with a predominant size of 0.05 mm. The largest free-gold particles are associated with tellurides. A significant amount of finely dispersed gold in pyrite can be detected only by neutron-activation analysis. Silver occurs in the form of tellurides or as free submicroscopic particles in pyrite, chalcopyrite, and quartz. The gold-silver ratio is 4:1.

Gold grades averaged around 6-7 g/t during Soviet exploitation, with individual grades up to five times higher or lower, but economic mineralization is generally not continuous, and the veins often contain a few subparallel lenses and ore shoots. The ore shoots are controlled by bends and intersections of ore-bearing fractures.

The total gold resources of the Zod deposit are approximately 6-7 Moz. No data are available on gold production from this deposit during the Soviet era. The First Dynasty Mines Ltd. in a news release of 1997 stated that the remaining measured and indicated resources of the deposit, based on Armenian data, are 14,435,000 tonnes of ore grading 6.2 g/t (2.9 Moz), while inferred resources are 9,747,000 tonnes grading 7.6 g/t (2.3 Moz). The mineable reserves of the deposit are significantly smaller because of the high stripping ratio for an open-pit operation and the structural complexity for underground operations.

The Mnogovershinnoye Deposit (54°10'N-139°55'E)

The Mnogovershinnoye deposit was discovered in 1959 near the south shore of the Sea of Okhotsk, 132 km west-northwest of Nikolayevsk-na-Amure, the regional center of Khabarovsk Krai, Russia.

The deposit is located at the north end of the Mesozoic-Cenozoic East Sikhote-Alin or Primorskii volcanic belt, near its border with the

Amgun synclinorium of the Mesozoic Sikhote-Alin fold-and-fault system (Konstantinov et al. 2000). The Mnogovershinnoye deposit is confined to the northwest part of the Bekcheul rise at the periphery of the Kiselevskii rigid block (Salun 1969). The block has a crystalline basement with a relatively high structural position under folded Mesozoic sediments and Late Cretaceous-Paleocene andesite-dacite volcanics.

The Mnogovershinnoye ore field is in the volcano-tectonic graben of east-west direction bordered to the north and south by regional faults. The ore field is bounded to the southeast by the Bekcheul granitoid pluton and to the southwest by the Paleogene Ul depression (Fig. 47). The basement of the graben consists of Jurassic-Early Cretaceous flyschlike interbedding of shales, siltstones, and sandstone folded into northeast-striking folds with steep limbs.

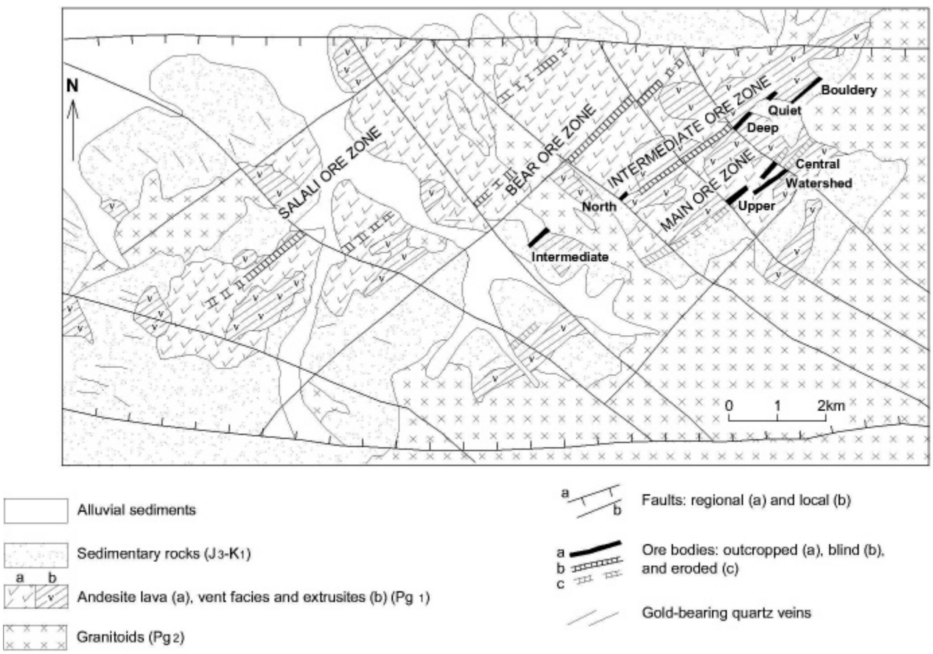


Figure 47. Schematic geologic map of the Mnogovershinnoye deposit (simplified after Konstantinov et al. 2000).

The pyroxene and hornblende andesite-basalt, andesite, and andesite-dacite volcanics of the upper structural stage cover approximately 40% of the ore-field area and overlie folded sediments with angular unconformity.

The mostly eroded stratified volcanics (70-65 Ma) consist of lava, lava breccia, and tuff of andesite and andesite-dacite with layers and lenses of lava agglomerate and with blocks of tuff siltstones in the lower part.

Bodies of extrusive andesite and andesite-dacite porphyry with lavas, pyroclastic breccias, and tuff facies of the same andesite and andesite-dacite composition represent the roots of volcanic structures that have stayed at the current level of erosion and are elongated in a northeasterly direction. The Eocene (57-39 Ma) extrusive stocks consist of andesite, granodiorite, and diorite porphyry.

The sedimentary and volcanic rocks are intruded to the southeast of the deposit by a large (500 km^2) Late Paleocene-Early Eocene (62-40 Ma) composite pluton consisting of hornblende diorite, quartz diorite, granodiorite, granodiorite-porphyry, monzonite granodiorite, and hornblende granite. The essentially alkaline granitoids with high coefficients of iron oxidation (Moiseenko and Eirish 1996) are comagmatic with the volcanics. The surface of the pluton dips gently to the northwest under the ore field and was intersected by drill holes 1,200 m below the surface of the Mnogovershinnoye deposit.

Stocks, laccolites, pipe- and dikelike bodies of quartz diorite, diorite porphyry, and granodiorite porphyry with a radiometric age of 52-37 Ma, possible satellites of the pluton, are encountered in the southwest part of the ore field. In addition, numerous dikes of diorite porphyry, andesite, basalt, and granite porphyry intrude the volcanics and intrusive rocks.

The host rocks of the deposit have undergone multiple stages of hydrothermal and contact alteration (Konstantinov et al. 2000). Regional (medium-temperature) propylite alteration of chlorite-albite-epidote composition is widespread in sedimentary and volcanic rocks throughout the entire deposit area. Local low-temperature chlorite-carbonate-pyrite propylite with sericite, quartz, and albite forms narrow, northeasterly-trending zones. Their inner parts consist of quartz, quartz-sericite, quartz-chlorite-sericite, and quartz-adularia alteration that are confined to zones of intense fracturing up to 120 m wide and contain gold-bearing quartz bodies and veins in the core parts. The Paleocene age of the gold-bearing quartz veins is well defined because of their intersection with Eocene granitoids and is supported by the radiometric age of the quartz-sericite (76-65 Ma) and adularia-quartz-hydromica (74-63 Ma) alteration.

Diopside, quartz-feldspar-biotite, biotite-cordierite, and cordierite hornfels form aureoles up to 1 km wide along the contacts of the granitoid pluton. Post-ore quartz-muscovite and tourmaline-quartz-muscovite greisenization of the sedimentary rocks and granitoids is accompanied by widespread quartz-feldspar and quartz-tourmaline alteration. The latest small-scale argillic alteration is found along the northwestern faults.

Northeast- and northwest-striking faults play a major role in the distribution of volcanics, intrusives, and gold mineralization. The deposit area is divided by the northwest-trending concealed fault of the Left Ul into two nearly equal blocks that have different rates of erosion: the lower northeast block hosts most of the ore bodies (see figure 47).

The main ore bodies are located at the northeasterly faults and fractures that control the extrusive volcanics and subvolcanic intrusives at the major magmatic vents and are represented by thick veinlike bodies up to 20-30 m wide that can be traced for a few hundred meters below the surface. The Main and the Intermediate northeast-striking ore zones are divided by northwest faults into blocks with dextral displacement for a few tens of meters. The Main zone, 5.8 km long and up to 60 m wide, which steeply dips to the northwest, contains the Upper, Central, Reindeer, and Watershed (Divide) ore bodies. The Upper ore body, for example, is 440 m long, has an average thickness of 15.9 m, and can be traced to a depth of 350 m from the surface (Fig. 48). The Upper and Central ore bodies are accompanied along the hanging walls by a series of parallel short quartz veins 1-2 m thick.

The ore bodies consist of central veins composed by fine-grained metasomatic quartz with 1-2% sulfides (low in gold) or bodies of banded colloform quartz and adularia with up to 5% sulfides (the main economic one). The quartz ore bodies usually have relatively sharp contacts with the host rocks but may be surrounded by quartz veinlets.

The Intermediate ore zone, about 6 km long and 20 m to 80 m wide, is 1.5 km northwest of the main zone. It contains the Intermediate, South, Flank, North, Deep, Quiet, and Rocky ore bodies, which are divided by northwestern faults with vertical and horizontal displacements. The thick veinlike quartz ore bodies are surrounded by quartz veinlets. Two other mineralized zones, the Bear and Salali, which parallel to the Intermediate zone, are located farther to northwest but do not contain economic ore bodies.

According to T. Kosovets and V. Krylova (TsNIGRI), most of the steeply dipping ore bodies are located in a volcanic environment. Near the contact with the underlying sedimentary rocks, the total amount of sulfide mineralization and the gold grades in the ore bodies become significantly lower.

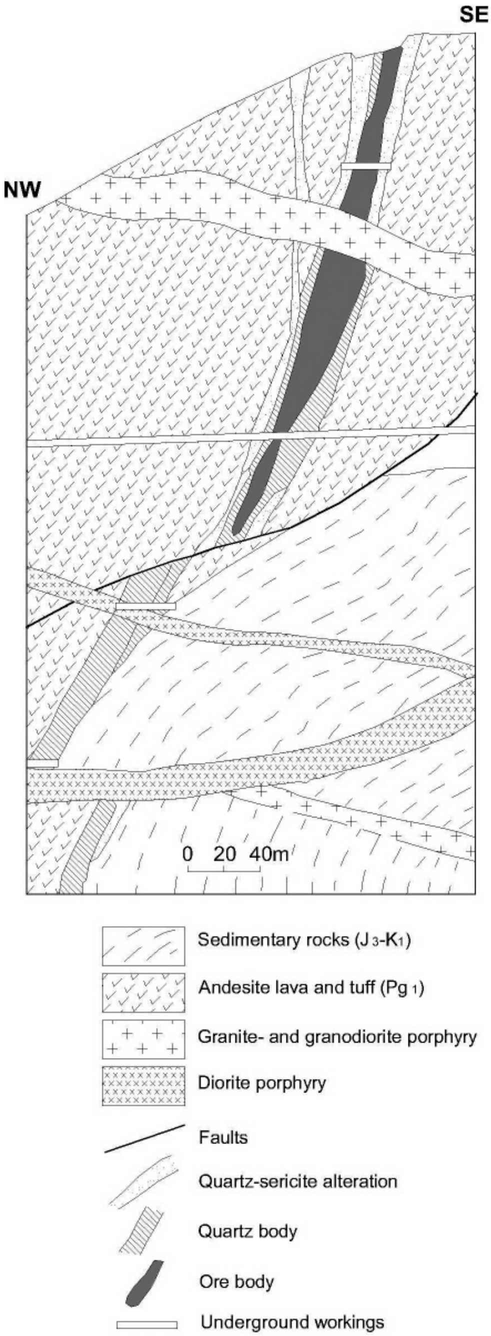


Figure 48. Mnogovershinnoye deposit. Cross section of the Upper ore body (after Konstantinov et al. 2000).

The main gangue minerals of the ore bodies are quartz (up to 95%), adularia (up to 20%), and sericite (up to 10%), with admixtures of tourmaline, epidote, chlorite, and halloysite. The ore minerals constitute 1-5% of the vein volume and include pyrite, arsenopyrite, pyrrhotite, sphalerite, galena, chalcopyrite, and gray copper ore; rarely argentite, freibergite, pyrargyrite, altaite, petzite, hessite, bismuthinite, and bournonite; and very rarely cassiterite, wolframite, cinnabar, magnetite, and hematite. Oxide minerals are cuprite, malachite, scorodite, smithsonite, anglesite, limonite, and manganese oxide.

The gold-bearing mineralization is formed in three stages (Konstantinov et al. 1998, 2000). The first (early productive) stage includes two successive but spatially different productive mineral complexes: (1) quartz-adularia-hydromica with gold-chalcopyrite-gray copper ore productive mineral association and (2) quartz-rhodonite-carbonate complex with a gold-sphalerite-telluride productive association. Mineralization of this stage formed at temperatures of 470-100°C from bicarbonate-sulfate (Na-K-Ca) solutions enriched with K for the early productive mineral association and with Na for the later one. This stage is spatially and genetically related to the Paleocene volcanics.

The second (skarn) and third (tourmaline) postproductive stages of mineralization are related to the Eocene granitoid pluton and are responsible for cluster and veinlet mineral assemblages superimposed on first-stage products and partially remobilized gold. Solutions of the skarn stage of mineralization contain Mg, Ca, and anions of SO_4 and $HSiO_3$, while the third (tourmaline) stage solutions are enriched by Na and K and also contain a similar complex of anions. The main volume of the ore bodies consists of quartz, quartz-adularia-hydromica, and quartz-rhodonite-carbonate mineral associations, while most of the other associations developed as a network of thin veinlets, impregnations, and clusters.

Native gold of 575 to 960 fineness (average 750-850) forms lumpy, dendritic, platelike, and wirelike particles 0.01-0.2 mm in size, mostly in cavities of leached sulfides that are replaced by iron hydroxides, scorodite, pyromorphite, and malachite. Gold is present also as thin impregnations in quartz and sulfides and in association with tellurides, sulfides, sulfosalts, and apatite. The relatively high average gold fineness and the small amounts of admixtures are most likely due to contact metamorphism and recrystallization by granitoid intrusion.

The Mnogovershinnoye deposit has clear vertical mineral zoning. The early, gold-chalcopyrite-gray copper ore, productive mineral association is present at lower horizons and is succeeded at upper levels by a late gold-sphalerite-gray copper ore association. The most upper horizons contain quartz-adularia-hydromica vein mineralization with argentite, freibergite, pyrargyrite, and cinnabar. The total amount of sulfides increases with depth; and the quartz-carbonate-rhodonite mineral association with sphalerite, galena, chalcopyrite, and low-silver gray copper ore is more typical of the middle and lower ore horizons. Tellurides occur in all horizons of the deposit, but their large clusters are more often in the middle and lower levels of the ore bodies.

The gold composition and fineness also changes with depth: electrum of 575 fineness is typical for the upper levels of the ore bodies, but at their deeper levels the fineness of the electrum reaches 750. Native gold with a fineness of 850 or higher also has been encountered at the same deep levels of the deposit.

The gold-silver ratio varies between 1:1 and 1:4, with average gold grades of 7-10 g/t; but the distribution of gold is markedly uneven, with ore-shoot grades of 20-25 g/t or higher. According to earlier Russian estimates, the geological resources of the Mnogovershinnoye deposit are about 110 t of gold. A small amount of gold was mined during the Russian operation from 1991 to 1997, when those operations were halted. The Highland Gold Co., which has operated the deposit since 1999, has stated that the proven reserves ($B+C_1$) of the deposit are 8.0 million tonnes of ore grading 8.9 g/t, or 2.289 Moz of gold (71.2 t) and 2.292 Moz of silver. The indicated resources (C_2) are 1.74 million tonnes of ore grading 10.8 g/t, or 1.872 Moz of gold and 536,000 Moz of silver.

The Kochbulak Deposit (41°00’N-70°10’E)

This deposit was discovered in 1960 15 km east of the city of Angren (eastern Uzbekistan) in the Central (Sredinny) Tien Shan. The deposit area is confined to the Lashkerek volcano-tectonic structure of the Late Paleozoic Kurama volcanic arc and accretionary complex, north of the Late Paleozoic Turkestan suture (Mores and Fibridg, eds. 1997). A magmatic arc is developed over the Chatkal-Fergana part of the Turkestan-Syr Darya rigid massif, which consists of a Proterozoic basement covered by Late Proterozoic and Early Paleozoic passive-margin and rift sediments. The volcano-plutonic complexes of the arc are Devonian, Late Carboniferous, and Early Permian in age and consist mainly of andesite-dacite and rhyolite volcanics, subvolcanic intrusions with comagmatic granodiorite-granite, and syenite intrusives.

The deposit is located (Kovalenker et al. 1997) in the southwest segment of an eroded caldera filled with Middle-Late Carboniferous calc-alkaline andesite-dacite volcanics and explosion breccia, which forms concordant and discordant bodies to the bedding. There also are laccolith-shaped extrusives of andesite-dacite and trachyandesite composition. The andesite-dacite lava, tuff, and agglomerate that host the deposit and that are considered to be the flank of the caldera dip 15-30° to the north and northwest. The central part of caldera is cut off by the regional Angren fault and buried under Mesozoic coal-bearing sediments of the Angren graben. According to another interpretation (Berger et al. 1994), the Kochbulak ore field is confined to the stratovolcano edifice.

A system of northwesterly, northerly, and northeasterly faults defines the ore-controlling structure and contains the main ore bodies and dikes (Fig. 49). The northwesterly and westerly-trending, high-angle thrusts and normal faults with displacements of up to a few hundred meters are dividing the relatively large blocks of the ore field. Low-angle (15-40°) westerly faults are formed along the contacts of the tuff horizon with andesite-dacite lava and along the contacts of subvolcanic bodies.

Gold mineralization of the Kochbulak deposit is concentrated (Islamov et al. 1999) in the area of near-vent facies of the Middle-Late Carboniferous volcanics surrounded by subvolcanic intrusions. About 120 explored ore bodies are controlled by 32 ore-bearing structures.

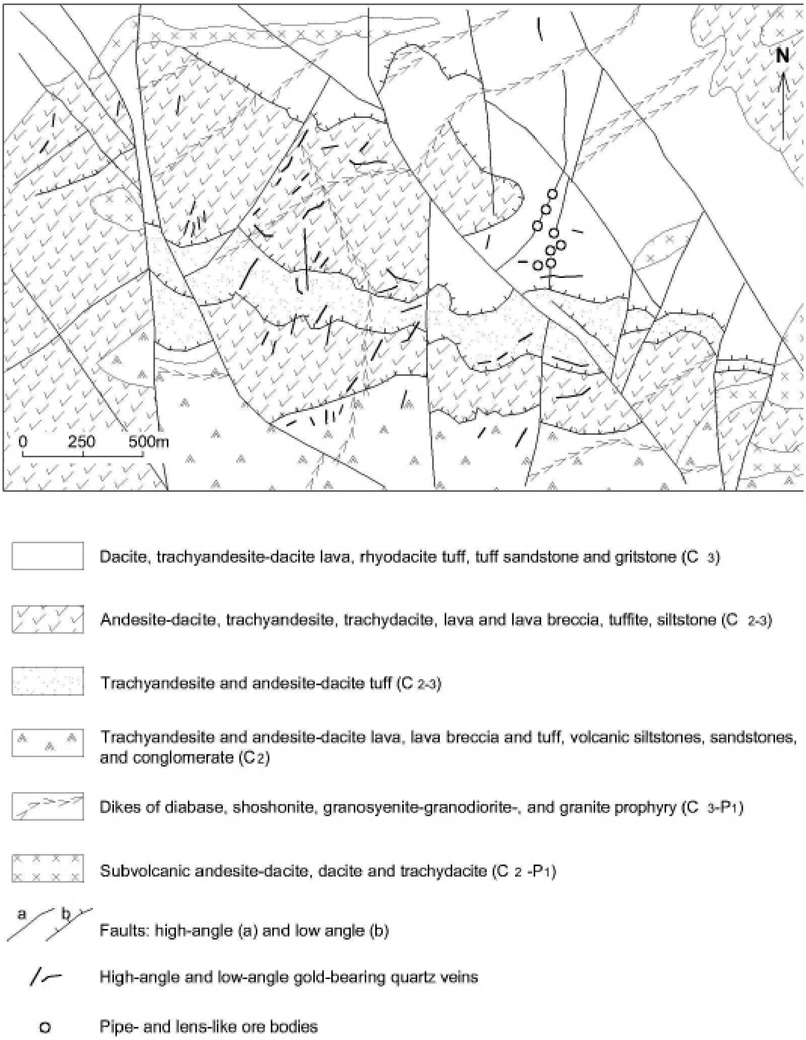


Figure 49. Schematic geologic map of the Kochbulak deposit (simplified after Kovalenker et al. 1997).

The three structural-morphologic types of ore bodies at the Kochbulak deposit are (1) high-angle discordant veins (40% of total reserves), (2) low-angle (20-40°) lenticular concordant veins and vein zones with about 20% of reserves (Fig. 50), and (3) steep pipe- and lenslike bodies (40% of reserves). Numerous individual quartz veins up to 1-2 m wide and tens of

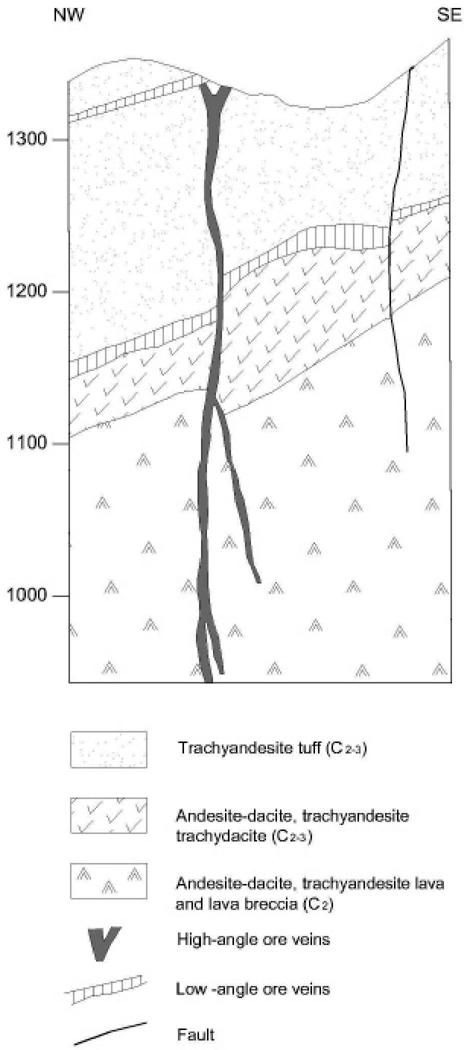


Figure 50. Kochbulak deposit: Cross section of the ore zone (after Kovalenker et al. 1997).

meters to a few hundred meters long or systems of thin quartz veins and veinlets in silicified and sericitized volcanics represent the first type of ore bodies. They are controlled by steeply dipping northwesterly and northerly faults and are concentrated in several ore zones up to 1-2 km long with average gold grades up to 20-25 g/t and silver grades of 70-75 g/t.

The low-angle concordant veins and vein zones of the second type form ore bodies up to 2-3 m thick, which are located in extended zones of silicification with sulfide impregnations up to 10-30 m wide. Such zones are confined to low-angle westerly faults along contacts of volcanic horizons, which have different petrophysical characteristics. The gold grades in these ore bodies are lower than in the high-angle veins but can increase sharply at intersections with the steeply dipping veins and faults.

Pipelike ore bodies, up to 100 by 150-200 m, are confined to steeply dipping north-northeast faults and composed of mineralized explosion breccia. Fourteen such bodies are traced downward for more than 400 m and due to high gold grades contain the same amount of reserves as numerous steeply dipping vein ore bodies.

The hydrothermal host-rock alteration of the Kochbulak deposit has an age of 280-290 Ma and differs from the deposits described above mainly since adularia and alunite are not typical of the deposit. The alteration consists of a sericite-ankerite-dolomite-quartz-pyrite assemblage along the veins and vein zones. Such zones of alteration, 10-30 m wide and up to 1 km long, are superimposed on propylite alteration of andesite-dacite volcanics along high- and low-angle ore zones. Alteration within and around the pipelike ore bodies, due to intensive acid leaching, appear mainly as a quartz-diaspore mass that contains cavities inlaid with quartz crystals, carbonates, mica, clay material, native gold, sulfides, sulfosalts, and tellurides.

The Kochbulak ore bodies contain up to 5 to 20% sulfides with more than a hundred minerals and mineral varieties (Kovalenker et al. 1997), many of which (wolfsonite, kuramite, mohite, nekrasovite, and chatkalite) were first discovered here. Pyrite, chalcopyrite, sphalerite, galena, and gray copper ore are the main ore minerals. The ore formation is subdivided into the pre-ore, ore I-III, and post-ore stages.

The four mineral associations of the first ore stage are dominated by fine-grained to cryptocrystalline quartz associated with variable amounts of pyrite and contained native gold and tellurides. The second stage consists of rhythmically banded crystalline quartz (90-95 vol. %) with segregations of native gold, bismuthinite, and tellurides in the earlier rhythms of banded quartz. The third ore stage contains pyrite, chalcopyrite, tetrahedrite, goldfieldite, famatinite-luzonite, and minor amounts of gold and silver tellurides, sulfosalts, and various tellurium minerals.

Sb-rich minerals of the tetrahedrite-tennantite series dominate the gray copper ore group of minerals with low Ag concentration. Goldfieldite

(Te-bearing gray copper ore) and intermediate members of the tetrahedrite-tennantite-goldfieldite series are typical of pipelike ore bodies. Tellurides (calaverite, sylvanite, kostovite, petzite, hessite, altaite, and native tellurium) occur in all ores but are abundant in high-grade bonanza bodies and are associated with melonite, tellurantimony, tellurbismuthinite, coloradoite, and other minerals in the pipelike ore bodies. Some crystals of native tellurium, calaverite, sylvanite, and petzite are up to 3-5 cm in size.

Low-sulfide gold-quartz-silver-gray copper ore with gold-silver-galena-sphalerite, or gold-silver-telluride mineral associations are typical of vein-type and low-angle ore bodies. This type of ore bodies in low-angle structures contains sometimes an unusual network of thin (0.1-0.5 mm) veinlets of Ag-Cu-Pb-Bi-Se sulfosalts in association with electrum, Cu-Fe-V sulfostannates, hessite, petzite, and volynskite ($AgBiTe_2$).

Bonanza ores in both vein- and pipelike ore bodies are significantly enriched in sulfides and tellurides, while ore bodies in low-angle structures have higher grades of silver than gold and lower grades of gold, tellurium, and bismuth than do high-angle veins.

The gold occurs mainly as microinclusions but also forms dendritelike and clotty grains at the upper levels of the deposit, while spongy and drusy grains are typical at its lower levels. The silver content in native gold of each ore stage increases from earlier mineral associations with quartz, pyrite, tellurides of gold, altaite, coloradoite, and bismuthinite to later associations with petzite, hessite, empressite, and Ag-Cu-Pb-Bi-Se sulfosalts. The amount and number of silver minerals also increases in the direction from earlier associations to later ones, causing a gradual increase in the gold/silver ratio from less than 1 to 5-10 in earlier high-temperature associations to 50-100 in ores dominated by later low-temperature associations. However, a native-gold fineness of more than 800 is prevalent for all productive associations.

A fluid-inclusions study showed a wide range of homogenization temperatures, from 465 to 100°C, and pressures higher than 0.9-1.6 kbar, with water as the major volatile component (97.3-99.9 mol. %) and small variable amounts of CO_2 (0.05-2.56 mol. %), CH_4 (<0.01-0.11 mol. %), and Na_2 (<0.01-0.12 mol. %). The sulfur-isotope composition ($\delta^{34}S = 0 \pm 3‰$) is typical of magmatic sulfur.

Proven gold reserves of the Kochbulak deposit (Islamov et al. 1999) are 5,600,000 tonnes of ore grading 13.4 g/t gold (74.9 t or 2.42 Moz) and 58.93 g/t silver (330 t or 10.65 Moz). The ore contains 0.2% Cu, 101.4 g/t Te, and 0.01% Bi.

The Ozernovskoye deposit of central Kamchatka is similar mineralogically to Kochbulak. It has three productive mineral assemblages: (1) gold-goldfieldite, (2) tellurium-sylvanite-goldfieldite-kaolinite-quartz, and (3) gold-hessite-hydromica-quartz containing not only goldfieldite but also tetrahedrite-tennantite. The main difference is the extensive development of quartz-sericite, quartz-kaolinite, and quartz-montmorillonite-hydromica facies of argillic alteration, often with pyrite and alunite. Such pyrite-alunite-kaolinite-quartz alteration is confined to an extensive fracture systems in the vent zone of the central volcanic structure and forms linear platelike bodies up to 100 m thick, which host the largest ore bodies of the Ozernovskoye deposit.

The best-known examples of the gold-gray copper ore-telluride mineral type deposits outside the CIS include the Goldfield (Nevada) and Summitville (Colorado) deposits of the U.S. and El-Indio deposit in Chile.

The major common features of the deposits described are an abundance of tellurides in their productive mineral associations, with a close relationship between gold tellurides and low silver grades (Au/Ag ratio from 1:1 to 10:1). The gold-silver ratio does not change, regardless of the amount of sulfides and sulfosalts in the ore (less than 1% in the Aginskoye deposit and up to 20% in the bonanza of the Kochbulak deposit) and their composition.

Most of the gold-telluride deposits of the CIS are clearly associated with calc-alkali basalt-andesite-dacite volcanics. The only exceptions are the Kochbulak deposit and, to a lesser degree, the Ozernovskoye deposit, which are associated with a trachybasalt-trachyandesite series of volcanics remotely similar to the alkaline volcanics and extrusives that host gold-telluride deposits in other gold provinces of the world (Cripple Creek in the Western United States, Emperor Mine in Fiji, etc.).

Discovery of the Aginskoye, Zod, Mnogovershinnoye, and Kochbulak deposits significantly widened the range of geological settings for gold-telluride deposits, which generally are considered to be products of alkaline magmatism (Bonham 1984, 1988).

4.3.2 Veins, Stockworks, and Metasomatic Bodies of Epithermal Gold Mineralization Associated with Andesite-Dacite (Rhyolite) Volcanics

4.3.2.1 Gold-Adularia-Quartz (High-Sulfidation) Deposits

This type includes the largest epithermal gold deposits in the CIS, such as Baley-Taseevo and Kuranakh, with initial resources of hundreds of tonnes of gold. Gold mineralization is associated with andesite-dacite (sometimes with rhyolite as the youngest member of the series) volcanics in a specific geotectonic environment. Many of these deposits are located in regions of Paleozoic or Mesozoic tectonic and magmatic activity (activization in Russian terminology) of rigid Archean-Proterozoic structures or in Paleozoic structures that underwent Mesozoic regeneration.

Good examples of these deposits are the Kubaka deposit, which is associated with volcanics developed during Paleozoic tectono-magmatic activity in the Omolon rigid massif (Magadan Oblast), as well as the Pokrovskoye (Amur Oblast) and Kuranakh (Yakutia) deposits, which developed during Mesozoic magmatic activity in the Bureinskii massif and Aldan shield, respectively. The Baley-Taseevo ore field (Chita Oblast, Transbaikalia) is an example of such Mesozoic tectonic and magmatic activity in the Paleozoic Mongolian-Okhotsk fold-and-fault belt. Other deposits of this type, such as Karamken and Kupol, are confined to the marginal Mesozoic Okhotsk-Chukotka volcano-plutonic belt. But all these regions have in common a well-developed sialic crust, which may be responsible for mostly low-sulfide mineralization (0.5-3%) with markedly secondary amounts of sulfosalts and tellurides and a high Au-Ag ratio that varies from around 1:1-1:2, rarely to 1:10-1:15.

In contrast to the gold-telluride deposits, some of this group of epithermal gold deposits are cryptomagmatic and are not located directly in volcanics. For example, the Baley-Taseevo deposit, with typical epithermal features, is located partly in granitoids and partly in sedimentary host rocks, while the Kuranakh deposit is located at the contact of Cambrian carbonate and Jurassic sedimentary host rocks. However, there are sufficient data to link these deposits to Mesozoic volcanic magmatism.

The Kubaka Deposit (63°51'N-160°02'E)

The Kubaka deposit is located in the north Evensk district of the Magadan Oblast (Russian Northeast), about 285 km north of the district's administrative center, the village of Evensk. The deposit was discovered in 1972 and explored from 1984 until 1992. It was one of the first deposits successfully put into operation in 1996 by a joint venture between Russian and U.S. companies.

The deposit is in the western part of the Omolon rigid massif. The basement of the massif consists of typical Precambrian (3,400-2,000 Ma) metamorphic rocks of granulite facies, alkali charnockite, granite-gneiss domes, and greenstone belts (Zonenshain et al. 1990). The basement is covered by platform-type Vendian (Late Proterozoic) tillite, followed by predominantly carbonate Cambrian deposits. The Middle to Late Devonian volcanics, which host the Kubaka deposit, are formed after a pronounced unconformity due to Paleozoic tectonic and magmatic activity. Together with subvolcanic bodies and granitoid intrusives, the Devonian volcanics belong to a calc-alkaline volcano-plutonic series similar to the one that exists along Andean-type, active continental margins. The overlying Upper Paleozoic and Lower Mesozoic sediments (conglomerate, coal-bearing shales, and siltstones) are a few hundred meters thick and contain numerous erosional disconformities.

The Kubaka deposit is located in the southwest part of the Avlandinskii stratovolcano, at the intersection of northeast- and northwest-trending tectonic structures that have been described as ore-concentrating faults (Stepanov and Shishakova 1994). The vent of the volcano structure consists of trachyrhyolite ignimbrite and automagmatic breccia surrounded by ignimbrite with flows of rhyolite lava and volcanic-sedimentary deposits of andesite-rhyolite composition.

A series of trachyrhyolite subvolcanic bodies have intruded into semicircular concentric faults around the vent. The inclination of the flow texture changes from 60-80° near the vent to 10-30° on its periphery. Subvolcanic bodies, sills, and dikes of trachyrhyolite, rhyodacite, and trachyandesite are located on the periphery of the volcano structure.

Stratified Middle-Upper Devonian tuff sands, tuff siltstones, andesite-rhyolite tuff and ignimbrite, as well as a rhyodacite-dacite sill, host the ore bodies of the Kubaka deposit. The volcanics are a remote facies of the volcano and dip gently (10-15°) away from the volcano vent. A northwesterly-elongated sill of rhyodacite-dacite composition plays an important role in ore localization. The ore bodies are located mainly in the western part of the sill and partly in the volcanic-sedimentary rocks. A few pre-ore trachyrhyolite dikes are encountered also. Most geologists attribute the post-ore dikes and sills of dolerite to the Upper Jurassic series.

Known gold-bearing vein-veinlet zones of carbonate-fluorite-adularia-quartz composition are concentrated in a block about 8 km^2 in size that is elongated in a northwesterly direction (Fig. 51). The Tsokol, South, Central, and North zones (200-400 m to 2 km long) contain several ore bodies. The Central zone containing the main gold resources can be traced for more than 2 km along the strike and 500 m down dip and is best studied during exploration and development.

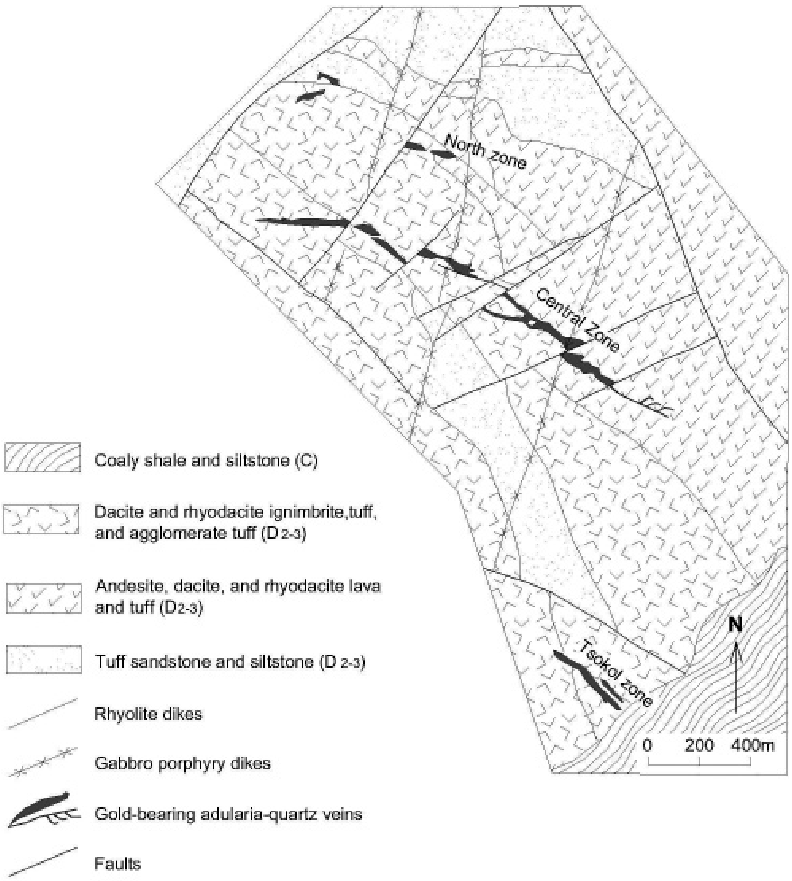


Figure 51. Geologic scheme of the Kubaka deposit (after Konstantinov et al. 1992).

The ore-hosting structure of the central zone is a near-vertical large fissure of northwesterly direction (Fig. 52). Crosscutting faults divide the zone into four approximately equal parts with dextral displacement of up to 100 m relative to each other. The zone contains nine vein and veinlet ore bodies. The lower parts of the ore bodies are narrow (1-3 to 6-8 m) quartz-adularia veins. The veins in the middle level are replaced by intricately shaped thick zones of netting vein and veinlet silicification up to 40-50 m wide, with bulges and pinches. The upper parts of the ore bodies split like a fan into separate vein-veinlet zones with a combined width up to 60-80 m.

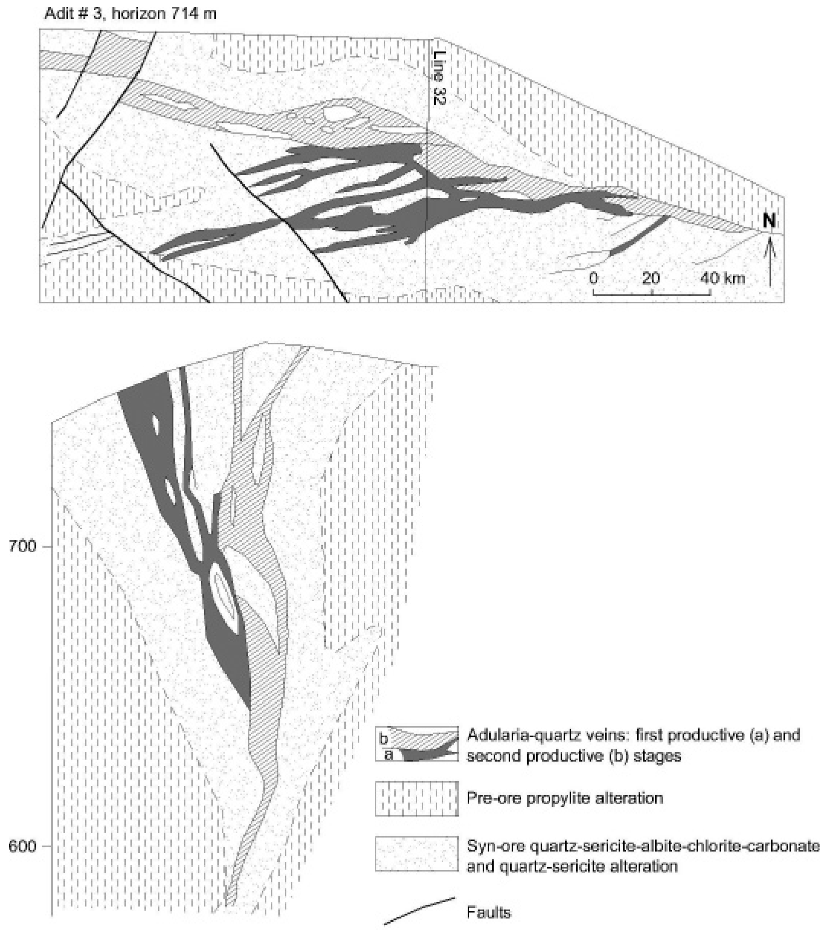


Figure 52. Central ore zone of the Kubaka deposit: fragment of the ore body structure (plan and cross section [after Konstantinov et al. 1992]).

The different style of the ore bodies on different levels is due to lithologic control: mainly tuff sandstone for the lower parts, rhyodacite sill for the middle parts, and ignimbrite for the upper parts of the ore bodies.

The gold ore consists of quartz-adularia, quartz, and occasionally carbonate-quartz and fluorite-quartz veins and veinlets. The core part of the ore bodies contains quartz-adularia veins that have fanlike splitting along the strike and often transformed into vein-veinlet zones. The central parts of the veins have massive and laminated textures with alternation of quartz and adularia bands. They are surrounded by breccia envelopes that contain silicified debris and blocks of host rocks or by vein-veinlet zones, and occasionally by linear stockworks consisting of thin veins and a dense network of veinlets.

The middle and lower parts of the ore bodies contain later veins composed of chalcedonic quartz that cements the abundant detritus of altered host rocks and ore-bearing quartz. Such "hydrothermal breccia" contains gold only at the intersections of gold-productive veins.

Syn- and postvolcanic, low-temperature propylitic alteration with calcite-albite-chlorite and epidote-chlorite facies is widespread in the host rocks. Near-ore hydrothermal alteration includes an adularia-hydromica-quartz inner zone, a quartz-carbonate-albite-chlorite intermediate zone, and a quartz-sericite-albite-chlorite-carbonate outer zone of alteration outside the ore bodies (see figure 52).

Ore of the Kubaka deposit is low-sulfide with 0.1-0.5% ore minerals. L. Shishakova has described more than 50 ore minerals; but only about 20 of them, including gold, electrum, kustellite (gold-rich silver), pyrite, chalcopyrite, galena, sphalerite, acanthite, freibergite, hessite, polybasite, stephanite, and naumannite, are relatively widespread. The set of silver minerals (Sakharova et al. 1998) includes native silver, its selenides, tellurides, gray copper ore, and Ag-Sb and Ag-As sulfosalts. Mineral phases of Ag-As sulfosalts with a large amount of silver [$Ag_8As_2S_7$ and $Ag_5(Sb, As)S_4$] are encountered only in the Kubaka deposit. However, notwithstanding this mineralogical feature, the gold-silver ratio of the ore is 1:1.

The pre-ore, main-ore, and post-ore stages of ore deposition are recognized at the deposit. The pre-ore stage consists of quartz-adularia, carbonate-quartz, and chlorite-quartz-barite associations and does not contain gold-silver mineralization.

The main ore stage contains six mineral associations, three of which are gold-productive. The first productive association, gold-hydromica-carbonate-adularia, differs from the other two in the extensive development of breccia structures, recrystallization of minerals, and the presence of native gold and silver as the main ore minerals. The second productive, gold-chlorite-carbonate-quartz, association has mainly laminated vein structures, a larger size of native gold and silver, and large amounts of sulfides that deposited almost simultaneously with the chlorite. The ore of the third productive (gold-silver-carbonate-adularia-quartz) association has a symmetrically laminated or scalloped-laminated vein structure, gold-low electrum, and kustellite, as well as an extensive suite of silver minerals, including native silver, sulfide, sulfosalts, and selenides of silver.

The deposition of the early gold-productive associations occurred in the temperature range 450-200°C, while the late gold-silver association formed at 380-120°C, indicating inversion of the physical and chemical regime (Sakharova et al. 1998).

The primary gold and silver minerals are native gold with two groups of fineness (750-920 and 600-750), electrum (450-600 and 300-450), kustellite with a gold content of 14-30%, and gold-bearing silver containing up to 6.4% gold. The gold of the Kubaka deposit forms mainly small (0.01-0.03 mm) distorted cubic-octahedral grains localized predominantly in quartz and often as intergrowths with pyrite, galena, and naumannite. Gold is often present as nestlike, clustered aggregates containing from 10-15 to 150 grains.

The geological gold resources of the Kubaka deposit were estimated in 1992 to be 100 t of gold with an average gold grade of 25.3 g/t. Proven and probable reserves of the deposit, as calculated by the Amax Gold Co. (U.S.) in the period 1993-1995, are 4,477,800 tonnes of ore grading 18 g/t (80.6 t, or 2.6 Moz).

The distribution of gold and silver is bonanza-like, with high fluctuations up to 285 g/t of gold and 275 g/t of silver. According to the Kinross Gold Corp., the owner and operator of the deposit, the average gold grade during the first years of open-pit working of Kubaka was 20-22 g/t. In the period 2000-2004, the gold grade declined to 15-16 g/t.

The locations of the gold-silver mineralization of the Kubaka deposit in the Middle-Late Devonian volcanics but near the Mesozoic Okhotsk-

Chukotka volcano-plutonic belt has prompted lengthy discussions about the age of the mineralization. The geological data supports a Middle Paleozoic age: the basal horizon of the Early Carboniferous sedimentary sequence, which overlays the altered Devonian volcanics with gold-bearing adularia-quartz veins of the Tsokol zone, contains fragments of quartz veins (Stepanov and Shishakova 1994). These fragments consist mainly of metasomatic quartz analogous to the quartz developed at the selvages of gold-adularia-quartz veins, as well as chalcedonic quartz and fragments of laminated quartz veinlets containing up to 23.9 g/t of gold. Furthermore, presumably Jurassic age dolerite dikes intersect the ore bodies. K-Ar dating of the sericite in the quartz-adularia veins, which is the main argument for the younger age of the mineralization, gives wide-ranging values, from 88.1 to 312.5 Ma, which may owe to the Omolon massif's Mesozoic magmatic activity.

The Pokrovskoye Deposit (53°21'N-126°22'E)

This deposit is located 10 km from the Tygda railway station of Amur Oblast in Russian Far East. It was discovered in 1975 and explored by Russian geologists through the late 1980s.

The Pokrovskoye deposit is confined to the Tygda-Ulunga volcano-tectonic graben of the Late Mesozoic Umlekano-Ogodzha volcanic belt on the north rim of the Precambrian Bureya rigid massif. The deposit is located at the edge of an Early Cretaceous granitoid pluton intruding a sedimentary Late Jurassic sequence that is partially overlain by Early Cretaceous volcanics (Moiseenko and Eirish 1996; Moiseenko et al. 1999). The Late Jurassic sediments consist of shales and siltstones in the lower part and oligomictic sandstones of the upper part of sequence that forms a northwesterly anticline.

The Sergiyevskii granitoid pluton, with a K-Ar age of 126-138 Ma, is an albite-biotite and biotite-amphibole granite with granodiorite and quartz monzonite. Subhorizontal zones of small-grained and porphyry varieties are known. The pluton has a slablike shape up to 1-1.2 km thick and is intruded by dikes of granite and granodiorite porphyry, dacite, and rhyodacite.

The southern part of the pluton is occupied by an Early Cretaceous paleovolcano with andesite-dacite, dacite, and rhyolite explosion breccia and lava, up to 125-150 m thick near its center. The extrusive dome of the volcano and its sill-like apophyses, 10-15 to 65 m thick, are composed of rhyolite and rhyodacite. An important ore-controlling role is played by a sill-like dacite body in the lower part of the granitoid slab along the near-horizontal tectonic rupture.

All host rocks of the Pokrovskoye deposit underwent propylitic and argillic alteration; the propylite zone is up to a few hundred meters thick. Argillic alteration of the granitoids and volcanics forms linear zones along northeast-striking faults but does not affect the distribution of gold ore to depth, which is limited by the dacite sill. In the central part of the deposit, the aureole of argillic alteration is combined with quartz-sericite-hydromica alteration, which accompanied the subhorizontal ore bodies. The granitoid rocks also contain feldspathic alteration.

The structure of the Pokrovskoye deposit is defined by its location at the intersection of the regional northwesterly Amur-Zeya fault with steep northeasterly and horizontal faults. The main gold mineralization is located in the north limb of the northeasterly, sinistral strike-slip fault system with a displacement of about 1.5 km (Fig. 53).

Platelike horizontal and gently dipping gold ore zones with the Glavnoye (main), Zeiskoye, and Novoye (new) ore bodies are located at the apical part of the granitoid pluton. They are limited from above by volcanics and thin dacite sills and from below by the aforementioned thick dacite sill measuring 3.3 x 2.0 km, which has a poorly discernible dome structure. The thickness of the ore zones varies from 30-50 m to 80 m. They consist of variously silicified and crushed granitoids with series of up to 7 steep and gently dipping quartz and carbonate-quartz veins and veinlets. The ore bodies inside such zones are delineated by sampling and have an average thickness of 8-9 m with bulges and pinches. Along the strike and down dip, subhorizontal ore zones are replaced by dispersed veinlets and gradually fade. Steeply dipping ore bodies are encountered only in the northwestern part of the deposit and are represented by thicker quartz veins and veinlet zones.

The Ozernoye (lake), Molodyozhnoye (youth), and Vostochnoye (east) ore bodies are confined to tectonic zones along the contact of the

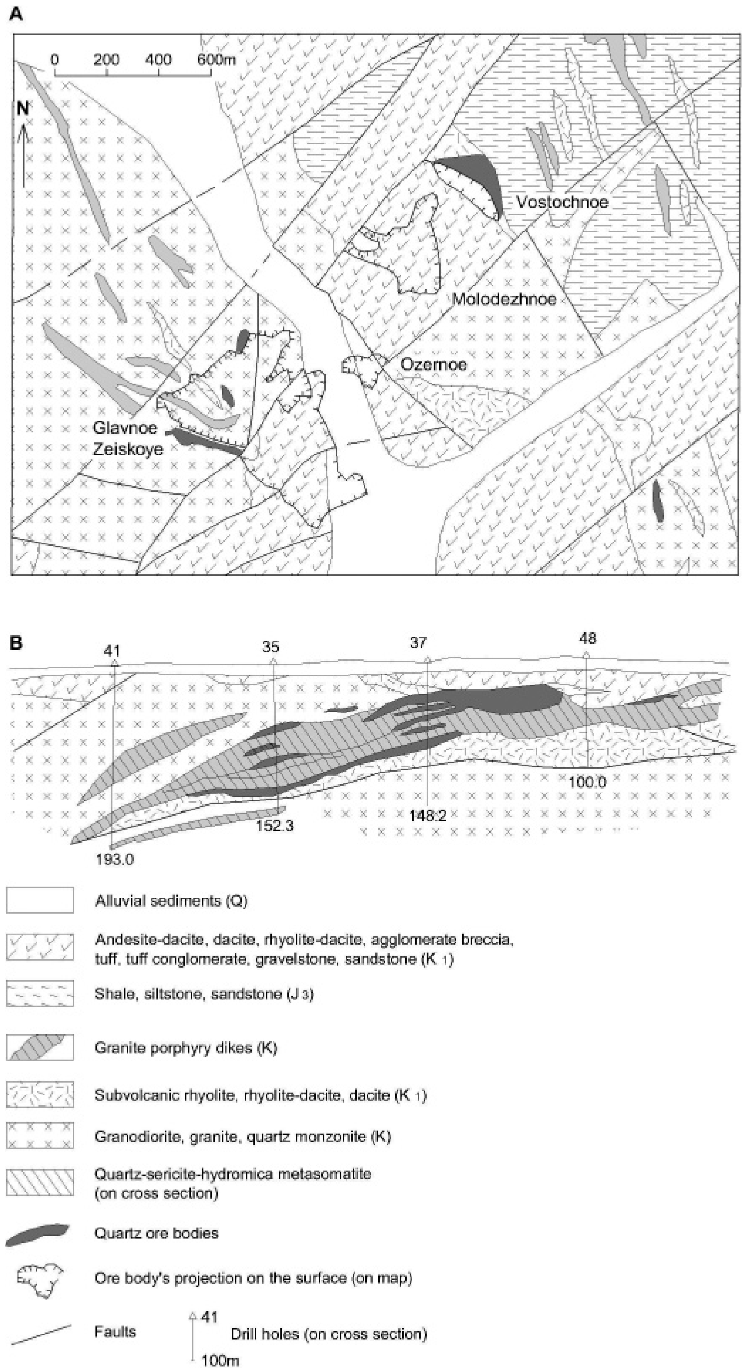


Figure 53. Geologic map (A) and cross section (B) of the Pokrovskoye deposit (simplified after Moiseenko et al. 1999 [a]; Moiseenko and Eirish 1996 [b]).

granitoid pluton with overlying and underlying volcanics and to fractures in volcanic flows.

The ore bodies are hosted by volcanics and granitoids with varying degrees of silicification and/or argillic alteration containing highly irregular disseminated or veinlet-disseminated gold-silver-sulfide mineralization. The quartz constitutes up to 95-97% of the ore bodies. The amount of quartz in veinlet zones decreases to 55-60% due to presence of feldspar relics. Ankerite, dolomite, calcite, hydromica, sericite, adularia, and kaolinite are present in small amounts. Sulfide minerals make up no more than 1% of ore bodies with a prevalence of pyrite and smaller amounts of marcasite, arsenopyrite, sphalerite, galena, stibnite, silver sulfosalts, and native gold.

Novikov and Mikhailova (1985) identified five stages of mineralization and several mineral associations. The pre-ore quartz-hematite stage includes quartz-chlorite, quartz-chlorite-hematite, and quartz-carbonate-pyrite associations. The early productive, gold-carbonate-quartz, stage forms the major gold-bearing quartz veins and zones and contains gold-hydromica mineral association. The main productive, gold-adularia-quartz, stage contains gold-adularia-quartz and gold-sulfoantimonite associations in lamellar, banded, breccia, and cockade structures. The bonanza ores with gold grades up to hundreds of grams per tonne are typical for this stage. The quartz-carbonate-sulfide stage forms disordered veinlets in the upper parts of the ore bodies, which are mainly confined to the flanks of the deposit and composed of the quartz-polysulfide association with pyrite, galena, sphalerite, stibnite, chalcopyrite, and arsenopyrite. The silver content in the galena and sphalerite of this association is up to 196 and 3,245 g/t, respectively, but the gold grades are low. The post-ore quartz-carbonate, association represents the final stage of mineralization of the Pokrovskoye deposit.

Thin particles, 0.001-0.1 mm in size, of low-fineness (625-735) gold form crystalline, stringy, and lenticular segregations in quartz. Gold contains traces of Ag, Sb, Hg, Mn, and Cu. Tiny (3-10 μm) inclusions of gold occur in pyrite and other sulfides.

Variously oxidized ore makes up about 40% of the resources of the Pokrovskoye deposit. The oxide ore is confined mainly to the veins hosted in a volcanic sequence. Oxidation penetrates ore bodies in granitoids only along fault zones. Oxide minerals are goethite, hydrogoethite, and hydrohematite. Secondary enrichment of the gold ore is all but nonexistent because of the very small amount of sulfides, but oxidation occasionally resulted in a higher gold fineness up to 850-900.

The Rb-Sr isotopic composition in the adularia, calcite, carbonate, and albite associated with the productive stages of mineralization gives an estimated age of the Pokrovskoye deposit as Early Cretaceous (131 ± 12 Ma). This age is similar to the age of the dacite-rhyolite volcanics and comagmatic granitoids of the Sergiyevskii pluton.

According to Peter Hambro Mining PLC, which is working the deposit, the proven and probable reserves of the Pokrovskoye deposit (C_1+C_2 in Russian classification) are about 17,261,000 tonnes of ore containing of 2.45 Moz, or almost 76 t of gold. The indicated and inferred gold resources of the deposit are another 6.98 Moz of gold. Average gold grades vary from year to year of operation. In 2002, the gold grade of mined ore was 4.1 g/t but just 3.5 g/t in 2003. The gold-silver ratio varies from 1:1 to 1:2 and in some parts to 1:5.

The Kupol Deposit (66°31'N-169°19'E)

The Kupol deposit is located in the Chukotka Autonomous Okrug of the most northeasterly part of Russia. The nearest settlement is the town of Bilibino, about 300 km to the north-northeast by winter road; and Pevek, the nearest seaport on the Arctic Ocean, is another 300 km to the north.

Fragments of colloform and crustified quartz with high gold and silver grades were found in the vicinity of the Kupol deposit in 1966 in a course of Soviet regional geological mapping program at a scale of 1:200,000. But the deposit itself was discovered by a local state-funded geological expedition only in 1995, during soil geochemical and geophysical surveys, which accompanied geological mapping and exploration. It was the first discovery of a large gold deposit after some ten years of unsuccessful exploration efforts in the CIS.

Local geologists continued exploration of the Kupol deposit with trenching and drilling until 2002, when the Russian government revoked the exploration license, on account of nonpayment by contractors and incomplete reporting. Since December 2002, the Bema Gold Corp. has successfully finished exploration and in the period 2005-2006 started to develop the Kupol deposit. The following description of the deposit was kindly authorized by the Bema Gold Corp. and is based on the results of its exploration and on a brief visit to the site by the author in May 2005.

The Kupol deposit is at the north end of the 3000 km long Mesozoic Okhotsk-Chukotka volcanic belt, which is similar to the Andean belt and marks the Cretaceous active margin of the Siberian continent. The Cretaceous andesite, rhyolite, and sometimes andesite-basalt volcanics of calc-alkaline series of the belt lie with sharp unconformity on folded Jurassic sediments to the northwest of the deposit and on all older structures of northeastern Russia.

The best-known Julietta, Karamken, and Khakandzha gold deposits and gold-silver deposits such as the Dukat and Lunnyi are located in the central and southern part of the Okhotsk-Chukotka volcanic belt. Only a few small gold deposits and numerous ore showings have been explored in the Chukotka part of the belt, which contains many gold placers and gold-bearing the Peschanka and Nakhodka porphyry copper-molybdenum deposits. The porphyry mineralization is similar to deposits in the Andean volcanic belt of South America. The discovery of the Kupol deposit indicates that the Chukotka part of the volcanic belt has a higher potential for lode gold than was expected before.

The deposit area is situated near the boundary of the 11 x 5-7 km Kovalevsk caldera, which is located along the western margins of a 100 km wide Late Cretaceous volcano-tectonic depression. There are two main fault systems: the north-south Kaiyemraveyem regional fault and the northwest-southeast-trending Malyi Anui River strike-slip fault. The volcanic succession in the area is 1,300 m thick.

The Kupol deposit is located on the ring structure of the Kovalevskii volcanic caldera at its intersection by the north-south Kaiyemraveyem regional fault. This combination resulted in the intrusion of rhyolite dikes, a rhyolite and dacite flow-dome complex, and basalt dikes into the Upper Cretaceous (?) andesite sequence (Fig. 54). This sequence is more than 700 m thick and hosts most of the explored zones of mineralization.

The stratigraphically lowest unit identified to date in the deposit area consists of laterally continuous and massive feldspar phyric or porphyritic andesite and amygdaloidal andesite interlayered with andesite pyroclastics that form several traceable markers. Continuous and discontinuous layers of ash, lapilli, and pyroclastic agglomerate tuffs make up 5-10% of the andesite sequence and are up to 20-30 to 100 m thick.

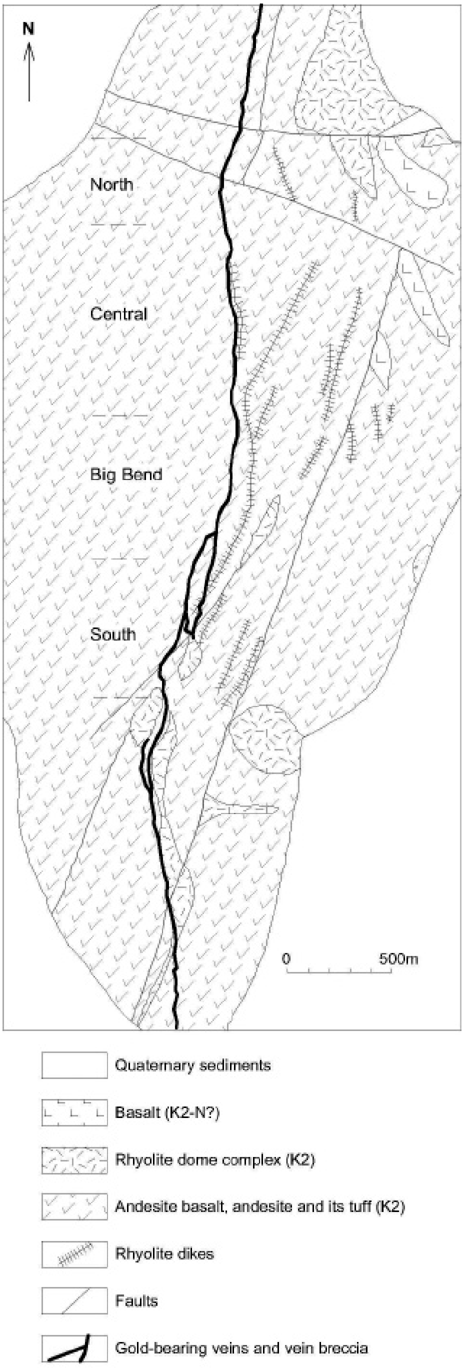


Figure 54. Schematic geologic map of the Kupol deposit (after Bema Gold Technical Report, 2005).

The composition of the andesite sequence, with its prevalence of massive varieties of volcanics, continuity of marker tuff units, and relatively few coarse-sized fragments, suggests that this sequence is distal to a vent area and may represent volcanics outside the caldera boundaries.

The upper units of the andesite sequence are overlain unconformably in the north and east part of the explored area by Paleocene basalt flows with a narrow regolith at the base. The basalt flows are spatially associated with but postdate massive and banded rhyolite-rhyodacite, which may belong to flow-dome complexes and eruptive centers.

Subvolcanic basalt and rhyolite dikes intrude into the andesite sequence. The basalt forms mainly narrow dikes 1.5-6.0 m thick throughout the main mineralized area, and an irregular northeast-trending stock or large dike intersected by drilling in the central part of the mineralized area. Basalt dikes cut the veins and in turn are cut by rhyolite dikes and faults.

Rhyolite and rhyodacite dikes comprise 20-25% of the rock volume in the 100 to 200 m wide north-northeast-trending corridor in the central and south parts of the deposit. The dikes form an anastomosing network that follows the Kupol vein system and frequently pass through or split the veins. Individual dikes vary in thickness between 0.1 and 20 m and are sometimes up to 50 m thick, with a length of up to 1 km along the vein corridor. The rhyolite dikes fill dilational structures but do not displace the vein system.

The structure of the Kupol deposit mineralized zone is defined by the pre- or syn-mineral, north-south-trending splay of the regional Kaiyemraveyem fault. The main vein system of the same strike is a linear fissure that dips steeply to the east at 75-90° and contains local dilational jogs, sinusoidal sways, and sigmoidal loops (see figure 54). The jogs often correspond to thickening of the veins and development of ore shoots.

The syn- to post-ore faults are mainly northeast trending and are filled by rhyolite dikes that do not appear to offset the vein structure. The postmineral faulting has west-northwest, north-northeast, and north orientations, with dips in varying directions. The west-northwest- and north-northeast-striking faults with steep southwest to vertical dip are typical of the southern part of the deposit and exhibit minor (<1-3 m) to large (up to 20-40 m) dextral or sinistral displacements. The most significant post-ore faults are located in the northern part of the explored area and have produced downthrown displacements from 20-40 up to 100-150 m as determined by the position of veins and stratigraphic markers. All the faults can be traced by discontinuous zones of clay gouge and cataclastic breccia up to 15 m thick along the full length of the vein structure.

Regional propylite alteration of volcanic host rocks (chlorite-sericite-calcite ± pyrite ± epidote) occurs within 400 m of the Kupol vein system, mainly at its hanging wall, and coincides with a zone of magnetite destruction. More local argillic syn-ore alteration is interpreted as steam-heated or advanced argillic alteration at the top of the hydrothermal system. This alteration affects the pyroclastics more strongly than the flow units and extends 40-150 m into the hanging wall of the structure and up to 10-15 m locally into the footwall. Clay alteration is often accompanied by calcium carbonate ± pyrite and is stronger in the northern part of the deposit, while clay-acid sulfate (jarosite-gypsum) alteration zone with dominant kaolinite continues to the south. A broad chlorite zone replaces clay alteration at the deep levels of the system and consists of chlorite-pyrite ± magnetite-rich bands and clots within the banded quartz veins.

Another type of near-vein hydrothermal alteration consists of silica, adularia, and pervasive illite and sometimes extends up to 40 m from the vein contacts.

Colloform and crustiform-banded quartz-adularia veins and polyphase breccias host the gold-silver mineralization of the Kupol deposit. According to S. Vartanyan, Yu. Schepotiev, and L. Bochek of TsNIGRI, who in the early stage of exploration studied the mineralization of this deposit, sulfide mineralization generally amounts to less than 2% of the vein and breccia material but may reach 7%. The main gold and silver minerals are electrum, kustellite, native gold, silver-rich freibergite, acanthite, and numerous kinds of sulfosalts in association with marcasite, chalcopyrite, sphalerite, and pyrite. Arsenopyrite and galena are less common, and stibnite is rare. Minor selenium-bearing sulfosalts (stephanite, pyrargyrite, acanthite), naumannite, and berthierite are also present. The main vein minerals are quartz and adularia, with small amounts of hydromica, sericite, chlorite, rare albite, natrolite, pyrophyllite, and anhydrite. Fine-sized (0.005-0.1 mm) ore minerals occur in banded quartz-adularia veins.

The sequence of the hypogene stage mineral complexes identified during the early stage of exploration include (1) a pyrite adularia-quartz *preproductive* complex and association; (2) a arsenopyrite-pyrite-adularia-quartz *low-productive* complex with arsenopyrite-pyrite, tennantite-pyrite, and amethyst-quartz mineral associations formed at 260-185°C; (3) the *main-productive* gold-stephanite-pyrargyrite-adularia-quartz stage with gold-pearceite-chalcopyrite (265-240°C), gold-freibergite-stephanite-pyrargyrite (220-200°C), and gold-aguilarite-Se pyrargyrite mineral associations (180-160°C); and (4) a stibnite-marcasite-quartz *postproductive* complex with pyrite-marcasite, berthierite-stibnite, and gypsum-anhydrite-chlorite mineral associations formed at 240-220°C.

The acid-sulfate supergene stage includes an acanthite-jarosite complex with acanthite-covellite, acanthite-jarosite, alunite, gypsum, and iron-hydroxide mineral associations.

Gold and electrum are the most valuable minerals of the Kupol deposit. The native gold is mostly fine-grained (<0.74 mm), but the size of the gold particles varies from 0.005 to 2.2 mm. The particles form interstitial platelike and angular grains that are often lumpy and sometimes spongy with an uneven, porous surface. Gold particles over 1 mm in size form intergrowths with quartz, hydromica, chalcopyrite, tennantite, perceite, freibergite, and pyrargyrite. Gold particles of the main productive complex have fineness between 610 and 735, while the earlier, low-productive, complex contains higher-fineness (850-875) gold. However, some gold particles have fineness as low as 298.

According to selective float sampling, the gold grades in the low-productive mineral complex do not exceed 1.9 g/t of gold and 20 g/t of silver. In the main productive complex, however, the gold grades vary widely, reaching 5,589 g/t of gold and 9,940 g/t of silver in some float samples. The average ratio of gold to silver varies from 1:4 to 1:20.

The vein and stockworklike ore bodies of the Kupol deposit occur in a steeply dipping mineralized zone that has been traced for more than 3,500 m and that was divided during exploration into six ore zones with different structural and morphological characteristics (see figure 54). The Big Bend ore zone, for example, is located in an area where there is a directional change in the mineralized structure. The ore zone is comprised of a large single-banded fissure vein with associated veining traced for about 575 m along strike and 200-400 m deep. The true width of the vein varies between 0.25 and 15.5 m, averaging 4.82 m, and the vein is accompanied by a lower-grade stockwork mineralization up to 30 m wide. The ore zone is divided into footwall and hanging-wall segments by a rhyolite dike up to 20-40 m wide (Fig. 55). The average gold and silver grades for this zone are 29.07 g/t and 358.7 g/t, respectively.

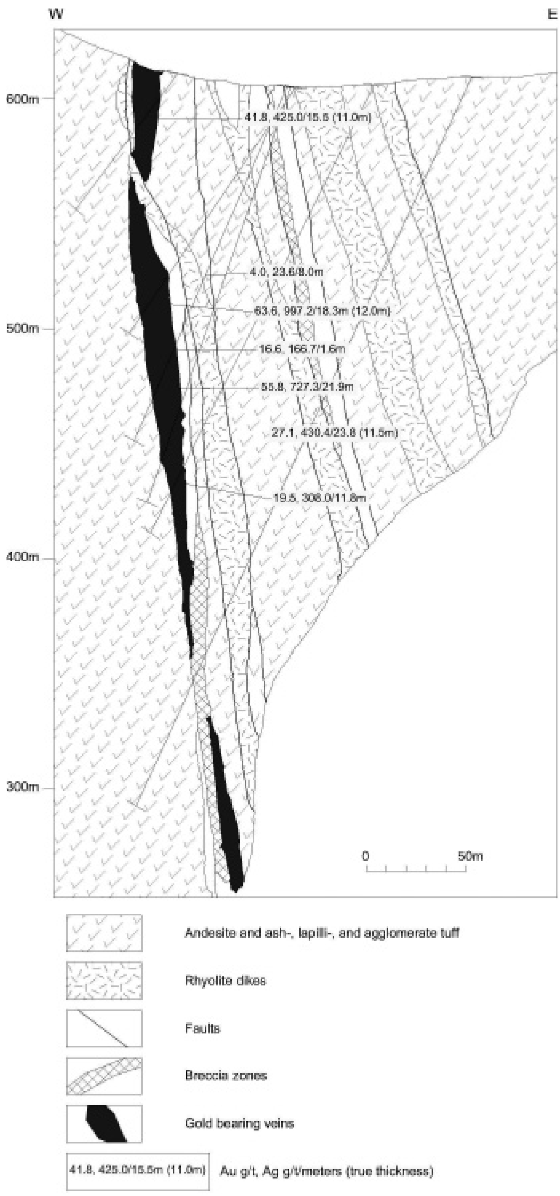


Figure 55. Kupol deposit. Cross section of the Big Bend zone (simplified after Bema Gold Technical Report, 2005).

The Central ore zone, located directly to the north of Big Bend, ranges in width from 5 to 30 m and can be traced for more than 800 m along the strike and to 430 m below the surface. The mineralization is concentrated in one or two continuous colloform-banded and brecciated veins 0.29-19.33 m wide (averaging 3.81 m) enveloped by stockwork veining up to 9-10 m wide. The ore zone contains three high-grade shoots with up to 223.9 g/t of gold and 2,674 g/t of silver, which range in length from 75 to 175 m and are open to depth. Lower-grade areas, dikes, and faults separate the ore shoots.

Other ore zones to the south of Big Bend (the South and South Extension zones) and to the north of the Central zone (the North and North extension zones) contain from three up to five quartz-adularia veins of smaller length and width, as well as lower gold and silver grades.

The average gold grade across the vein width varies from less than 2 to 64 g/t. The grade is much higher in ore shoots, but mineable gold grades at the cutoff of 6 g/t averaged from about 11 to 29 g/t in different parts of the ore zones. The mineable silver grade averaged between 145 and 358 g/t.

The gold-bearing veins and breccias have different textures, from massive to banded colloform and crustiform, comprising cyclical banding of chalcedonic to fine-grained quartz and sulfide/sulfosalts. Most of the high-grade mineralization is concentrated within the banded veins. Smaller amounts of gold and silver are found in stockworklike vein mineralization located either within the main veins or, more often, in the hanging wall or footwall of the vein system. Some of the gold-silver mineralization also occurs within quartz breccia.

Supergene gold-silver enrichment has not been detected at the Kupol deposit: the gold-grade values obtained by surface trenching and undercut drilling correlate well. Weak to moderate oxidation with limonite, goethite, hematite, and hydrous oxides occurs near the surface in and near mineralized zones along fractures. The fracture-controlled oxidation in the ore zone has a maximum depth of 175 m below the surface, but intense oxidation is developed mostly to depths of 45-75 m.

According to a Bema Gold Corp. news release of May 25, 2006, the probable reserves of the Kupol deposit are 8,225,000 tonnes of ore grading 16.8 g/t Au, or about 4.45 Moz of gold, and 205 g/t Ag, equal approximately to 54.2 Moz of silver.

The wide distribution of colloform- and crustiform-banded ore-bearing quartz-adularia vein structures with ovoid, globular, and spheroid adularia aggregates at the Kupol deposit is typical of volcanic-related epithermal gold-silver deposits. Study of fluid inclusions in quartz indicates that ore deposition occurs from a predominantly low-salinity (0.4-8.3 wt. %) hydrothermal solution that mixed with meteoric water at low pressure not exceeding 200 bar of saturated vapor.

The Karamken Deposit (60°23'N-150°51'E)

The deposit is located on a tributary of the Khasyn River about 100 km to the north-northeast of the city of Magadan, the regional capital of northeast Russia. It was discovered in 1964 and completely mined out by the beginning of the 1990s.

The Karamken deposit is on the southeast flank of the Arman depression of the Okhotsk-Chukotka volcanic belt and is confined to the northeastern part of a relatively small (30 km^2) volcanic caldera, near an east-west major fault (Konstantinov et al. 2000; Bryzgalov 2001).

The caldera's basement is made up of Early-Middle Cretaceous andesite and coarse sedimentary facies intruded by hypabyssal stocks of potassium-low granite porphyry and quartz diorite porphyry. Late Cretaceous dacite and its pyroclastics fill the lower part of the caldera, while the middle section is composed of andesite-basalt volcanics, and the upper part is made up of rhyolite tuff and ignimbrite. The Late Cretaceous volcanics are intruded (in the following order) by subvolcanic bodies of dacite and rhyodacite; automagmatic breccia of andesite and trachyandesite, rhyolite and trachyrhyolite, and post-ore basalt and lamprophyre dikes (Fig. 56). The subvolcanic bodies are accompanied by pipelike explosion breccia with quartz-sulfide matrix.

The caldera structure is emphasized by semicircular faults and fanlike fractures, by the concentrically distribution of the volcanic facies, and by the clearly zonal distribution of alteration. The intensive silicification and near-vein quartz-hydromica-adularia and quartz-kaolinite facies of alteration are developed in the central part of the ore field, while low-temperature propylitic quartz-chlorite alteration is widespread at its periphery. The ore is overlain by an aureole of hydrothermal alteration consisting of quartz-kaolinite-alunite and a high sulfidization zone (Sakharova et al. 1998).

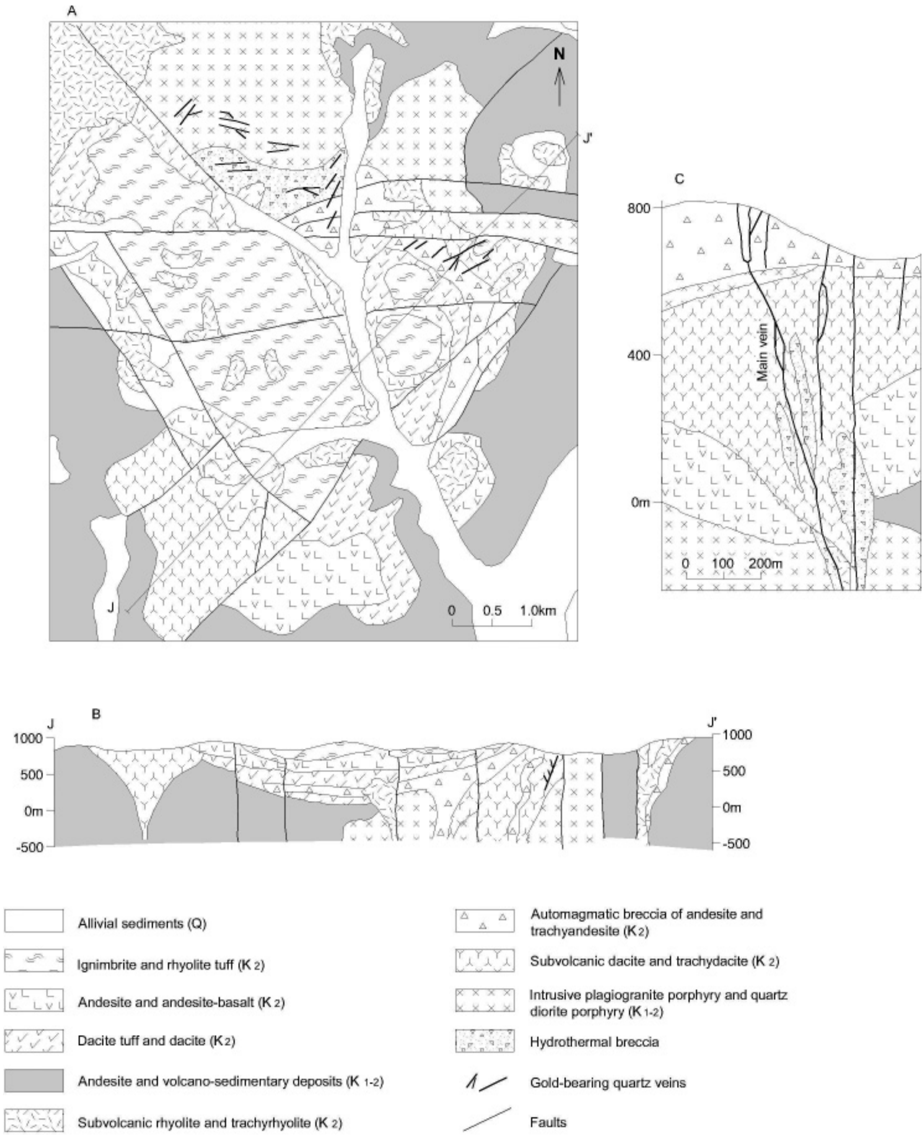


Figure 56. Karamken deposit. Geologic map (A), cross section (B) of the deposit, and cross section of the Glavnaya ore zone (after Konstantinov et al. 1992).

The ore bodies are concentrated in the upper part of the rhyolite-dacite sequence. They are grouped into three sectors in the northern and northeastern parts of the caldera: the eastern (main one), central, and northwestern. The eastern sector, with up to 80% of the deposit reserves, is situated at the northeastern margin of the caldera with a semicircular subvolcanic body of rhyolite and dacite playing a substantial role in its structure. It contains 14 ore bodies, of which the Glavnoye (main) ore zone makes up more than 75% of mineable reserves. This zone consists of a northeast-striking, steeply dipping quartz-adularia-calcite vein zone with a few subparallel veins and apophyses (see figure 56c). The thickness of the veins is 0.1-7.0 m with an average of 2.0 m. The vein zone traced for about 800 m along the strike and more than 400 m down dip.

The Glavnaya vein has sharp contacts with host rocks and a relatively simple platelike shape. The rhythmically banded, colloform, scalloped, and lamellar structures of the shallow part of the deposit, which are typical of the entire class of the epithermal deposits, changed to coarse-lamellar and massive structure at deep levels.

The ore bodies consist of veins and mineralized zones of quartz, quartz-adularia (with the highest gold grades), and carbonate-adularia-quartz composition with hydromica, ferriferous carbonate, chlorite, montmorillonite, kaolinite, dickite, dolomite, and zeolite as accessory minerals. Ore minerals, 0.05-0.5 mm in size, constitute no more than 0.5-1.5% of the vein volume and consist (Konstantinov et al. 2000*)* of pyrite, chalcopyrite, sphalerite, galena, marcasite, freibergite, tennantite, sulfostannates (selenium canfieldite, stannite, and franckeite), selenides (naumannite, aguilarite, and berzelianite), silver sulfosalts (pyrargyrite, miargyrite, polybasite, and proustite), electrum, kustellite, and silver. Bryzgalov (2001) also has described the presence of arsenopyrite, cassiterite, and hessite in the main vein.

Silver-rich sulfides include (Sakharova et al. 1998) silver-bearing gray copper ore, especially freibergite, which contains from 15-30 to more than 50 wt. % of silver and has high contents of Sb, Hg, and Se. Selenium-bearing canfieldite (up to 10.7 wt. % Se) is one of the main silver minerals in the upper levels of the ore bodies. According to this study, other silver-bearing minerals are jalpaite and sternbergite, and Sb-bearing stephanite and perceite. The ores of Karamken are notable for their high selenium content, the dominant role of silver-rich sulfoantimonite, and the presence of sulfostannates, which reflect the close relationships of Ag to Sb and Sn.

Several mineral stages (complexes) include (Konstantinov et al. 2000) an early quartz-adularia-sulfide complex with quartz-pyrite, hessite-polymetal, and quartz-hydromica-adularia mineral associations. The first productive, gold-adularia-quartz, complex consists of pyrite-sphalerite-canfieldite, gold-adularia-quartz, and quartz associations. Native gold (600 fineness) is associated with quartz and is one of the major minerals. The presence of cassiterite, stannite, and canfieldite is typical of the complex.

The second productive, gold-quartz-polymetal, complex includes gold-pyrite, gold-chalcopyrite-freibergite, and gold-polybasite associations that also contain sphalerite, galena, canfieldite, polybasite, electrum, and native silver. The gold contains admixtures of Se, Te, Cu, and occasionally Sb; and its fineness decreases from the early association (549) to the late ones (400).

The third productive, gold-silver-quartz-carbonate, stage consists of corrensite-gold-pyrite and silver-naumannite-polybasite mineral associations. The last one is typical of the upper parts of the ore bodies.

In general, the mineral associations of the early quartz-adularia-sulfide complex occur commonly at the lower levels of the deposit, while the area with all the three gold-productive mineral associations decreases with depth. The amounts of adularia, carbonate, and hydromica and the gold and silver grades also decrease from the upper to the lower horizons of the Karamken deposit.

The native gold forms (Bryzgalov 2001) an impregnation of rounded, elongated, or interstitial angular grains in quartz up to 30-60 μm and in rare cases 1-1.5 mm in size. The gold grains are concentrated often at the contact between quartz and quartz-adularia rhythms or form intergrowths with pyrite and chalcopyrite. The gold also is associated with sphalerite and tennantite-tetrahedrite.

The native silver forms grains of complex shape that cement all early deposited minerals, including native gold. The silver grains often contain abundant inclusions of polybasite, acanthite, and other silver minerals, which indicate that its deposition occurs in the final stages of mineralization.

A. Nekrasova (Konstantinov et al. 2000) has identified in ore of the Karamken deposit a native gold of heterogeneous composition, such as electrum I (590-690), electrum II (370-415), kustellite (130-250), and native silver.

The native gold and native silver, respectively, contain up to 1.86 wt. % and 3.29 wt. % mercury (Bryzgalov 2001). The amount of Sb in the native silver is reaching 5.55 wt. %. Such elements as Fe, As, Bi, S, Te, Cu, As, and Se are found in about one-tens of all analyzed specimens ranging in amount from 0.2 to 0.5 wt. %.

According to experimental data quoted by I. Bryzgalov, the cassiterite-sulfide mineral complex of the Karamken deposit was deposited from solutions with relatively low sulfur content (fS_2 = 10^{-2}-10^{-22} bar) at low oxygen fugacity (10^{-30} bar) and at a temperature of 249 ± 30°C. The conditions of mineral formation for Au-Ag associations varied considerably. The early freibergite-canfieldite association was deposited at temperatures of 240-180°C from near-neutral solutions, while the late polybasite-selenide association was deposited at a temperature below 122°C. The oxygen fugacity was relatively low (fO_2 = 10^{-55}-10^{-40} bar).

The experimental data are similar to the data on homogenization of fluid inclusions in quartz (Sakharova et al. 1998), according to which the ore deposition temperature ranged over the interval 300-100°C with crystallization of gold-bearing parageneses at 240-180°C. The shallow depth of ore deposition (0.5-1.0 km) resulted in the unstable deposition regime, loss of volatile components such as Cl, F, and CO_2, the decrease in H_2S partial pressure, and the change in the sulfur and oxygen regimes. The fluctuation of physical and chemical parameters is responsible for the rhythmic crystallization of the ore and gangue vein minerals. According to S. Struzhkov (TsNIGRI), the Ar-Ar age of mineralization of the Karamken deposit varies between 78.4 and 79.5 Ma.

Total gold reserves of the Karamken deposit were nearly 2 Moz (59 t). Two metallurgical tests (Moiseenko and Eirish 1996) showed gold grades of 39.8-40.1 g/t, while the silver grade varies from 69.4 to 164 g/t. However, the gold distribution was typically bonanza-like. Ore shoots with gold and silver grades up to hundreds of grams per tonne dipped to the southwest, toward the center of the caldera and confined often to mylonite zones or to the contact of subvolcanic dacite with hydrothermal breccia.

The Karamken gold-silver ratio varied from 1:2-1:4 in the upper levels of the rich ore bodies to 1:14 at their deep intersections.

The Baley and Taseevo Deposits (52°15'N-113°01'E)

The Baley ore field with the Baley and Taseevo deposits is located in the outskirts of the town of Baley in the Transbaikal region of Chita Oblast (Russia). The Baley deposit was discovered in 1927 in the vicinity of well-known placer deposits that have been mined from the 1830s. Drilling in 1941 discovered the blind ore bodies of the Taseevo deposit. These two large gold deposits are located nearby and have similar geotectonic settings and mineralogical features modified to the lithology of the host rocks. The Baley ore bodies are hosted by Paleozoic granodiorite, while the Taseevo ore bodies are hosted by slightly metamorphosed Mesozoic volcanogenic-sedimentary rocks (Borodayevskaya in Smirnov 1977; Yurgenson and Grabeklis 1995).

The ore field is confined to the Mesozoic Baley graben located in the northern part of the Paleozoic Mongolian-Okhotsk fold belt, which underwent Mesozoic riftogenesis and intraplate effusive and intrusive magmatism. The graben is part of the Undino-Dain depression controlled by the regional northeast-trending Borshchevochny fault and is located at the intersection of the depression by the northwest-striking regional Baley-Darasun fault system (Fig. 57).

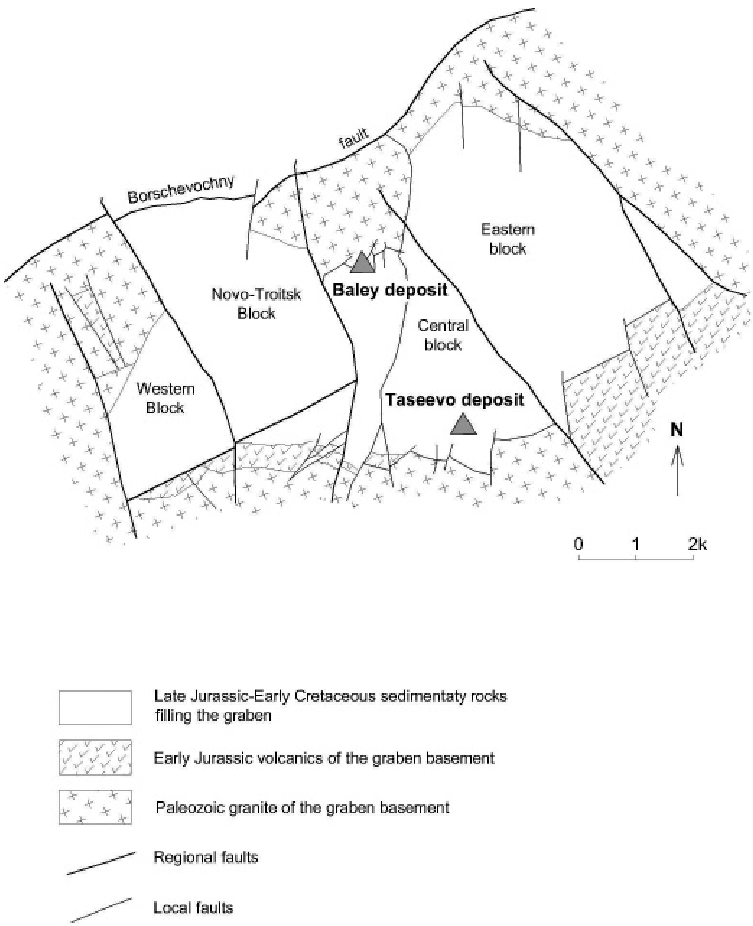


Figure 57. Scheme of the Baley graben block structure (after I. Eleeva, TsNIGRI).

The Baley graben is filled with Late Jurassic-Early Cretaceous cryptovolcanic-sedimentary and slope wash sediments. The basement of the graben consists of Late Paleozoic granitoids covered in the southern and western parts of the graben by Jurassic andesite-dacite volcanics about 200 m thick, which outcrop along the southern boundary of the graben.

The Late Jurassic-Early Cretaceous stratigraphic sequence of the Baley graben is subdivided into three parts. The lower (Baley) part begins with heterogeneous conglomerate containing lenses of sandstone and gravelstone changing in the upper part to sandstone with interlayers of conglomerate and siltstones. The upper part of this section, the Upper Baley formation, consists of breccia and conglomerate breccia thick horizons with layers of sandstones, siltstones, gravelstone, and conglomerates. An interlayer of andesite-dacite tuff is located at the base of the Upper Baley formation, while the chert bodies often are developed near the top, defining the upper boundary of ore mineralization (Fig. 58).

The middle section of the graben sediments (the Novotroitsk formation) consists of a similar intercalation of sandstone, conglomerate breccia, and grus with a horizon of volcanic conglomerate at the base. The upper part of the graben is filled with variegated Early Cretaceous conglomerate of the Kamensk formation.

N. Fogel'man (TsNIGRI) has described at the Baley deposit outcrops of dikelike explosion breccia and silicified tuff, which, together with the tuff horizon at the base of Upper Baley formation, she regards as cryptovolcanic manifestations of the Early Cretaceous volcanism responsible for the development of the epithermal gold mineralization of the Baley and Taseevo deposits.

The sedimentary formations of the Baley graben form a gentle syncline complicated by numerous linear and arcuate faults of the northeast, east-west, and north-south directions. An important role belongs to northwesterly transverse ore-concentrating faults, which also control the Darasun deposit farther to the northwest. These faults divide the Baley graben into the West, Novo-Troitsk, Central, and East large blocks, which have sunk to different depths (see figure 57). The principal commercial mineralization is concentrated in the Central block with the most intensive tectonic deformations.

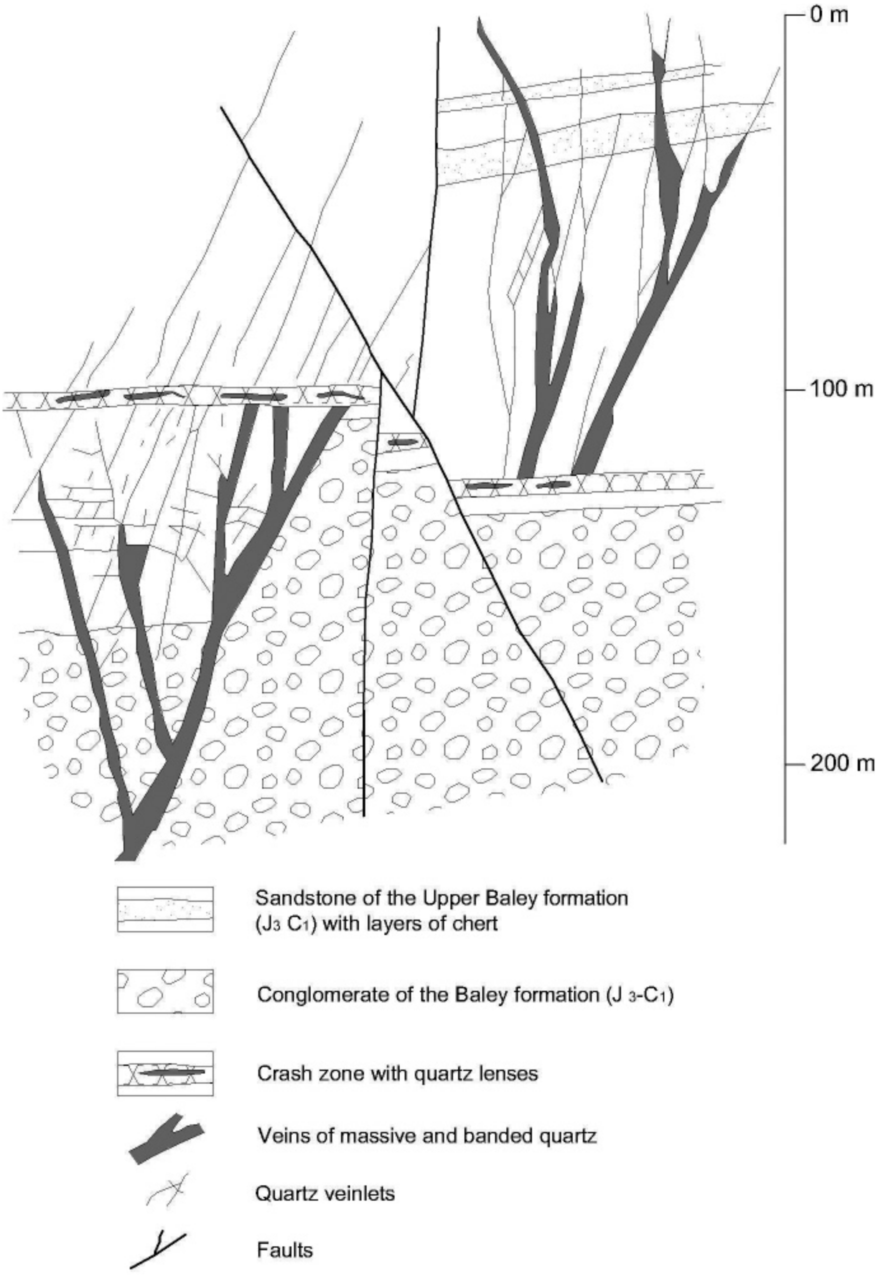


Figure 58. Distribution of quartz-vein apophyses at the conglomerate-sandstone contact of the Upper Baley formation (simplified after Yurgenson and Grabeklis 1995).

There is a substantial difference in the structure of the north and south sectors of the ore field, which respectively contain the Baley and Taseevo deposits. The structure of the north sector has been determined by a combination of flat-lying concentric crush zones, formed over a dome due to granite intrusion, and steeply dipping joints associated with northerly faults. These systems are developed both in the graben sediments and also in the granodiorite pluton adjoining the graben.

The two types of the Baley deposit's ore bodies inherit the structural systems described above. The ore bodies in the gently dipping concentric structures are short and thin lenticular quartz veins in crushed and silicified zones. At the center of the dome structure, such zones and veins are almost flat, but at the periphery their dip angle increases to 50-60°. The ore bodies in steeply dipping joints form cross connectors between the previously described ore bodies. They have a complex shape, are near vertical, and together with the ore bodies of the concentric structures form a stockworklike network of thin (0.1-0.2 m), short veins.

The southern sector, which contains the Taseevo deposit, is characterized by near-horizontal bedding of clastic Jurassic-Early Cretaceous sediments intersected by extensive, steeply dipping northeasterly and east-west faults. All the major veins of the Taseevo deposit are confined to such faults and have greater thickness and length. The ore bodies in faults with a single seam or small numbers of seams have a relatively simple vein shape. Such veins are longer (200-300 m) and wider (1-2 up to 3-4 m) than at the Baley deposit. Inside the multiseam faults of the southern sector, the ore bodies are vein-veinlet series in zones 100-200 m wide and from 600 m to 4 km long. These zones have usually the core vein surrounded by numerous apophyses, thin veins (5-10 cm), and veinlets.

The longest quartz veins are confined to the northeast shear fractures, while some of their apophyses and veinlets of later quartz inside the core veins are located in rupture joints. The apophyses tend to develop mostly at the contact zone of conglomerate and overlying sandstone of the Baley formation (see figure 58). The current position of the ore's upper boundary is determined by the gradual plunge of portions of the veins to the northeast as a result of post-ore north-south faults.

The ore veins of the Baley and Taseevo deposits consist of chalcedonic quartz of festooned and platy structure (50-99%); calcite, dolomite, and ankerite (0.1-20%); kaolinite and dickite (0.1-20%); and adularia (0.1-20%), mainly in ore shoots. The amount of sulfides is 0.5-1.5%, occasionally rising to 3-5%. The main ore minerals are pyrite, marcasite, berthierite, arsenopyrite, chalcopyrite, galena, sphalerite, stibnite, tetrahedrite, pyrargyrite, miargyrite, freibergite, and stephanite. Hessite, calaverite, and telluride of bismuth occur sporadically.

Gold is the most widely encountered mineral in the ore and often is associated with freibergite and tetrahedrite. The gold-silver ratio varies from 3:1 to 1:2 in the ore shoots and is 1:2-1:4 outside them. The bulk of the gold consists of a finely dispersed variety of greenish color. Coarser-grained particles (0.2-0.5 mm) of yellow color are less frequent. The gold grades sometimes are reaching hundreds of kilograms per tonne of ore. Available data for the Taseevo deposit (Highland Gold's scooping study, 1995) showed an average gold grade during 1946-1994 operations of 12.2 g/t.

Gold is found not only in the veins but also in the intervein spaces with veinlet mineralization that forms typical ore shoots. Despite the significant length of the veins down dip (400-600 m), commercial gold grades and the main ore shoots are confined to a vertical interval of 250-300 m. In this zone, the gold grades increase twentyfold over the average grades from the flank of the veins to their core parts.

The pre-ore mineral associations consist of dark quartz, pyrite, marcasite, arsenopyrite or light-colored quartz, and pyrite. The adularia-quartz and kaolinite-hydromica-quartz veins with gold-gray copper ore-miargyrite and gold-telluride early productive mineral associations are developed only at the margins of the Baley and Taseevo deposits. The late productive, gold-pyrargyrite-miargyrite-quartz, association is distributed not only inside the deposits but also outside their boundaries. The veinlets of quartz-arsenopyrite and stibnite-quartz composition are post-ore associations.

Different inner structures of the gold ore bodies are developed in different stages of ore deposition. The following succession of structures is typical in general: (1) brecciated or banded preproductive structures; (2) banded (festooned), rhythmically banded, massive micro- and macrospherulite, and platelike productive structures; and (3) massive, coarse-banded, cavernous, and druse- and comblike post-ore structures.

The multiphase hydrothermal alteration of the host rocks along the ore bodies are represented by early quartz-carbonate-chlorite-pyrite and propylitic alteration, followed by argillic alteration of kaolinite, dickite-kaolinite, montmorillonite, and hydromica facies. The sandstone host rocks along quartz veins are silicified, pyritized, and argillized for a distance of up to 100 m, whereas gold veins cutting conglomerate have narrow (2-3 m) alteration envelopes. Adularization accompanies the ore bodies that are richest in gold. The thickness of the alteration envelopes decreases with depth.

The lateral and vertical zoning of the Baley and Taseevo deposits is determined by decrease of the gold-productive and late mineral associations toward the flanks of the veins, with a simultaneous increase in preproductive associations. The preproductive mineral associations are widely distributed vertically, while the zone with maximum development of gold-productive associations includes only the middle and upper parts of the ore bodies. The amounts of silver sulfosalts, adularia, and gold decrease in the lower parts of ore bodies. Miargyrite and pyrargyrite disappear almost entirely, and gold is associated mainly with gray copper ore, chalcopyrite, and pyrite.

Computer modeling of ore formation at the Baley-Taseevo deposits (Yurgenson and Grabeklis 1995) showed that mineralization of the quartz veins occurs in the temperature interval 500-100°C and at pressures of 30-40 MPa. According to another study (Spiridonov et al. 2001), the temperature interval for these deposits was between 355 and 130°C, and the pressure was 16.5-4.5 MPa.

The Baley and Taseevo deposits have been mined since 1929 and 1947, respectively, and have produced significant amounts of gold; but different authors give different gold outputs for this period. According to Yurgenson and Grabeklis (1995), the mines have produced more than 1,000 tonnes of gold. Another estimate (Leshkov et al. 2000) is significantly lower: 300 tonnes of gold for both deposits. The Highland Gold PLC data for past production from the Taseevo deposit only confirm its gold output from 1946 to 1994 as 198.5 tonnes. The higher gold grades of the Baley deposit and its longer period of operation (since 1929) suggest much larger gold output from this ore field, in the range 500-600 tonnes, making it comparable in size to the largest epithermal deposits, such as Cripple Creek in the United States or Ladolam and Porgera in Papua New Guinea.

Residual indicated gold resource of the Taseevo deposit suitable for open-pit operation is 25.4 million tonnes of ore grading 3.4 g/t, or 2.78 Moz.

The Kuranakh Deposit (Ore Field) (58°15'N-126°40'E)

This ore field is located in the Aldan Ulus (district) in the southern part of the Republic of Sakha (Yakutiya), about 50 km south of the town of Aldan (Russian Federation). The central ore body of the Kuranakh deposit was discovered in 1950 after reconnaissance of the area, using previous data on existing piles of mineralized quartz rocks with a gold grade up to 13.2 g/t. Exploration of the deposit started immediately and led to development of the first mine in 1956. Exploration was continued on and off until the 1990s.

In a geotectonic sense, the Kuranakh ore field is situated on the north slope of the Aldan shield where the Archean crystalline basement dips under the platform cover (Konstantinov et al. 2000; Vetluzhskikh et al. 2002). The Archean basement consists of biotite-amphibole and pyroxene-amphibole gneiss, schists, and granitoids; but it does not crop out in the area. The Vendian (Late Precambrian)-Early Cambrian platform cover of variegated limestone, marl, and dolomite with basal conglomerate and sandstone overlies the crystalline basement and dips 2-3° to the north. The thickness of the platform cover in the ore field area is 650 m. The cavernous and porous limestone and dolomite contain unevenly distributed organic matter and are pyritized.

An Early Jurassic continental formation, up to 70 m thick, of fine-grained feldspar-quartz sandstone with interlayers of pebble conglomerate and clay horizon lies on the eroded surface of Cambrian carbonate sequences. The Jurassic sediments have been preserved mainly in the watershed areas of the ore field. Fragments of pre-Jurassic residual weathering material are found along the contact between the Jurassic and Cambrian sequences. This material consists of carbonate-rich weathering crust of variable thickness (0-15 m) containing weathered fragments of limestone cemented by clay. The rocks of this layer are intensely ferruginous and contain an elevated amount of gold.

Extensive karst zones, formed in Cambrian carbonate sequences during post-Jurassic development, are filled with coarse, unconsolidated deposits of clayey-sandy matrix containing boulders and smaller fragments of carbonate and sedimentary rocks, Mesozoic dikes, and hydrothermally altered rocks with sulfide mineralization.

Mesozoic intrusives of subalkaline and alkaline hornblende syenite porphyry, augite-biotite porphyry, bostonite, and lamprophyre form sills, steeply dipping small stocks, and northerly-trending dikes confined to faults. Small necks of potassic picrite and subvolcanic potassic trachyte are known in the western part of the ore field.

The Cambrian and Jurassic formations underwent intensive silicification, low-temperature K-feldspathization, pyritization, and development of iron hydroxides along their contact. The silicified carbonate rocks contain fine-grained chalcedony quartz and quartz with relics of colloform structure. Feldspathization of the carbonates leads to the almost-complete replacement of the carbonate rocks by fine-grained, near-monomineralic K-feldspar zones, 0.3-0.5 to 5-10 m thick. The feldspathization of the Jurassic sandstone and clay horizon is fixed by the introduction of K and SiO_2 and the replacement of microcline by more stable low-temperature modification.

The Kuranakh ore field coincides with the Kuranakh grabenlike depression, 15-20 km wide and up to 30 km long. The depression is intersected by north-northwesterly normal faults that divide the ore field into zones (Fig. 59). The western zone controls the Bokovoye, Pervukhinskoye, and Yuzhnoye (south) ore bodies (deposits). The main central zone controls the Severnoye (North), Porphyry, Central, Yukokutskoye, and Kanavnoye (Trench) deposits. The eastern zone controls the Delbe and Dorozhnoye deposits and a few ore showings. The ore-controlling northerly structures are zones of crushing and jointing along low-amplitude normal faults.

Gold mineralization is confined to the contact zone of the Cambrian and Jurassic formations, developing a gold ore-productive horizon 150 m thick that often is associated spatially with northerly dikes. Two types of ore bodies are most common in the ore field: (1) bandlike bodies along the steeply dipping north-northwesterly and northerly-striking faults and Mesozoic dikes and (2) subhorizontal ore beds along the contact of the Cambrian and Jurassic formations. The last type is the

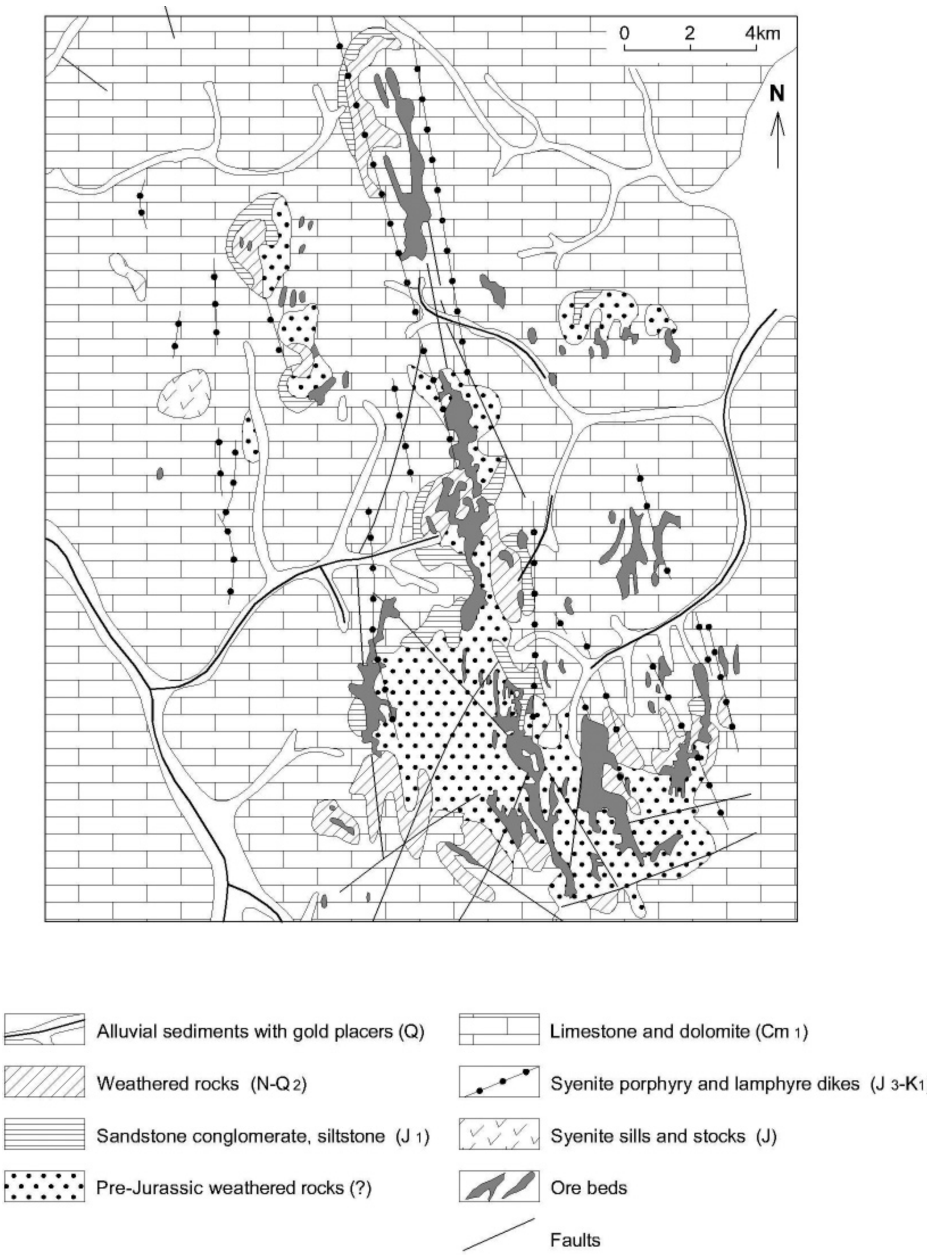


Figure 59. Structural scheme of the Kuranakh ore field (after Vetluzhskikh et al. 2002).

major one and contains most of Kuranakh's resources. Ore beds from 700 m to 2-4-6 km long and from 10-200 m to 700-1,000 m wide follow the relief of the pre-Jurassic depression and coincide with the karst contour. The thickness of the ore bodies varies from 1-2 to 50-60 m (Fig. 60).

At the footwall, the ore beds are separated from less altered, dense Cambrian rocks by a horizon of leached carbonate rocks, sometimes replaced by clay. The thickness of this horizon is uneven. The hanging walls of the ore beds are separated from dense unaltered Jurassic rocks by friable sandstones. Economic gold mineralization extends into the Jurassic sediments no more than 10-25 m above their contact with the Cambrian carbonate rocks.

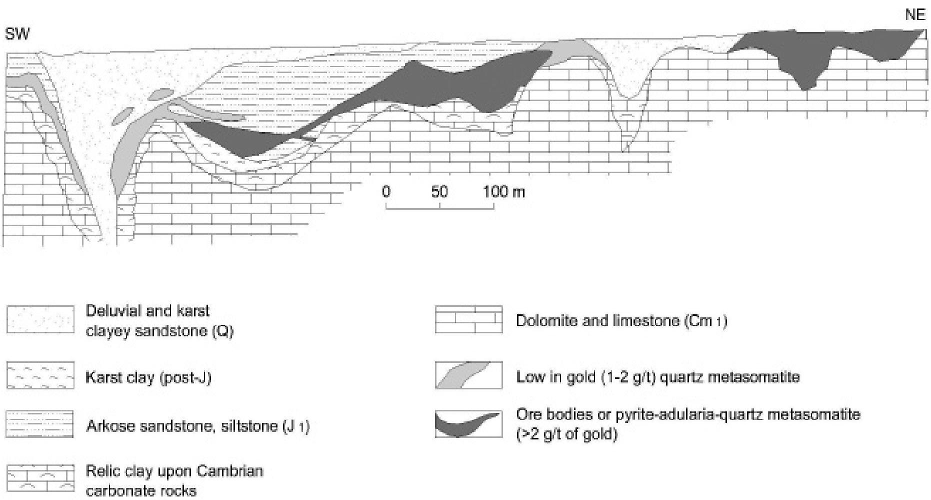


Figure 60. The central ore bed of the Kuranakh deposit: cross section along exploration line 17 (after A. Kazarinov, 1967 in Konstantinov et al. 2000).

The original shape of the ore bodies was almost tabular, but during weathering they underwent substantial change and now are defined by the contours of karst cavities. The ore beds are mainly single layers but sometimes split into two or three bands that are parallel in section and that are divided by sand or sand-clay material.

The gold ore bodies consist of pyrite-adularia-quartz replacement zones after the primary carbonate and quartz-feldspar sandstones, as well as after karst breccia of these rocks. They contain variable amounts of sulfides, mainly pyrite and iron hydroxides. The network of branched veinlets of hydrothermal, fine-grained, and comblike quartz penetrates Jurassic sediments at the hanging walls of the ore bodies.

The mineral composition of the replacement zone includes 70-95% quartz and feldspar, up to 25% adularia, and significantly lesser amount of calcite, sericite, barite, fluorite, and pyrite. The amount of pyrite can reach from 2-3 to 40%, while the amount of other ore minerals, including gold, chalcopyrite, magnetite, sphalerite, arsenopyrite, pyrrhotite, and gray copper ore, is no more than 1%.

The mineral composition of ore that has undergone supergene alteration is completely different: 47-74% quartz and feldspar, 2-35 to 40% hydromica and kaolinite, 10-38% hydrogoethite and hydrohematite, and 0.5-3% carbonates.

S. Yablokova (Konstantinov et al. 2000) has outlined several mineral associations of the primary ore. These are (1) adularia-quartz, (2) gold-pyrite-quartz, (3) gold-sulfide-quartz, (4) gold-telluride, and (5) late quartz associations. The early productive gold-pyrite-quartz association is ubiquitous and consists of fine-grained, ricelike quartz, pyrite with submicroscopic gold inclusions, and acicular arsenopyrite. The pyrite contains admixtures of As (up to 1%), Cu, and Mo. The monomineralic pyrite fraction contains 30-100 g/t of gold. The gold-silver ratio of this association is 1:7-10.

The second productive association, gold-sulfide-quartz, has a more local distribution and contains more coarse-grained quartz veinlets, pyrite II, and small amounts of chalcopyrite, arsenopyrite, sphalerite, galena, bismuthinite, and gray copper ore, forming microinclusions in pyrite. The pyrite II contains less gold (0.7-30 g/t) than the pyrite I. The gold-silver ratio is 1:0.3-1.7.

The gold-telluride association has a more local distribution in some ore bodies and consists of quartz- and calcite-montmorillonite veinlets containing impregnations of native gold, coloradoite, altaite, naumannite, clausthalite, orpiment, and cinnabar.

The finely dispersed gold of the early productive association has 870-900 fineness and forms isometric or slightly elongated flattened crystals 1-4 μm in size. The gold II of the gold-sulfide-quartz association (725-860 fineness) forms larger, 0.05-0.25 mm, inclusions in the sulfides and in mineralized quartz. This gold generation comprises films, stringer-plate, and dendritelike particles. Small nuggets measuring up to 8 x 15 x 19 mm also have been found. The gold III of the latest gold-telluride association forms tear-shaped and plate-shaped particles up to 1 mm in size, with 900-980 fineness.

The gold of the primary ore as determined by spark mass spectrometry has small admixtures of Cu, Pb, Fe, Mn, Te, and Cr. Chlorine, bromine, and iodine, which are typical of the ore-forming fluids of volcanogenic gold deposits, were also detected. Based on the homogenization and decrepitation of the fluid inclusions, the early fine-grained quartz crystallized at 350-200°C. The ricelike quartz of the second generation precipitated at 250-200°C. The homogenization temperature of the liquid inclusions in the post-ore calcite is 122-110°C.

The oxide zone of the Kuranakh deposit has a thickness of 40-60 m, increasing to 200 m along some of the faults. This zone consists of clayey and clayey-sandy deposits with lenses of loose quartz and fragments of weathered quartz and feldspathized rocks. The main minerals are quartz, hydromica, kaolinite, and halloysite, with accessory montmorillonite, barite, gypsum, and calcite. The ore minerals are limonite, hydrogoethite, goethite, hematite, hydrohematite, psilomelane, pyrolusite, and kuranakhite (Pb-Mn tellurate) first discovered at this deposit.

Secondary gold makes up to 40-70% of the gold amount in the ore. About 30-60% of it is residual gold of primary ore modified by the supergene process, and the rest is newly formed supergene gold in close association with such supergene minerals as kaolinite, quartz, calcite, and iron hydroxides. The supergene gold forms cloddy, stringy-platy, and dendritelike particles from 20 μm to a few millimeters in size, with variable fineness of 790-930. The gold grains have a fine porous surface, indicating their metacolloidal origin. Nuggets of secondary gold are more common and may weigh more than 1,500 mg.

The gold distribution in Kuranakh ore is uneven, reaching 13.3 g/t in hydrothermal replacement and 105 g/t in karst breccia, but the average gold grades are 1.08-1.95 g/t. The geological resources of gold at the end of 1990s were estimated as about 200.0 million tonnes of ore grading 1.08 g/t, or 6.9 Moz (~215 t). Proven and probable reserves (Russian categories C_1+C_2) amount to 66.5 million tonnes of ore grading 1.94 g/t and containing about 4.15 Moz (129 t) of gold. Together with about 6 Moz mined from the deposit through the end of 1990s, the total gold reserves of the Kuranakh deposit exceed 10 Moz, which makes this deposit one of the largest epithermal deposits in the CIS.

Russian geologists view the formation of the Kuranakh deposit quite differently. Most of them believe its development to be related to Early Mesozoic subvolcanic magmatism, while others see it as a result of ancient weathering. However. the concentration of some ore bodies along Early Mesozoic dikes, the extensive development of low-temperature silicification and K-feldspathization, and hydrothermal argillic alteration support the former point of view.

On the basis of numerous data compiled in the last two descriptions of the Kuranakh deposit (Konstantinov et al. 2000; Vetluzhskikh et al. 2002), it is formed in three stages separated in time. The first stage resulted in pre-Jurassic weathering and karstitization of the Cambrian carbonate rocks with accumulation of residual clays. The accumulation of arkosic sediments in the Early Jurassic stage on a Cambrian karst topography was followed by intrusion of alkali lamprophyre, subvolcanic syenite porphyry, and bostonite, pebbles of which occur in interformation conglomerate horizons of the Jurassic sediments. Early Mesozoic magmatism was accompanied by potassic metasomatism and silicification, followed by ore deposition. In the last, the Late Neogene-Early Quaternary, stage karst formation with oxidation of the host rocks and ores led to redistribution of the primary ore components and to the formation of gold-bearing ore beds of the residual-karst type.

The increase in the amounts of dacite and rhyolite components in magmatism productive for epithermal gold deposits, confined to the intracontinental zones of tectonic and magmatic activity and volcanic belts, resulted in an increase in the silver grade of the productive mineral associations and accordingly in a decrease in the gold-silver ratio to 1:2-1:20, vis-a-vis the gold-telluride deposits.

The most common igneous rocks associated with this group of deposits are andesites and dacites. The amount of sulfides is from 0.5% to a few percent, and mineralization accompanied by the frequent development of silicification and argillic alteration. These are similar to those of the high-sulfur (high-sulfidation) type of epithermal gold deposits (Bonham

1988), which contain high-sulfide metallic compounds. However, none of the described Russian deposits contains the enargite-luzonite group of minerals typical of such deposits in Pacific island arcs with reduced crust, such as Taiwan, the Philippines, Fiji, and New Zealand (Rusinov 2001).

The association of at least one of deposits described (Kubaka) with Devonian Paleozoic magmatism requires more thorough exploration of other CIS zones with Paleozoic magmatism, such as the Devonian volcanic belt of Kazakhstan and the Late Paleozoic belt of the Kurama-Fergana rigid massif in the Central Asia. The cryptovolcanic position of two other deposits (Baley-Taseevo and Kuranakh) makes zones of later tectonic and magmatic activity of consolidated structures not only in Russia but also in other CIS and world gold provinces interesting targets for exploration for this type of gold deposit.

The most unusual of the deposits described in this section is Kuranakh. Despite the quite clearly epithermal character of mineralization related to Mesozoic magmatism, many Russian geologists describe it as a result of ancient weathering and karst formation. In spite of these differing views about genesis, the entire north rim of the Aldan shield has the potential for the discovery of other deposits like Kuranakh.

4.3.3 Veins and Mineralized Zones of Gold-Silver Mineralization Associated with Andesite-Rhyolite Magmatism

4.3.3.1 Gold-Silver-Adularia-Rhodonite-Quartz (Low-Sulfidation) Deposits

All the epithermal low-sulfidation gold deposits, which have the largest resources in the CIS (Dukat, Lunnyi, and Khakandzha), are concentrated in the Okhotsk-Chukotka marginal volcanic belt (Russia) with a mature sialic crust (Ryzhov et al. 2000; Konstantinov et al. 2003). All deposits are associated with Cretaceous andesite-rhyolite volcanics accompanied by comagmatic granitoid intrusives and are confined to volcano-dome or intrusive-dome edifices. The ore of such deposits is characterized by considerable prevalence of silver over gold, with a gold-silver ratio of from 1:25-1:30 to 1:100-1:1,000.

All of these deposits belong to the adularia-quartz type with hydromica, carbonates, and low-sulfide mineralization exhibiting various rhythmically banded vein structures. The main ore minerals are pyrite, sphalerite, galena, tetrahedrite, freibergite, sulfides, and sulfoantimonides of silver; low-fineness gold (mainly kustelite and electrum); and native silver formed in the quartz-adularia and quartz-rhodonite stages of mineralization. Accordingly, the mineralization contains large amounts of rhodonite, rhodochrosite, and manganocalcite, which are not common of other epithermal deposits.

Typical alteration of the host rocks preceding ore deposition is propylite and sometimes quartz-sericite-chlorite-carbonate-pyrite. Adularization or K-feldspathization is the main syn-ore alteration, forming quartz-adularia rims along gold-bearing veins. Argillic alteration is developed mainly at the periphery of the deposits (Khakandzha) and is not always clearly related to the ore process.

The Dukat Deposit (62°36’N-155°11’E)

The Dukat deposit, the largest gold-silver deposit in Russia, is located near the town of Omsukchan, in the Magadan region of northeastern Russia, about 600 km north of the city of Magadan. Radiometric anomalies (airborne potassium, thorium), soil anomalies (Pb, Zn, Cu, Ag), and gravity and magnetic geophysical anomalies at the site of the deposit were originally recognized in 1965-1967. Subsequent exploration led to the discovery of the deposit in 1973.

The deposit occurs (Konstantinov et al. 2000, 2003) in the central section of the Omsukchan (Balygychan-Sugoi) riftlike trough formed in the Early Cretaceous on an intensely folded Triassic-Jurassic sedimentary basement along a north-south fault system (Konstantinov et al. 2000). The depression extends for about 150 km to the north of the northeast-trending Okhotsk-Chukotka volcanic belt and is filled with Early Cretaceous continental coal-bearing molasse unconformably overlain by Early and Late Cretaceous rhyolite and andesite. The framework of the depression consists of Triassic-Jurassic sedimentary sequences intruded by numerous Early and Late Cretaceous diorite-granodiorite-granite polyphase stocks and plutons, Late Cretaceous felsite, rhyolite, and rhyodacite porphyry and Paleogene basalt dikes. Aside from the Dukat, Lunnyi, and Arylakh gold-silver deposits, the depression contains tin, silver-tin, and silver-polymetal deposits and occurrences (Fig. 61).

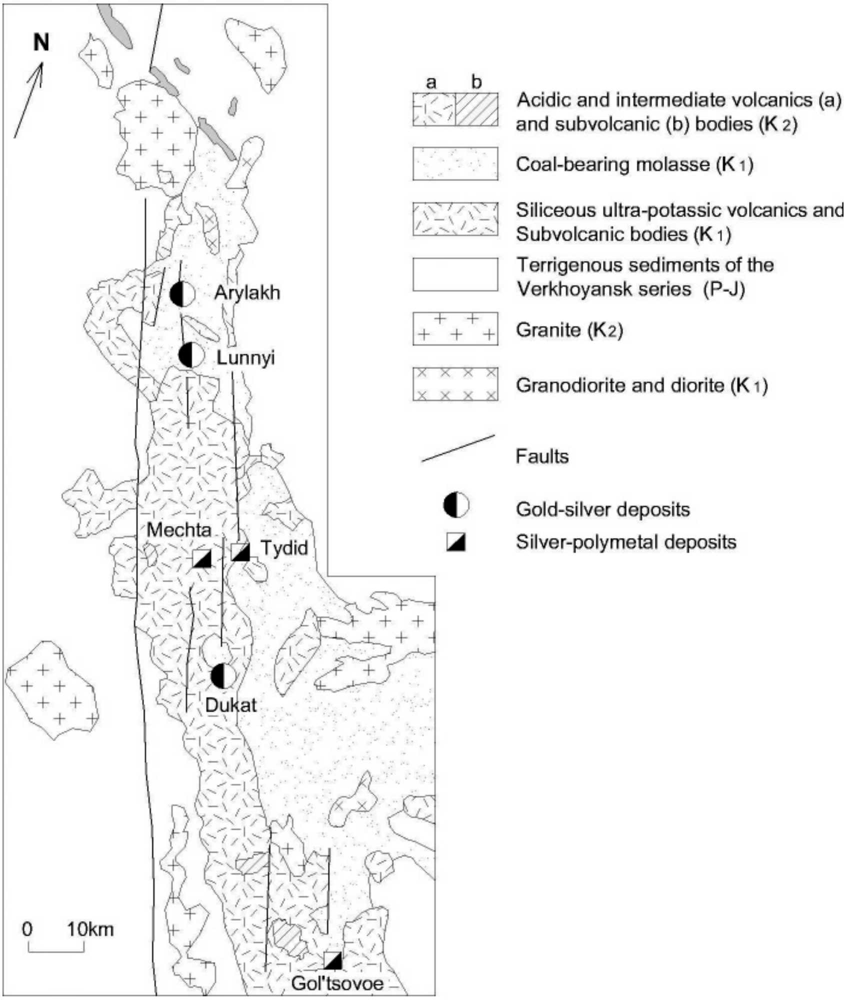


Figure 61. Distribution of gold-silver and silver-polymetal deposits in the Balygychan-Sugoi depression (simplified after Konstantinov et al. 1992).

The major structural element of the Ducat ore field is the intersection of the northerly Omsukchan and the northeasterly-striking Buyundino-Gizhigin faults and their accompanying fractures, which control magmatism and associated gold-silver mineralization. The central part of the ore field contains a domelike structure (Fig. 62), 35 km^2 in area, produced by a large leucocratic granite-granodiorite pluton intersected by drill holes at a depth of 1,200-1,500 m below the surface. The Rb-Sr isotopic age of this pluton that has metamorphosed the Early Cretaceous volcanics of the Askol'd complex varies between 93 ± 4 and 88.5 ± 3.7 Ma (Rozinov et al. 2004).

The domelike structure consists of the Early Cretaceous (119.3 ± 3.4 Ma) Askol'd formation, 750-780 m thick, of K-rhyolite and ignimbrite with associated tuffs, and intercalation of black shale layers. A large stock of rhyolite intrudes the center of the dome structure; comagmatic fluidal rhyolite flows are distributed around the stock, dipping 35-25°outside it. The core part of the dome is surrounded by Early Cretaceous coal-bearing molasse and is unconformably overlain by flat-lying Late Cretaceous andesite and rhyolite flows with conglomerate and tuff horizons. Subvolcanic bodies and dikes of rhyolite, including aphyric and phenocrystic varieties, and diorite stocks form a half-circle along its north border.

The host rocks of the Dukat ore field have undergone regional metamorphic and hydrothermal alteration and contact metamorphism related to the intrusion of Late Cretaceous granitoids (Konstantinov et al. 2000). Low-temperature, chlorite-hydromica-quartz propylitic alteration prevails in the central part of the ore field. Hydromica-quartz alteration in this part of the ore field is distributed mostly along ore-controlling faults and fractures. Argillic alteration is common in areas of intensive cataclasis, and albite-chlorite-epidote propylitic alteration is known on the ore field periphery and at its deep levels.

The intrusion of the Late Cretaceous granitoid pluton, accompanied by the development of a hornfels zone with andalusite, muscovite, garnet, and tourmaline, includes the area up to 500 m from the apical part of the pluton. An aureole of low hornfels alteration with biotite replacing the chlorite in propylitic zone is developed at a distance of up to 1,050 m from the pluton. High-temperature postmagmatic solutions caused the formation of skarnlike garnet-magnetite and greisen (mica-tourmaline-quartz) mineralization at the deep levels of the deposit but spread along ore-bearing faults to its upper levels.

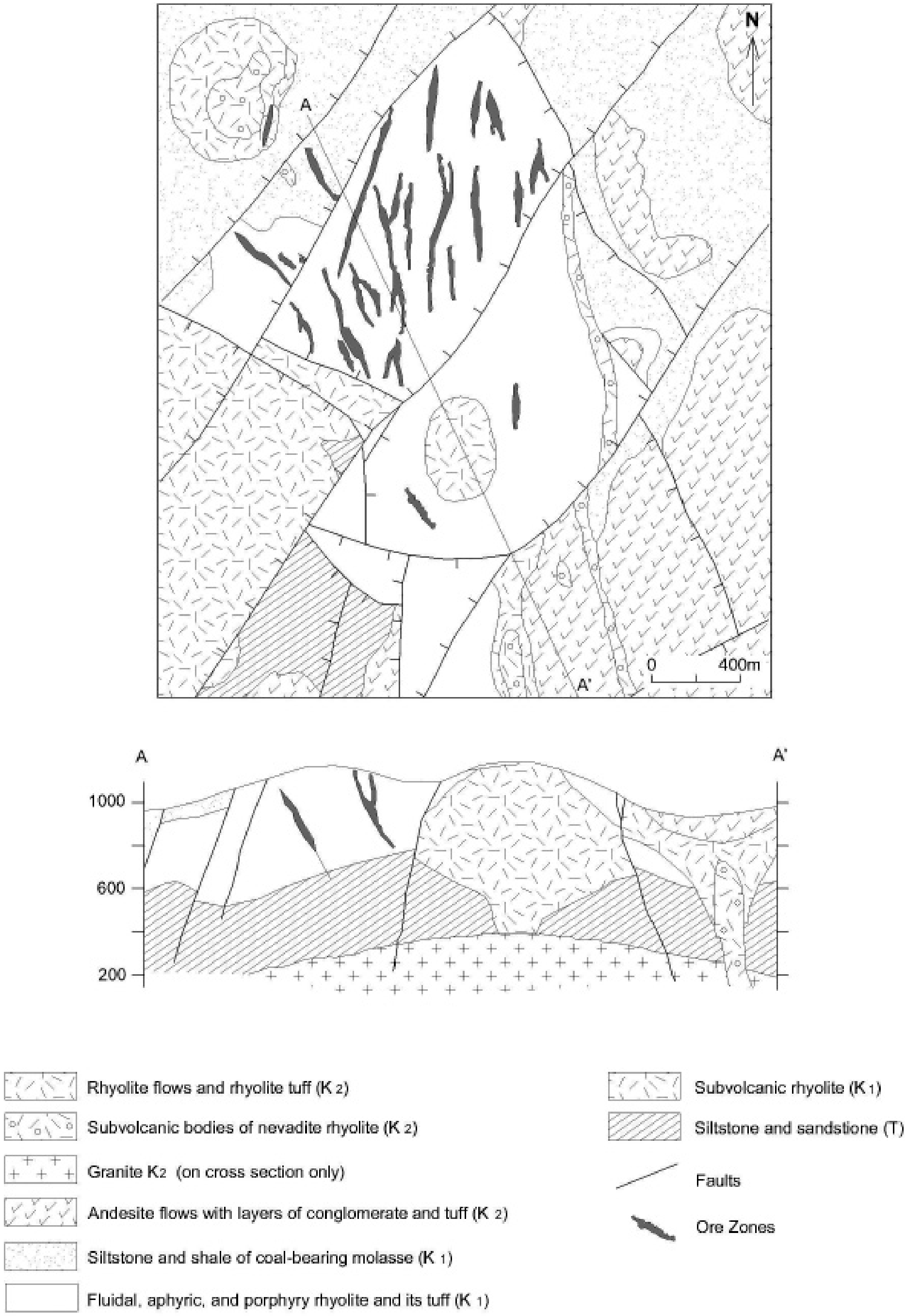


Figure 62. Geologic structure of the Dukat ore field (simplified after Konstantinov et al. 2003).

The domal structure is broken up by a series of northeasterly (the main faults) and northwesterly faults filled with mylonite, which were active during magmatic events and in the pre-ore, ore, and post-ore stages. The main elements of the Dukat deposit that govern the ore bodies' structure and distribution are zones of local fracturing consisting of systems of near-subparallel shear cracks, zones of mylonite along faults, and individual large fractures. The numerous explosion breccias, which form treelike dikes that broaden toward the surface, and linear lenses and veins controlled by faults, are in close spatial association with the ore bodies. Some of the breccia bodies have been traced to depths of up to 300 m.

The Dukat deposit consists of a series of northerly and northwesterly zones of mineralization and veins, which are concentrated in the northern part of the ore field, on the slope of the dome structure. Mineralized zones, up to 100-200 m wide, (Fig. 63) can be traced 300-1,200 m along the strike. They are controlled by systems of subparallel shear fractures that form long bands of pre-ore and syn-ore fracturing and crushing. Such zones contain one to several brecciated core veins 3-5 m thick and bands of veinlet-disseminated mineralization up to 1-3 m wide. The veins are surrounded by veinlets of different orientation and thickness but with similar multistage mineralization. The early productive, silver-adularia-quartz, mineralization is located commonly in northeasterly-trending structures, while northwest-striking and gently dipping zones contain platelike quartz-rhodonite veins up to 3-4 m thick surrounded by halos of veinlet-disseminated mineralization 1-3 m thick.

The single ore veins, 0.5-2 m thick, in contrast to the mineralized zones, are in individual open fractures filled with one stage of mineralization. All the veins have sharp, wavy boundaries and surrounded by a small number of veinlets.

The ore bodies of the Dukat deposit contain more than a hundred primary minerals (Konstantinov et al. 1992, 2003; Sakharova et al. 1998). Sulfide minerals constitute up to 5-8% of the ore bodies and include pyrite, galena, and sphalerite (the main minerals), as well as chalcopyrite, arsenopyrite, pyrrhotite, magnetite, and smaller amount of accessory minerals.

The early productive stage of mineralization, which is possibly related to the Early Cretaceous rhyolite magmatism, consists of quartz-chlorite, quartz-sulfide, and quartz-chlorite-adularia (productive for gold-silver) paragenetic mineral associations with sulfides, acanthite, freibergite, stromeyerite ($Cu_2S{\cdot}Ag_2S$), sternbergite, mackinstryite, and jalpaite, and Ag-Sb intermetallic compounds.

The skarnoid minerals and quartz-rhodonite-rhodochrosite-silver associations of the late productive stage with native silver, acanthite, freibergite, polybasite, pyrargyrite, stephanite, and naumannite are clearly related in time and space to the Late Cretaceous granitoid pluton and the later stage of the hydrothermal process. The gold-silver ratio is 1:340 in the quartz-chlorite-adularia ore of the early productive stage and 1:550 in the quartz-rhodonite ore of the late stage.

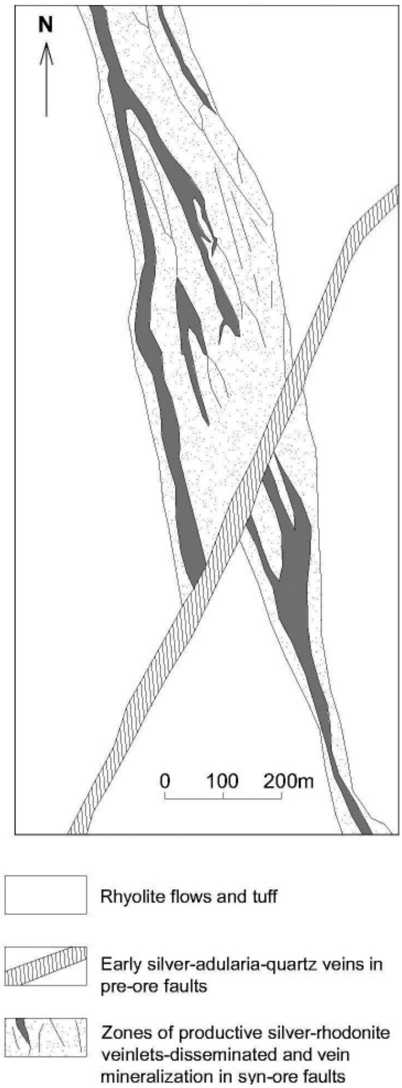


Figure 63. Dukat deposit: ore zones in northwestern and northeastern faults (after Konstantinov et al. 2003).

The final, quartz-tourmaline and sulfide-chloride, stages of mineralization contain cassiterite, galena, sphalerite, rhodochrosite, and lesser amounts of pyrrhotite and pyrite.

The main forms of silver in Dukat's ore are native silver, which makes up to 20-45% of its total amount, and acanthite. Acanthite is found in all the mineral associations but is most prevalent in productive associations. It forms unevenly distributed veinletlike and disseminated particles in quartz, adularia, rhodonite-rhodochrosite, and chlorite. The acanthite contains on average 82.0% silver, 0.08% gold, 2.9% iron, 12.5% sulfur, and 0.25% selenium. Kustelite (native silver with up to 10 wt. % gold), electrum (300-500 fineness), and native gold (700 and higher fineness) are also present but are less common. The average fineness of the gold-silver compounds of the Dukat deposit is 212 (Konstantinov et al. 2003).

The native silver forms lumpy, dendritelike, wirelike, and idiomorphic crystals ranging from a few thousandths of a millimeter to 2 mm in size. The kustelite and native silver usually corrode acanthite, sulfosalts of silver, chalcopyrite, galena, and sphalerite. Gold-silver minerals form interstitials in quartz and chlorite, rarely in adularia and rhodonite-rhodochrosite aggregate. The average gold grades at the Dukat deposit do not exceed 1 g/t, while the silver grades vary from 340 g/t for the early productive association to 550 g/t for rhodonite-rhodochrosite ore.

The mineralization of the Dukat deposit contains not only original hypogene native silver but also silver regenerated and remobilized during intraore metamorphism, as well as hypergene silver. Hypogene silver under an electron microscope has clear, rhythmically zoned, or fibrous textures, while the regenerated silver is characterized by a platelike or fine-grained texture.

The host rocks of Dukat underwent pre-ore chlorite-hydromica-quartz, syn-ore adularia, and albite hydrothermal alteration, as well as post-ore skarnlike alteration and tourmalinization. The pre-ore alteration is widespread and is accompanied by an inflow of potassium and water and by outflow of silica, iron, calcium, and sodium. Syn-ore alteration has a composition similar to the pre-ore but with more intensive inflow of potassium, manganese, and rubidium and forms up to a few tens of centimeters thick halos to ore veins. An extensive post-ore stage of alteration includes deposition of garnet, pyroxene, magnetite, carbonates, chlorites, and sulfides. Recrystallization of early hypogene sulfides and native silver also occurs during the post-ore stage.

Study of fluid inclusions by microthermometry, microprobe analyses of salt residue, and Raman spectrometry (Borovikov and Kravtsova 2001) showed that the early quartz-orthoclase-adularia veins are formed from low salt (1.6-0.7 wt. %), $MgCl_2$+NaCl (KCl)+H_2O fluids at 355-285°C and pressures not exceeding 130-70 bar. The late silver-productive quartz-rhodonite veins are formed from heterogeneous fluids boiling at 375-165°C. The fluids have variable salt concentration (9.2-0.7 wt. %), with predominance of NaCl, KCl, and $CaCl_2$, while iron, zinc, and sulfur are also detected.

Sakharova et al. (1998) noted, however, the presence of a temperature inversion and a sharp increase in temperature, which reaches 450-550°C prior to deposition of the late productive mineralization and is related to the intrusion of the granitoid pluton.

Studies of the Pb-, Sr-, and Nd-isotope compositions of the hydrothermal products and magmatic rocks of the Dukat deposit (Chernishev et al. 2005) supports the idea of release of gold-bearing fluids directly from a large shallow magma chamber with a high degree of homogeneity of Pb-isotope composition. The calculated ^{207}Pb-^{206}Pb modal age is 72 ± 16 Ma, which suggests that separation of lead from its source took place shortly before ore deposition.

The Dukat deposit is the largest gold-silver deposit of the Russian Federation and already has yielded more than 2,000 tonnes of silver. According to a March 2005 news release of the Russian Polymetal Co., which operates the Dukat deposit, the proven and probable reserves of the deposit are 464 million ounces (14,384 t) of silver and 954,000 ounces (30.8 t) of gold. In its geotectonic setting, mineralogy, and resources, the Dukat deposit is similar (Konstantinov et al. 2003) to such Mexican deposits as Guanajuato and Fresnillo.

The Lunnyi Deposit (63°23'N-155°12'E)

The Lunnyi gold-silver deposit is located approximately 60 km north of the Dukat in the Early Cretaceous Arylakh volcano-tectonic depression of the Balygychan-Sugoi offshoot to the Okhotsk-Chukotka volcanic belt (see figure 61). The first ore bodies at the deposit were discovered in 1978 in an outcropped and eroded part of the granite stock. However, the richest southern part of the deposit, with its blind ore bodies, was discovered considerably later, in the second half of the 1980s.

The Arylakh depression, about 600 km^2 in area, is filled (Ryzhov et al. 2000) with an Early-Late Cretaceous volcanic-sedimentary sequence that is 2,500 m thick. This section lies unconformably on folded Early Jurassic marine sediments. The lower part of this sequence, the Early Cretaceous Askol'd suite, 600-900 m thick, consists of rhyolite ignimbrites and their subvolcanic analogues: stocks and sills of rhyolite-dacite and phenocrystic rhyolite.

Sandstones, siltstones, and shales with coal interlayers of the Omsukchan suite are more than 1,000 m thick and are overlain unconformably by the Early-Late Cretaceous Kakhovsk suite, 420-440 m thick, of andesite tuff and andesite flows. The last suite of this stratigraphic sequence, the Late Cretaceous Shorokhovsk suite, consists of 50-240 m thick rhyolite tuff and ignimbrite.

The Kakhovsk and Shorokhovsk suites fill a volcanic caldera that developed in the southern part of the Arylakh depression. At the center of the caldera is Early Cretaceous coal-bearing molasse intruded by Early-Late Cretaceous Arylakh multiphase intrusive of diorite-granodiorite-granite porphyry composition that forms a domelike structure surrounded by subvolcanic dikes and sills of andesite, rhyodacite, and diorite porphyry (Fig. 64).

All rocks of the Lunnyi ore field underwent regional medium- and low-temperature propylitization, as well as hornfels, skarnlike, and greisenlike alteration that are associated with subsequent granitoid intrusion. Skarnlike alteration of garnet-magnetite-chlorite and epidote-magnetite-chlorite facies, as well as tourmaline-muscovite-quartz greisenization, spread to a distance up to 200 m from the intrusive. The late propylitic alteration associated with the Arylakh intrusive usually is superimposed on the hornfels and skarnlike alteration.

A series of large east-northeast and northwest-striking faults with displacement amplitudes up to 100-120 m subdivides the area of the Lunnyi deposit into several structural blocks. Smaller northeastern and northwestern faults of the second order host 10 vein zones of gold-silver mineralization. Only three of these zones—V, VII, and IX—are considered commercial. Vein zones V and VII are located in the central sector of the deposit and hosted by granodiorite or hornfelsed sandstones and siltstones at the contact of the intrusive (see figure 64). Mineralized veins of these two zones are confined to north-northeast-trending faults with small slip displacements and account for relatively small proportion of the total resources.

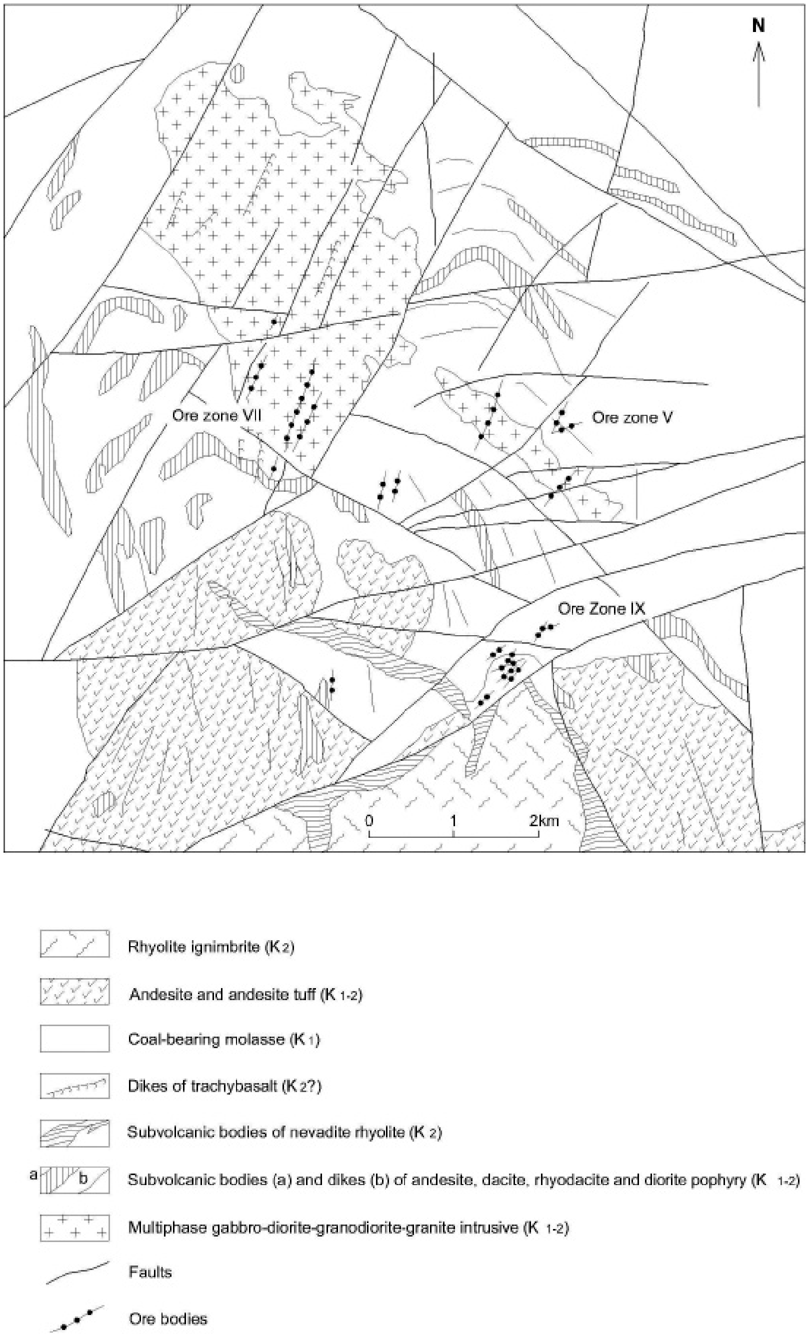


Figure 64. Geologic-structure scheme of the Lunnyi ore field (simplified after Ryzhov et al. 2000).

The main ore resources belong to zone IX in the southern sector of the Lunnyi deposit, approximately 3 km south of the central sector. This vein zone is hosted by andesite of the Kakhovsk suite and, to a lesser extent, by sediments of the Omsukchan suite. The ore zone is confined to the large fault that bounds the volcanic caldera on the north.

The steeply dipping (60-90°) vein zones consist of one or several veins, 0.2-2.0 m thick and up to 600-800 m long, surrounded by halos of veinlet-disseminated mineralization of similar thickness. The mostly sinuous veins have numerous apophyses and can be traced up to 350 m down dip. Ore shoots typical of this type of deposit are located at the junctions of ore-controlling fractures, large bends in them, and intersections of pre-ore faults by mineralized veins.

The gold-silver ore of the Lunnyi deposit contains more than 70 mineral species (Ryzhov et al. 2000), but the set of main minerals is fairly simple. Quartz, rhodonite, and pyrite with secondary rhodochrosite and manganocalcite are prevalent in the central sector, while quartz, manganocalcite, and pyrite predominate in the southern sector. Hydromica, sericite, adularia, sphalerite, chalcopyrite, galena, freibergite, silver sulfosalts, kustelite, and native silver occur in both sectors. Ore minerals constitute on average about 1 vol. % of the vein material but sometimes may reach 10-15 vol. %.

Two major stages of mineralization are the early postvolcanic megastage and the late postintrusive megastage, which are divided by the intrusion of the Arylakh granitoid stock. The *postvolcanic megastage* includes three stages of mineral associations. The pre-ore hydromica-quartz association with adularia and pyrite contains only traces of gold (0.01-0.03 g/t) and, based on the homogenization temperature of the fluid inclusions in the quartz, was deposited at 270-210°C.

The gold-quartz-selenide association is a system of subparallel veins up to 1 m thick with a crustified, rhythmically banded structure containing up to 5-10 rhythms of fine-grained massive, patchy, and impregnated aggregates. Quartz is the major vein mineral of this association, which also contains hydromica, adularia, ankerite, Fe-dolomite, and calcite. Iron-rich pyrite and sphalerite are the main ore minerals, with silver-bearing tetrahedrite (up to 23-24 wt. % Ag), naumannite, aguilarite, chalcopyrite, Se-argentite (9.66-6.47 wt. % Se), selenium-rich polybasite (6.70-4.02 wt.

% Se), and electrum as accessories. This association was deposited from boiling solutions at temperatures of 260-180°C.

The quartz-silver-sulfide association is located in the same structures as the previous one and consists mainly of comblike quartz that cements wide (up to 2-3 m) zones of brecciation or forms separate veins and veinlets with comblike and colloform-banded structures. Pyrite, sphalerite, and galena are widespread. The main gold and silver minerals are kustelite, freibergite, argentite, boulangerite, polybasite, and stephanite. This mineral association, according to a study of fluid inclusions, formed at 230-120°C.

The *postintrusive, or second, megastage* of gold-silver mineralization occurs after the granitoid-related hornfels, skarnlike, and greisen alteration and consists of four mineral associations. The earliest one, quartz-rhodonite-carbonate, is widespread mostly in the central sector of the Lunnyi deposit. This association forms veins and veinlets of rhythmically banded (mainly rhodonite and quartz bands), comblike, and crustified structure in granitoids and their host rocks. The main ore minerals are rhodonite-rhodochrosite, with minor amounts of hematite, magnetite, pyrite, arsenopyrite, sphalerite, chalcopyrite, and galena associated with native bismuth, arsenic sulfosalts, tetrahedrite, and electrum. The quartz-rhodonite veins in the central sector are formed at 430-250°C.

The veins at a distance 1-1.5 km from the intrusive are composed mainly of quartz-carbonate (rhodochrosite-manganocalcite) aggregates with smaller amounts of ore minerals. In the southern sector (ore zone IX) about 2-3 km from the intrusive, veins up to 10-12 m wide consist of calcite with secondary amounts of quartz, hydromica, dolomite, and adularia, with pyrite, arsenopyrite, sphalerite, chalcopyrite, galena, argentite, electrum, kustelite, native silver and bismuth, proustite, and pearceite. The argentite in this zone is almost selenium-free, and the native silver does not contain a mercury admixture. The homogenization temperatures of fluid inclusions in the quartz of the southern sector are 250-180°C.

Veins and veinlets of the next, sericite-quartz, association are known in the central sector and often replace quartz-rhodonite and rhodochrosite-quartz aggregates. These veins are composed of fine-grained adularia-quartz aggregate with minor sericite and dolomite and trace amounts of pyrite and arsenopyrite formed at 340-210°C.

The last, quartz-silver-polymetallic, association occurs in the central sector in the form of veins and veinlets containing fragments of earlier quartz-rhodonite-carbonate and sericite-quartz associations. The veins are rhythmically banded with alternation of comblike quartz and bands of fine-grained carbonate-hydromica-adularia-quartz aggregate with impregnation of ore minerals. Pyrite, arsenopyrite, sphalerite, galena, argentite, polybasite, Ag-tetrahedrite, freibergite, kustelite, native silver, stephanite, pyrargyrite, and jalpaite are concentrated mainly in the intergranular spaces of quartz aggregate or in druselike cavities. Homogenization of fluid inclusions in quartz from this association occurs between 260 and 180°C. The Rb-Sr age of adularia from this association is 87 ± 2 Ma, which supports its Late Cretaceous age.

The post-ore, quartz-carbonate, mineral associations form thin (1-15 cm) veinlets and were deposited at a temperature of 170-120°C.

The average gold-silver ratio in ore of the Lunnyi deposit is 1:500 but ranges from 1:170 to 1:1,900. Kustelite with a fineness of 120-330 is the main gold mineral, while electrum is rare. A minor admixture of gold, up to 0.50-0.75 wt. %, also is encountered in the native silver. The size of the kustelite particles varies from 0.001 to 1.0 mm. Small gold particles less than 0.01 mm in size in intergrowths with pyrite and silver minerals are more typical of early mineral associations. Larger gold particles measuring 0.1-1.0 mm often fill interstitials in the quartz.

Silver is present mainly in the form of silver minerals such as argentite, polybasite, pearceite, and pyrargyrite. Smaller amounts of silver are concentrated in freibergite, silver-rich tetrahedrite (15.28-33.54 wt. % silver) and in native silver.

Pre-ore, quartz-sericite-chlorite-carbonate-pyrite (beresite), alteration of the host rocks forms wide (50-100 m), linear halos extending up to 1,500 m along vein zones. The width of these halos significantly decreases down the dip of the vein zones. They contain higher but still subeconomic gold and silver grades in comparison with either propylitic or unaltered host rocks. Syn-ore, feldspar-bearing alteration forms narrow (10-20 cm) margins around ore veins and veinlets. Adularia and quartz replace fine-grained quartz sericite-carbonate-pyrite aggregate in the form of patches and lenses.

According to a news release by the Polymetal Co. (March 2005), the proven and probable (C_1+C_2) reserves of the Lunnyi deposit amount to 480,000 ounces of gold and 21 Moz of silver.

Another gold-silver deposit of similar composition is the Arylakh deposit about 10 km north of Lunnyi.

The Khakandzha Deposit (60°01'N-142°35'E)

This deposit is about 100 km north of the city of Okhotsk in Khabarovsk Krai of the Russian Far East. It was discovered in 1966 during a 1:200,000 geologic mapping program and was explored in the 1970s.

The Khakandzha deposit is situated on the west flank of the Okhotsk-Chukotka volcanic belt, near the southern boundary of the Okhotsk rigid massif, and is confined to the southwestern part of the Selemdzha volcanic depression (Khomich and Krylova 2001). The Cretaceous volcanic sequences that fill the depression lie unconformably on folded Late Triassic sedimentary rocks intruded by Cretaceous granitoids. The volcanic sequences consist of several complexes of pyroclastic-sedimentary, extrusive, and subvolcanic rocks. Pyroclastics and lava beds dip from the margins of the depression toward its center at 40-45°, but their dip is shallower in its central part.

Late Cretaceous felsic effusive, tuffogenic, and extrusive rocks cut by younger dolerite and andesite-basalt dikes are the host to the ore bodies in the Khakandzha ore field. The deposit area coincides with an isometric structure developed around the volcanic vent up to 600 m in diameter filled with fluidal rhyolite lava (Fig. 65). Some secondary vents with extrusive domes occur on the north and west slopes of the volcano. Several units and layers of the volcanic sequence correlate with the regional Ul'berikan and Amkinian volcano-sedimentary formations. Their thickness generally increases toward the center of the paleovolcanic structure. The fragment sizes in the pyroclastic layers increase in the same direction.

Northwest-striking dikes of felsite porphyry, granite porphyry, and syenite, from 0.5-1.0 to 20 m thick, dip at varying angles (from shallow to vertical). Later dolerite and andesite-basalt dikes, 3-4 m thick, have northeast strike and dip to the northwest at angles of 50-80°.

The three main fault systems identified in the deposit have westerly, northeasterly, and northerly trend. The large faults usually consist of several planes and are accompanied by a series of parallel fissures and fracture zones 2-3 m thick with gouge and slickensides. The displacements along these faults can reach up to 100-200 m. The post-ore, normal and reverse, mostly northeasterly faults have smaller displacements. In addition, intraformational gentle fissures and fracture zones are conformable to the stratification of the volcanics and occur sometimes along the lithologic contacts, especially in homogeneous rocks like ignimbrite, spherulitic lava, or fluidal felsite. These zones are filled with gouge, quartz, and carbonates.

All volcanic rocks of the Khakandzha deposit are propylitized to a chlorite-carbonate facies. Later, chlorite-carbonate-quartz-zeolite, alteration is developed along northeasterly-striking faults. Quartz-adularia alteration with a kaolinite overprint is common near the ore bodies, while hydromica-quartz and argillic alteration is encountered on the periphery of the deposit.

The vein-metasomatic, northwest-trending ore zones of brecciated and silicified rhyolite 40-80 m thick are traced for more than 1.5 km near the contact between Ul'berikan (K_1) andesite and Amkinian (K_2) silicified rhyolite (see figure 65). The ore zones are confined to gently dipping (from 5-10° to 50°) fracture zones and fissures and can be traced about 500-600 m down dip. Branching veins and veinlets, 01-1.0 m wide, of mostly quartz and adularia-quartz composition penetrate the metasomatic zones. The upper parts of the ore zones are thickest and contain up to 3-5 veins. The thickness and number of veins decrease gradually with depth.

The ore bodies consist of 4-6 m thick, linearly elongated zones of intense silicification and adularization with gold-silver mineralization. They contain numerous relics of altered rhyolite transformed into thin-grained hydromica-adularia-quartz aggregates intersected by quartz veinlets up to 10 cm thick. The ore bodies do not have clear boundaries and are identified by sampling. The ore has breccialike, massive, crustified, cockade, and thick-banded structure with alternating bands of massive, cavernous, or cockade quartz of various colors, as well as adularia bands. Thin rhythmic banding of quartz-adularia composition occurs in some parts of the veins.

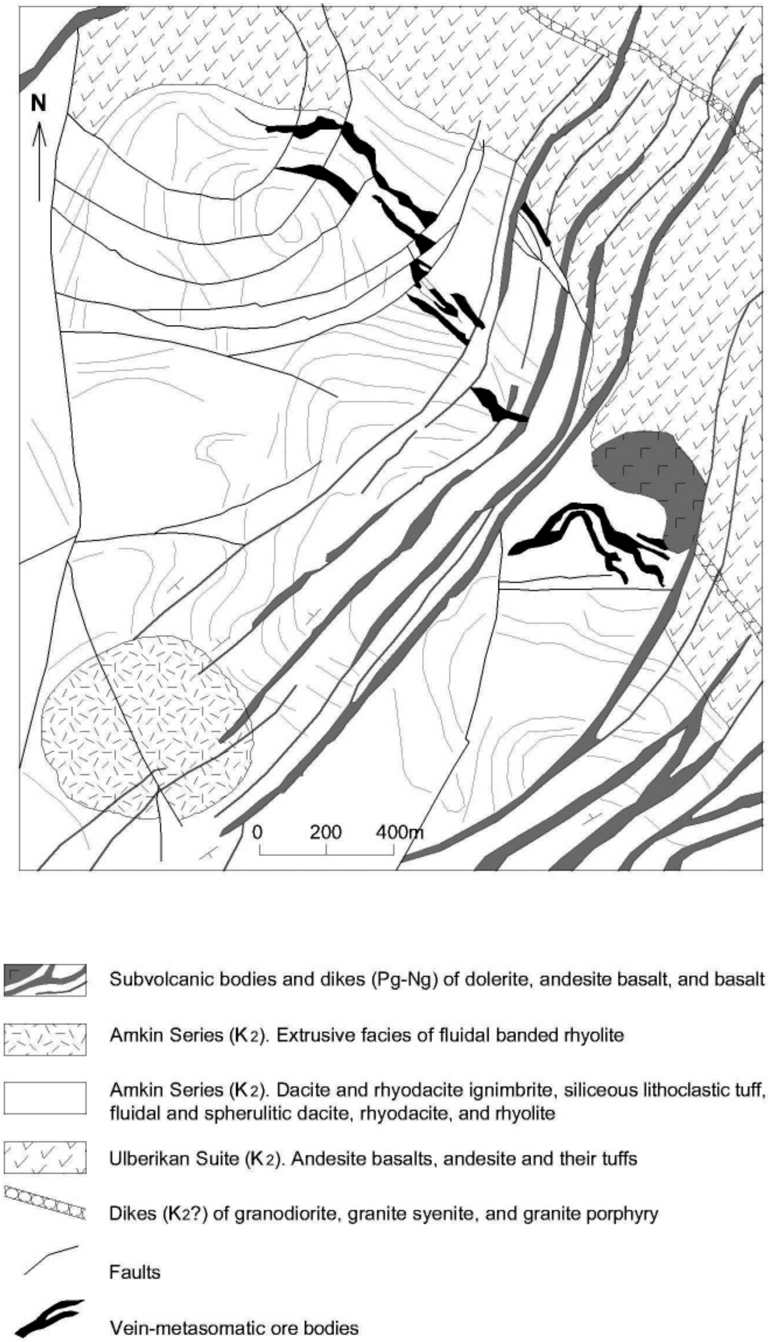


Figure 65. Geologic map of the Khakandzha deposit (simplified after Khomich and Krylova 2001).

The main vein's minerals are quartz, carbonate, adularia, chlorite, hydromica, and less often amethyst, rhodonite, rhodochrosite, bustamite and other manganese carbonates, and zeolite. The ore minerals account for up to 3 wt. %, mostly at the lower levels of the ore bodies, but averaged around 0.5%. The main ore minerals are sphalerite (up to 20%), chalcopyrite (up to 10%), pyrite and polybasite (up to 5%), and galena and pearceite (up to 4%). Secondary minerals (less than 2%) include acanthite (argentite), kustellite, native silver, native gold, pyrargyrite, As-polybasite, and electrum. In addition, marcasite, arsenopyrite, sternbergite, gray copper ores, semseyite, gersdorffite, cinnabar, stibnite, covellite, and freibergite are present in small amounts of up to 0.1-0.5%.

The early, quartz-adularia and later, quartz-rhodonite-carbonate complexes can be identified at the deposit and could be subdivided into several mineral associations. The quartz-adularia complex consists of the quartz-adularia-chlorite association, which is the main productive one and contains up to 1-2% of total ore minerals, and the quartz-carbonate association. The quartz-rhodonite-carbonate complex includes five mineral associations: (1) the garnet-magnetite association with yakobsite, hematite, and ilmenite; (2) the quartz-rhodonite-braunite association with tephroite, pyroxmangite, bustamite, hausmannite, biksbyte, hetaerolite, and cordierite; (3) the amphibole-epidote-manganite association with piemontite, kupletskite, pennantite, manganite, cryptomelane, hollandite, and coronadite; (4) the electrum-polybasite association with acanthite, stephanite, pyrargyrite, As-polybasite, pearceite, jalpaite, semseyite, tennantite, tetrahedrite, freibergite, sternbergite, gold, silver, electrum, kustellite, and cinnabar; and (5) the rhodochrosite-sulfide association with galena and sphalerite. The electrum-polybasite association is the most productive for gold and silver.

The quartz-adularia complex is typical of the upper levels of the deposit, while the quartz-rhodonite-carbonate complex is more common in the lower parts of the ore bodies, where it replaces the quartz-adularia complex. The content of silver minerals in the quartz-rhodonite-carbonate complex is higher than in the quartz-adularia complex.

The native gold is associated with quartz and other vein minerals and also with argentite, galena, sphalerite, and silver sulfosalts. It forms fine grains, about 90% of which are smaller than 0.2 mm in size. Some coarse grains up to 0.8-2.0 mm in size occur mainly in the upper levels of the ore bodies. The gold grains at this level often form deformed cubic crystals, rarely octahedral, cubic-octahedral, and rhombic dodecahedral ones. In the lower levels of the deposit, the number of crystals decreases; and the gold grains have mostly rough surfaces and an irregular angular, dendritic, and platy shape. The rare gold nuggets have a lumpy, irregular shape or a spongy and veinlike laminar shape. The gold composition varies from gold of 980 fineness to native silver of 70 fineness. In the rhodonite-rhodochrosite ore, the average gold fineness is 627, versus 536-544 for the deposit.

Minerals of the gold-silver group are the latest ore minerals but have a different distribution. Native gold with the highest fineness of 980 occurs mainly in quartz-adularia ore and, in small amounts, in the later quartz-rhodochrosite-carbonate complex. Electrum (300-700 fineness) is typical of both complexes (electrum I and II) in association with sulfides and silver sulfosalts or as separate grains in quartz, adularia, and rhodonite. Kustelite (100-300 fineness) and native silver (fineness <100) are more common in the later complex, forming veinlets and rims around electrum and other silver minerals and occurring as lumpy and wirelike crystalline or cryptocrystalline aggregates in quartz, rhodonite, bustamite, and manganese oxides.

The gold fineness decreases with depth along with the amount of argentite, galena, and manganese minerals; but the amounts of arsenopyrite, polybasite, sphalerite, silver sulfosalts, and siderite are increase in the same direction.

The usual gold grades vary from 10 to 20 g/t and the silver grades from 300 to 500-600 g/t, but in bonanza-like ore shoots, the gold grades are up to 50-100 g/t and the silver grades are 1-5 kg/t. The gold-silver ratio in the primary ores varies from 1:23-1:26 at the upper levels and from 1:30 to 1:36 at the deep levels of the deposit's central part. In the southeastern block, the ratio decreases to 1:100-1:120.

The oxide zone is widespread at the upper levels of the Karamken deposit, down to 120-150 m from the surface. It reaches 200 m as narrow bands along andesite-basalt dikes. The supergene mineral association contains psilomelane, todorokite, cryptomelane, goethite, hydrogoethite, lepidocrocite, and hydrohematite. Oxidized ore has porous, netlike, oolitic, and incrustation structures.

Late columnar quartz and calcite in the vein-metasomatic zones of the central part of the Khakandzha deposit crystallized, according to a fluid-inclusions study, at the relatively high temperature of 410-220°C, while the products of the early ore stage were deposited at 250-150°C. This unusual temperature evolution may owe to the rejuvenation process.

The vein-metasomatic ore zones of the Kuranakh deposit are hosted by the Amkin volcanic sequence (K_2), which is felsic in composition. The ore veinlets cut felsic porphyry and quartz porphyry dikes that are comagmatic with this sequence but which in turn are cut by later (Pg?) dikes of andesite-basalt. The isotopic geochronology (K-Ar method) of the quartz-adularia veins generally supports geologic observations of the Late Cretaceous age, giving estimates of 81-73 and 71 Ma for the age of the veins.

According to the Polymetal Co., which owns the deposit, the proven and probable (C_1+C_2) reserves of the Khakandzha deposit are over 6.1 million tonnes of ore grading 5.2 g/t gold (1.016 Moz, or 31.6 t) and 229 g/t silver (45.06 Moz, or 1,401.37 t).

The gold-silver deposits, which are related to rhyolite volcanics of marginal volcanic belts, form a much more homogenous group than do other volcanic-related epithermal gold deposits. All of these deposits confined to dome edifices of volcanic or intrusive origin, have a low sulfide content of 1-3 wt. % and a very low gold-silver ratio of 1:20 to 1:1,900. Another typical feature of the deposits is the development of the late quartz-rhodonite mineral association, with extensive development of rhodochrosite and manganocalcite. Gold-silver mineralization is accompanied by quartz-adularia-carbonate-sericite alteration.

The gold-silver deposits of this group are typical low-sulfur (Bonham 1984, 1988) or low-sulfidation epithermal deposits. All deposits of this group contain large silver reserves. The Dukat deposit, for example, is the largest Russian gold-silver deposit and the third largest silver deposit of its type in the world. The wide distribution of Mesozoic and Paleozoic marginal volcanic belts in the CIS and the discovery of blind ore bodies at the Lunnyi deposit make this type of mineralization quite interesting for future exploration.

CONCLUSION

The CIS, with gold production of 320,737 kg in 2004 (*USGS Minerals Yearbook*, 2004), was the second-largest gold producer after the Republic of South Africa (341,485 kg). Because of the ongoing decline of gold mining in South Africa, the CIS has a real chance to become the largest gold producer in the world. The explored proven and probable ($B+C_1+C_2$) gold reserves of the CIS are approximately 7,800-8,500 tonnes, but its undiscovered gold resources are even bigger.

The largest proven and probable gold reserves, some 3,000-3,500 tonnes (*Mineral Commodity Summaries*, 2006), belong to the Russian Federation. This amount could be increased by about 900 tonnes as a result of the comprehensive technological and geological-economic review of the Sukhoi Log deposit, which has been carried out by the Central Research Institute for Exploration of Base and Precious Metals (TsNIGRI). This review resulted in a sharp increase of the proven reserves from 1,041.2 tonnes verified by the Soviet Committee for Reserves in 1977 up to 1,952.9 tonnes of gold (Information-Analytical Center "Mineral," mineral.ru, February 2008).

According to an estimate by Uzbek geologists, the second-largest explored reserves, about 2,100 tonnes of gold, are in the Republic of Uzbekistan, which is also the second-largest gold producer, with 93 tonnes of gold in 2004. Other gold-producing countries of the CIS have smaller reserves.

Currently, just six states of the former Soviet Union produce gold. Apart from Russia and Uzbekistan, which are the main producers with about 155-180 and 80-90 tonnes of annual gold production, respectively, these states are Kazakhstan (28-30 t), Kyrgyzstan (16-22 t), Tajikistan (2-3 t), and Armenia (0.5-0.6 t).

The Russian Federation not only is the largest gold producer in the CIS but also has, according to the USGS Mineral Commodity Summaries (2006), the biggest gold reserves, about 3,000 tonnes. The recent reserve reevaluation of the Sukhoi Log and Natalka deposits to 1,952.9 and 1,270.6 tonnes respectively increase this estimation up to 4,900 tonnes of gold, i.e., the third largest reserves after South Africa and Australia. Approximately 53.4% of the gold reserves and resources in Russia are in lode gold deposits (Krivtsov et al. 2003), 28.8% are in other gold-bearing environments, mainly VMS and porphyry copper deposits, and some 17.8% of the reserves and resources are found in gold placers.

The latest available data on gold production in Russia (Society of Russian Gold Miners, mineral.ru, March 2, 2005) stated that in 2004 Russia produced 180,515 kg of gold. Of this amount, 158,830 kg was mined from lode gold deposits, 10,407 kg was a by-product from complex gold-bearing deposits, and 11,278 kg came from secondary sources through recycling of new and old scrap.

Some twelve main gold-producing regions delivered 96.2% of all gold mined: (1) Krasnoyarsk Krai—30,348 kg (versus 30,973 kg in 2003), (2) Magadan Oblast—23,042 kg (23,300 kg), (3) Khabarovsk Krai—20,925 kg, (4) the Sakha Republic (Yakutiya)—20,225 kg (18,652 kg), (5) Irkutsk Oblast—15,713 kg, (6) Amur Oblast—14,221 kg (14,711 kg), (7) the Buryat Republic—8,222 kg (7,600 kg), (8) Chita Oblast—6,300 kg, (9) Sverdlovsk Oblast—5,703 kg (5,379 kg), (10) the Chukotka Autonomous Okrug—4,289 kg (4,664 kg), (11) Chelyabinsk Oblast—3,156 kg (no data available for 2003), and (12) the Tuva Republic—1,621 kg (versus 1,758 kg in 2003). All other regions combined produced 2,628 kg of gold in 2004.

Today, 42% of gold production in Russia comes from placer deposits. This amount exceeded 70% in the early 1990s, whereas in the United States, Canada, and Australia, placer gold accounted for less than 2% of their total production (Benevol'sky 1995; Levitan 1995). Other gold-bearing VMS and porphyry copper-gold deposits provide an additional 12-15% of gold output.

The breakdown of Russian lode gold reserves (Krivtsov et al. 2003) by the geological/industrial types of the deposits differs sharply from that of gold reserves and gold production in other parts of the world. About half the world's gold reserves (excluding the CIS) are found in gold deposits in Archean greenstone belts and Early Precambrian gold-bearing conglomerates. Such economic deposits are unknown in Russian Federation. Instead, about two-thirds (62.4%) of its gold reserves are in the sediment-hosted deposits including found in metamorphic shales, unmetamorphosed black-shales, and carbonate-sedimentary formations. The remaining reserves are divided approximately equally between volcanic-related and intrusive-related gold deposits. However, according to Krivtsov et al. (2003), estimates of undiscovered gold resources within these three major groups of gold environment are quite similar: 34% sediment-hosted, 34% volcanic-related, and 32% intrusive-related gold deposits.

In contrast to the U.S., where about 90% of gold is mined by open-pit operations from sediment-hosted deposits, the proportion of open pits in Russian gold mining does not exceed 10-12%. Under the pressure of ever-increasing costs of equipment, power, transportation, materials, and labor, underground mining is uneconomical or marginal in Russia today, even where gold ore grades are relatively high (8-9 g/t). The development of open-pit deposits in Russia that have ore grades below 3 g/t and of hard-to-work deposits with ores that are highly carbonaceous and/or arsenical is burdened even more by the absence of the economical and environmentally benign extensive use of heap leaching. In 1992, just 0.2% of the gold production in Russia came from heap-leach processing. This fraction increased to 6.3% in 2005 but is still disproportionably low in comparison with the United States.

Use of the heap-leaching method in Russia, which permits development of deposits with gold grades down to below 1 g/t, is restrained by the climatic conditions in gold-bearing regions. Very widespread continental glaciations over the last 1-3 million years as well as presently arid climate of the Central Asia regions account for the lack of abundant, highly oxidized ore fields. In addition, the long periods (up to 8-9 months) of low winter temperatures are highly unfavorable for leaching. However, broad implementation of agitation leaching with carbon, bioleaching, or the "redox" technology could drastically improve the situation.

The level of gold mining in the Russian Federation for the period 1990-2000-2025 has been calculated (Krivtsov et al. 2003) on the basis of two different scenarios for different assumed growth rates. The maximum growth rate of gold mining under favorable economic conditions was assumed to be 2.39%, which is close to the growth rate in developed and emerging countries of the world other than the CIS. The minimum growth rate under unfavorable economic conditions was assumed to be only 0.35%.

The growth rate cited above is based on a period of actual decline of gold production in Russia (1990-1998) and on a period of slight increase (1999-2000) intensified by the ruble default in 1998 and the sharp fall in the price of gold on the world market. These circumstances resulted in the egress of Western mining companies and Western investments from Russia. The steady increase in the prices of gold and silver in the last few years and the growth of the world exploration budget to $1.8 billion in 2004 (*USGS Minerals Yearbook*, 2004) are once again rousing the interest of Western mining companies in Russian gold deposits.

In 2004, the Barrick Gold Corp. acquired a stake in Highland Gold Ltd., one of the most active junior operators in Russian gold mining and acquisition, and for the second time opened a new office in Moscow (April 2005) to coordinate the company's interests in Russia and Central Asia. Greg Wilkinson, president and CEO of the Barrick Co., said while attending the office opening that Russia has tremendous geological potential and that Barrick looks forward to applying its technical expertise to exploration, development, and operations and to putting its financial resources to use to the benefit of Russia and Barrick's shareholders.

In July 2004, Anglo-Gold Ashanti Ltd. agreed to acquire 29.9% of Trans-Siberian Gold PLC, which has three gold projects in Russia: the Asacha and Rodnikovoye projects in Kamchatka and the Veduga Project in the Krasnoyarsk region of Russia. At the same time, Newmont Corp. signed a private-placement agreement with Franc-Or Resources Co. of Canada, which created an exclusive strategic alliance for gold exploration in Russia by Newmont. The first Franc-Or project is the Bugdai polymetallic deposit in southeastern Chita region, with about 594 million tonnes of ore containing, in addition to lead and zinc, about 400,000 t of molybdenum, 700 t of gold, and 1,700 t of silver (mineral.ru of July 2005).

In June 2006, BHP Billiton, the world's largest diversified company, and Russia's largest Norilsk Nickel Mining and Metals Company, announced the launch of an alliance for mineral exploration and development in the Russian Federation. The agreement provides for joint identification of attractive mineral exploration and development prospects for a range of commodities, followed by the establishment of local companies to pursue and develop specific projects. In our view, one such project would be Sukhoi Log—the largest Russian gold deposit.

The return to the Russian gold mining sector of such major Western mining companies and the recent increase in state funding for exploration could significantly lift the growth rate cited above relative to the current level of gold mining in the Russian Federation.

Uzbekistan is the second-largest gold producer in the CIS, with about 85-93 tonnes of gold mined annually in the period 2000-2004 (*USGS Minerals Yearbook*, 2004). The lion's share of this production, about 60 t in 2004, comes from the Muruntau deposit (Reuters, March 12, 2005), one of the largest gold deposits in the world, and its tailings (7.6 t), which are being processed by the Newmont Co. in conjunction with the Uzbek Navoi Mining Co. The remaining production comes from Oxus Resources PLC from the Amantaytau gold deposit (about 5 tonnes) and as a by-product from the Kal'makyr porphyry copper and Uchkulach lead-zinc deposits (about 13 tonnes), as well as from smaller producers. A small amount, about 0.5-1.0 tonne of gold, was produced by placer operations.

The gold reserves of Uzbekistan (2,100 t) are concentrated in 41 explored deposits, only nine of which are being worked. The breakdown of the Uzbek gold reserves is quite similar to that described above for the Russian Federation. About three-quarters of the reserves are in sediment-hosted gold deposits; and the rest are equally divided among volcanic-related, intrusive-related, and gold-bearing porphyry and VMS deposits. The amount of placer gold in the breakdown of gold reserves is less than about 2%. The breakdown of the estimated undiscovered (inferred) resources is similar in general to that for the known reserves.

In contrast to Russia, more than 95% of the gold in Uzbekistan has been mined recently from lode gold deposits by open-pit operations; but this amount may decrease significantly with time when the Muruntau deposit, which is one of the largest open-pit gold mine in the world (3.5 x 3.0 km and 460 m deep), is forced to start underground operations.

The climate in Uzbekistan is much more favorable for heap leaching than in Russia. The successful heap-leaching gold extraction from the low-grade Muruntau stockpiles for more than a decade by the original joint venture between the Newmont Co. and the Navoi Mining and Metals Co. of Uzbekistan is a good illustration of this.

In the immediate future, the level of gold mining in Uzbekistan could be maintained at the current level of 85-90 tonnes of gold if new gold mines can be brought into production to offset a probable decrease of production at the Muruntau deposit.

The Republic of Kazakhstan, with approximately 28-30 tonnes of annual gold output (*USGS Minerals Yearbook*, 2004), is the third-largest producer of gold in the CIS, after Russia and Uzbekistan. Kazakhstan also has the third-largest reported gold reserves of 1,500 tonnes (*MBendi Profile*, 2005). Approximately 60% of these reserves are in 218 lode gold deposits, of which only 74 have been in operation at one time or another. Some 38% of these gold reserves are in polymetallic, volcanogenic massive sulfide, and porphyry copper deposits; and only about 2% of the gold reserves are in placer deposits.

The breakdown of the Kazakh lode gold reserves is more or less similar to that of Russian and Uzbek reserves: about 60% are in sediment-hosted deposits, like Bakirchik and Suzdal'skoye, while the remaining reserves are largely found in intrusive-related gold stockwork (Vasil'kovskoye) and numerous vein-type deposits. In contrast to Russia and Uzbekistan, the reserves of volcanic-related gold and gold-silver deposits are insignificant despite the extensive development of Paleozoic volcanics in Central Kazakhstan.

Current production from lode gold deposits is divided almost equally between open-pit and underground operations, but the future development of shale-hosted Bakirchik deposit and expansion of operations at the intrusive-hosted Vasil'kovskoye and Varvarinskoye deposits will definitely make open-pit mining the leading extraction method in Kazakhstan.

In the 1990s, following the collapse of the Soviet Union, large and small Western mining companies entered Kazakhstan in search of gold resources. These included Placer Dome and TECK Corp. of Canada, Santa Fe Pacific Gold Corp. and later Newmont Corp. of U.S., BHP World Exploration Inc. and Normandy Mining Group of Australia, as well as many small companies such as Goldbelt Resources Ltd., Central Asia Goldfields Ltd., and First Dynasty Mines Ltd. (later-Indochina Goldfields Ltd.) of Canada, Bakirchik Gold PLC, Kazakhstan Minerals Co., and Celtic Resources Holdings PLC (UK). However, only a few, mostly small Western mining companies, have continued gold mining and exploration in Kazakhstan: Celtic Resources Holdings PLC (the Suzdal gold deposit), Eurasia Gold Ltd. (the Mizek gold-copper and the Central Mukur gold deposits of eastern Kazakhstan), the European Mining Co. (the Varvarinskoye copper-gold deposit), Hambledon Mining PLC (the Sekisovskoye and smaller deposits in Altai region of eastern Kazakhstan), and Frontier Mining Ltd. (the Naimanjal gold-copper deposit).

Unfortunately, Ivanhoe Mines Ltd. has not undertaken to develop the Bakirchik gold deposit, the largest in Kazakhstan, with more than 400 tonnes of measured and indicated resources and large inferred resources, after many years in suspension. Ivanhoe has described Bakirchik ore as "double refractory" because most of its gold is enclosed in arsenopyrite and pyrite, and its ore-bearing sediments contain up to 4% carbon, which makes processing even more difficult. The best option to process this ore, according to Ivanhoe, is to roast it in rotary kilns, followed by leaching of the calcine by the carbon-in-leach technology. In 2004, the company began construction of a commercial demonstration roasting plant, but lack of financing once again may suspend the development of this project.

Tax-cutting amendments to existing law signed by the president of Kazakhstan in June 2006 may attract Western and local mining companies like Kazakhaltyn (KazakhGold) to intensify the exploration and development of gold deposits.

Kyrgyzstan, with 22 t of gold mined in 2004 (*USGS Minerals Yearbook*, 2004), is the fourth-largest producer of gold in the CIS. However, more than 20 tonnes of this production (20,432.7 kg) was from the Kumtor mine operated by Centerra Gold Corp. of Canada. With the sharp decline of Kumtor's production in 2005 to 15,581 kg (Centerra Web site, March 2006), total gold output in Kyrgyzstan also has fallen.

Official data on the Republic of Kyrgyzstan's gold reserves are not published. By our estimate, it has significantly smaller proven and probable reserves than Uzbekistan or Kazakhstan, about 500-600 tonnes of gold, of which almost two-thirds is attributed to the three largest gold deposits: Kumtor, Jerooy, and Taldybulak Levoberezhnyi (Leftbank). Approximately half of these gold reserves are in sediment-hosted deposits such as Kumtor, Taldybulak Leftbank, Savoyardy, and Terek (Karakala); and 30% are in intrusive-related deposits (Jerooy, Andagul-Unkortash, and many smaller ones). The rest of the reserves are concentrated in gold-bearing porphyry copper deposits (Andash, Aktash, Taldybulak) and skarn deposits (Kuru-Tegerek, Kichisandyk, Nasonovskoye). Placer deposits, which were intensively mined, especially in the Chatkal region of Kyrgyzstan, from the tenth to the twelfth centuries, do not play a significant role in current reserves and production.

To date, only the Cameco Corp. of Canada and its offshoot, the Centerra Gold Corp., have won the right to develop such major gold deposit as Kumtor and to continue to operate and explore it. Two other large deposits, Jerooy and Taldybulak Leftbank, have a long history of unsuccessful negotiations by Western companies with the Kyrgyz government.

In 1996 Kyrgyzstan dissolved a previous agreement with the MK Gold Co. for joint development of the Jerooy deposit, and in 1997 the Cameco Corp. decided that it was not interested in the same project. Normandy Mining Ltd. of Australia and British Oxus Resources PLC, which Normandy owns, started negotiations on the development of the Jerooy deposit in January 1998. After 8 years and millions of dollars spent by Oxus on a feasibility study and related items, Oxus Resources was not allowed to continue the Jerooy development because the Kyrgyz government revoked its license in December 2005. This was done on the allegation that Oxus had failed to make the investments necessary to start the project under the terms of its agreement with the government, which Oxus denied. In May 2006, the government granted a development license for the Jerooy deposit to Global Gold Holding GmbH of Austria, which has questionable experience in gold mining. It is a subsidiary of the Strategic Investment Group, a consulting company registered in Cyprus and is reportedly owned by undisclosed Russian and Georgian citizens. Oxus Resources continues to struggle with the Kyrgyz government, and the "Jerooy saga" continues.

Marston and Marston Inc. of the United States produced an initial feasibility study of the Taldybulak Leftbank gold deposit in 1995 at the request of Andre & Cie SA. In 1997, exploration and development rights for this deposit were granted to the Taldy-Bulak Mining Co., a joint venture between the Kyrgyz Kara-Balta Mining Enterprise and MMC Berhard Co. of Malaysia. The latter company retained Kilborn Engineering of Canada to produce a feasibility study, but no production was achieved by this joint venture. The next licensee for Taldybulak deposit was granted to Central Asia Gold Ltd. of Australia, which lost its license in 2005 over the same allegation made against Oxus Resources—too slow progress. At the beginning of 2006, the obscure Summer Gold Co. of Kazakhstan and the Kyrgyz state-owned Kyrgyzaltyn Co. organized a joint venture named Altynkan Co. for exploration and development of the same deposit.

Many years and many millions of dollars have been spent to no avail on the development of the Jerooy and Taldybulak deposits, which are the main alternatives to the imminent decline of gold production from the Kumtor deposit. The Kyrgyz government is trying to lay blame for the delay on Western mining companies, but a large part of the fault lies with the government itself.

The Republic of Tajikistan, with about 3 tonnes of gold output in 2004, is the fifth gold producer in the CIS. According to data of the Tajikistan Academy of Sciences (Geonews.com.ua, January 2006), 28 gold deposits explored in Tajikistan have 430 tonnes of gold reserves. Most of this amount belongs to sediment-hosted (Chore, Duoba) and intrusive-related (Jilau, Taror, etc.) gold deposits of the Hercynian South Tien Shan accretion zone. Much smaller reserves are found in the volcanic-related gold deposits of the Late Paleozoic Kurama volcanic belt of northern Tajikistan, which also host the large silver-lead-zinc Big Kanimansur deposit. Some 3-5% of reserves are in placer deposits in southern Tajikistan.

The Republic of Armenia is the smallest gold-producing country of the CIS. In 2004 it produced about 600 kilograms of gold (*USGS Minerals Yearbook*, 2004). Most of the 268 tonnes of gold reserves in Armenia are in volcanic-related gold deposits (Zod, Megradzor, Kapan, and Shaumyan) and a small amount in gold-bearing copper-molybdenum porphyry deposits (Kadjaran and smaller deposits). By the author's estimate, Armenia has a moderate potential for the discovery of epithermal, high sulfidation gold deposits.

The only other country in the CIS with the possibility of producing gold in the near future is the Republic of Ukraine. The first gold was produced in 1999 from the Mujievo (Muzhiyevo) lead-zinc deposit of the Transcarpathian region, but its production was uneconomic. The Precambrian gold deposits of the Ukrainian shield described earlier in this book have much greater potential. There is a little demonstrated potential for sediment-hosted gold deposits in Paleozoic sedimentary-carbonate formations of the south Donetsk coal basin. The potential for additional volcanic-related gold mineralization of the Rakhov ore district in Transcarpathian is thought to be moderate.

According to a news release by the Ukrainian State Geological Survey (geonews.com.ua, of June 2006), all enterprises of this agency must concentrate on preparing active economic resources and reserves for the gold-mining industry.

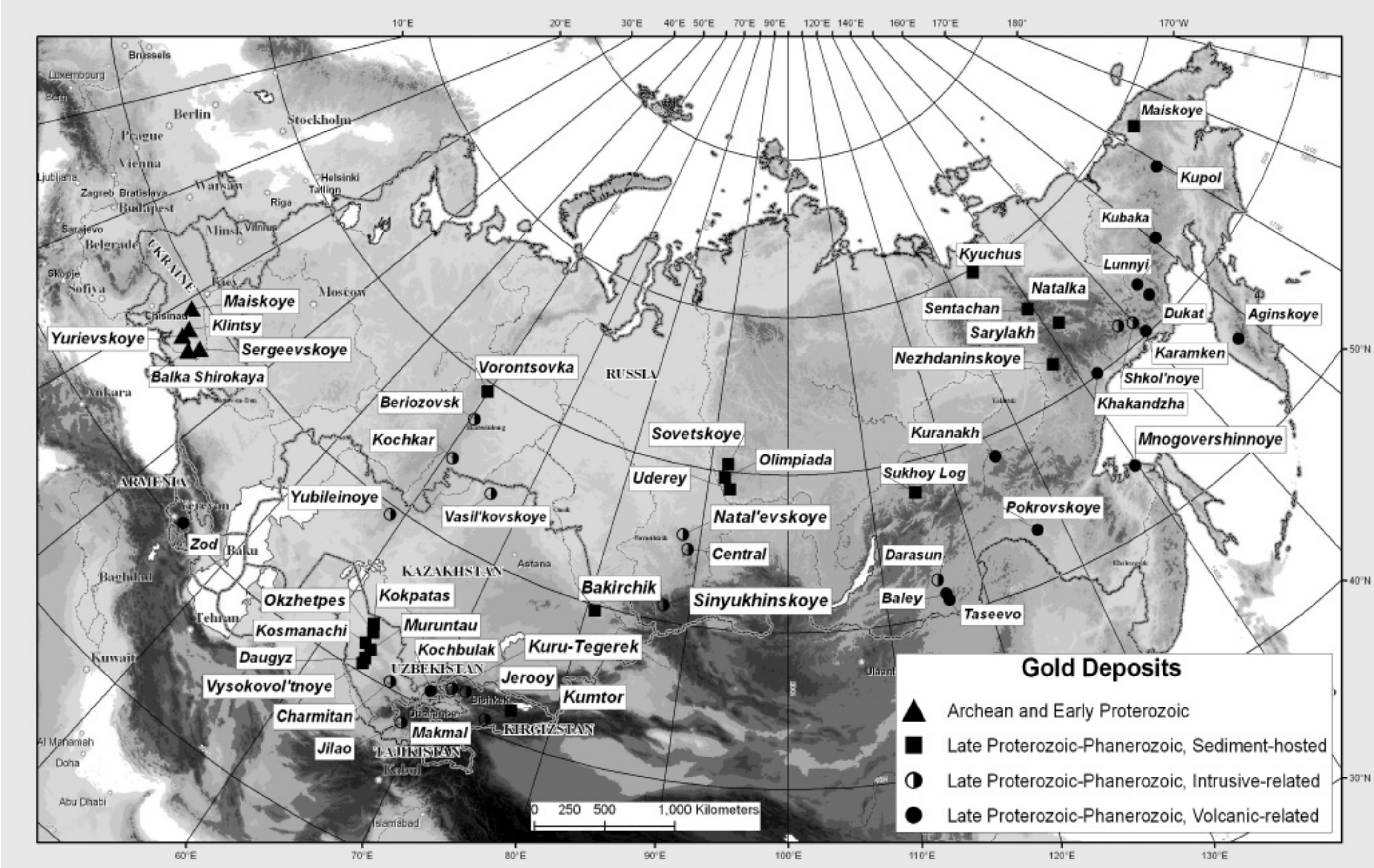
Ralf Bullies noted during the 2006 conference of the Prospectors & Developers Association of Canada in Toronto (Reuters, March 2006) that the wave of mergers and acquisitions over the last 15 years resulted in the creation of a few gold-mining megacompanies like Barrick and Newmont, with annual gold output of up to 7 Moz. However, the growth of gold production has come mainly not from exploration and discovery of new deposits but from acquisition and is now outpacing adequate growth of gold reserves.

The history of gold exploration over the last 25 years shows that the discovery rate of large gold deposits with resources over 3-5 Moz that are needed by large mining companies to sustain gold production at current levels have been diminishing. For this reason, many gold-mining companies are looking for new territories with good potential for gold exploration and development, such as the CIS and China.

The potential of the CIS for the discovery of new gold and gold-silver deposits is vast, given the size of the region (almost one-sixth of the world's dry land, as Soviet propaganda proudly proclaimed) and its huge unmined gold resources. The vast amount of information obtained over the many years of state-funded geological surveying, gold prospecting, and exploration of these unmined deposits is concentrated in the state and local archives. This invaluable database together with the highly educated and skilled workforce of the Russian mineral industry makes the CIS one of the most attractive regions for Western mining companies.

APPENDIX I

MAP OF THE CIS WITH LOCATION OF THE DESCRIBED GOLD DEPOSITS


Gold Deposits
Archean and Early Proterozoic
Late Proterozoic-Phanerozoic, Sediment-hosted
Late Proterozoic-Phanerozoic, Intrusive-related
Late Proterozoic-Phanerozoic, Volcanic-related
0 250 500 1,000 Kilometers
Maiskoye
Kupol
Kubaka
Lunnyi
Kyuchus
Natalka
Sentachan
Sarylakh
Dukat
Aginskoye
Karamken
Nezhdaninskoye
Shkol'noye
Khakandzha
Kuranakh
Mnogovershinnoye
Sukhoy Log
Pokrovskoye
Darasun
Baley
Taseevo
Sovetskoye
Olimpiada
Uderey
Natal'evskoye
Central
Bakirchik
Sinyukhinskoye
Maiskoye
Klintsy
Yurievskoye
Sergeevskoye
Balka Shirokaya
Vorontsovka
Beriozovsk
Kochkar
Yubileinoye
Vasil'kovskoye
Zod
Okzhetpes
Kokpatas
Kosmanachi
Muruntau
Daugyz
Kochbulak
Kuru-Tegerek
Vysokovol'tnoye
Jerooy
Kumtor
Charmitan
Makmal
Jilao
RUSSIA
KAZAKHSTAN
UZBEKISTAN
KIRGIZSTAN
TAJIKISTAN
UKRAINE
ARMENIA
Berlin
Stockholm
Prague
Vienna
Warsaw
Helsinki
Tallinn
Riga
Minsk
Vilnius
Kiev
Moscow
Budapest
Bratislava
Zagreb
Ljubljana
Brussels
Luxembourg
Bern
Sarajevo
Belgrade
Skopje
Sofiya
Chisinau
Ankara
Yerevan
Baku
Baghdad
Tehran
Kuwait
Al Manamah
Doha
Abu Dhabi
Astana
Dushanbe
Bishkek
Kabul
Islamabad
Ulaanbaatar
10°E
20°E
30°E
40°E
50°E
70°E
90°E
120°E
140°E
160°E
170°E
180°
170°W
50°N
40°N
30°N
60°E
70°E
80°E
90°E
100°E
110°E
120°E
130°E

APPENDIX II

RUSSIAN TERMINOLOGY

In this book, the author has tried to use mainly terminology that is well defined in American dictionaries and glossaries of geology but has retained some Russian geological and metallogenic terms and concepts in order to familiarize Western readers with the specifics of the Russian geological literature. Below are explanations of some of the most commonly used Russian terms, which have been taken from *Glossary of Geology*, 1972 [Gary, M., McAfee Jr., R., and Wolf, C. L., (eds.)], translated into Russian in 1977 and edited by L. P. Zonenshain; the *Dictionary of Mining, Mineral, and Related Terms* (Second Edition, 1997) compiled by the American Geological Institute; the *English-Russian/Russian-English Dictionary*, compiled by Kenneth Katzner (1994); the *Russian Metallogenic Dictionary*, Krivtsov, A. I. (ed.), 2003; and other sources.

1. Adamellite—a synonym for quartz monzonite in the United States, containing 0-50% quartz in felsic minerals and 35-60% plagioclase in the feldspar group of minerals.
2. Apo-, as in apobasite and apomagmatic, for example (from the Greek *apo*—"away from," "detached")—a prefix used in petrology, signifying metasomatic alteration without destruction of the original structure.
3. Basite—igneous rocks that have relatively low (45-50%) silica content or that are composed chiefly of dark-colored minerals.
4. Endocontact (from the Greek *endon*—"within," "inside")—the inner part of an intrusive body near its contact.
5. Exocontact (from the Greek *exo*—"outside," "outer part")—host rocks at the outer part of an intrusive contact.

6. Krai—an administrative region in Russia, which is larger than an oblast (see below) and includes as subdivisions autonomous oblasts (e.g., the Jewish AO in Khabarovsk Krai) or autonomous okrugs (e.g., the Dalgano-Nenets AO in Krasnoyarsk Krai).
7. Metabasalt, or metasedimentary rocks (from Greek *meta*—"after," "over")—a prefix that, if used before the name of a sedimentary or magmatic rock, indicates that the rock has undergone metamorphic alteration.
8. Oblast—an area in Russia similar to a state in the United States or a province in Canada, having offices for governing the territory and reporting to the national government.
9. Ore body—a natural accumulation of raw minerals confined to some structural-geological element or to a combination of such elements and bounded on all sides. In Russian terminology, this definition does not include any economic conditions.
10. Ore field—an ore-bearing area of up to tens of square kilometers, containing spatially close deposits and/or ore bodies of similar age, origin, and geological structure.
11. Ore node—part of an ore district with a concentration of ore deposits due to geological conditions favorable for ore deposition, such as intrusive domes and volcanic edifices.
12. Paleo—(from Greek *palaios*)—ancient, as in "paleovolcanic" or "paleocaldera."
13. Plagiogranite—a term used by Russian petrologists for potassium-low intrusive rocks, from quartz diorite to trondhjemite.
14. Polymetal ("polimetal")—a term commonly used for nonferrous (copper, lead, and zinc) ore deposits or as a name for multimetal mineralogical associations that contain galena, chalcopyrite, and sphalerite.
15. Activization, mainly as a "tectono-magmatic activization"—a term widely used in Russian metallogenic literature, which is taken to mean a manifestation of endogenous processes in stable structures of the earth's crust such as platforms, rigid massifs, and consolidated fold-and-fault belts. Such processes result in disruption of cratonic crust and in the formation of magmatic-related ore deposits of possible mantle origin (Scheglov

1987). They have not only an ore-generating but also an ore-concentrating capacity that results in the mobilization of ore components disseminated in crustal rocks along ore-distributing and ore-concentrating deep faults. This term also is used by the International Association on the Genesis of Ore Deposits (IAGOD) as the name of its Work Group-4 "Tectono-Magmatic Activization (DIWA)."

16. Riphean—the lower and middle part of the Late Proterozoic.
17. Suite—in the Russian literature, a term used to label the major stratigraphic units of a local stratigraphic scale similar to "formation" in the Western literature.
18. Tonalite—a synonym for quartz diorite with biotite and amphibole as major dark-colored minerals.
19. Vendian—the youngest Precambrian era in the Russian geological system. The approximate Western equivalent is the Sinian.

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Figure 52. Central ore zone of the Kubaka deposit: fragment of the ore body structure (plan and cross section [after Konstantinov et al. 1992]).

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Figure 54. Schematic geologic map of the Kupol deposit (after Bema Gold Technical Report, 2005).

Figure 55. Kupol deposit. Cross section of the Big Bend zone (simplified after Bema Gold Technical Report, 2005).

Figure 56. Karamken deposit. Geologic map (A), cross section (B) of the deposit, and cross section of the Glavnaya ore zone (after Konstantinov et al. 1992).

Figure 57. Scheme of the Baley graben block structure (after I. Eleeva, TsNIGRI).

Gold Deposits of the CIS represents the first comprehensive study in English of the gold and gold-silver deposits and resources of the CIS. The book includes (1) a history of gold exploration from ancient times; (2) a classification of the gold and gold-silver deposits; (3) a detailed description of more than fifty of the major and most representative gold deposits, including their location, geological settings, structure, alteration styles, mineralogy, and reserves and resources; and (4) an estimation of resources of all CIS gold-producing countries and their potential for possible new discoveries. For the first time, it contains description of recently explored the Kupol deposit of the Russian Northeast and some other CIS deposits never before described in English (Sarylakh, Sentachan, Natal'yevskoye, Kuru-Tegerek, Zod etc.).

The book should provide significant material for any comparative studies between the gold deposits of the CIS and the West. It should also provide a significant body of new information for scientists, exploration and mining companies, as well as faculties and students of mining schools concerned with the geology, exploration, and development of gold deposits in the world.

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