

Geology and Structural Features of Vein-Type Lead and Zinc Deposits

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Abstract—The geological and structural position and localization conditions of the vein-type Pb–Zn deposits of the Sadon (North Ossetia) and East Karamazar (North Tajikistan) ore districts are considered. The leading role of long-lived deep faults in the control of large deposits is emphasized. Examples of such deposits in different provinces are given. The study of fractures and faults at Pb–Zn deposits is important for understanding of the formation conditions of other hydrothermal deposits.

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INTRODUCTION

F.I. Wolfson is one of the geologists who started exploration for and investigation of lead ore at the vein-type Takeli deposit in the southwestern Karamazar. In the 1930s, this was very rich ore, readily mined from small open pits and adits.

At the present time, the economic importance of vein-type Pb–Zn deposits is not great; their contribution to the total production of these metals is only a few percent. Many vein-type Pb–Zn deposits have been exhausted. However, interest in this type of base-metal deposits continues unabated. Disciples and followers of Wolfson continue to study these deposits in order to recognize the fracture pattern, relationships between ore-controlling faults of various directions, relations of these faults to transverse and oblique premineral limitations and offsets of veins, the systematic arrangement of ore shoots, and many other things that cannot be observed at gold deposits of vein morphology. In contrast to the vein-type Pb–Zn deposits with visible galena and sphalerite, acceptable for direct observation, the internal structure of gold ore shoots and their location in ore-bearing fractures are obliterated.

Not only the structural features of vein-type Pb–Zn deposits are repeated at gold deposits. The scale of occurrence of both Pb–Zn and Au ores depends on the dimensions of ore-bearing faults. The complexly built and relatively thick fault zones that control large Pb and Zn reserves are comparable with structural elements that host large Au reserves. Such a geological and structural setting is characteristic, for example, for ore-bearing faults at the Olimpiada and Nezhdaninsky gold deposits in Russia, the Bakyrchik deposit in Kazakhstan, and some other deposits abroad.

The most important ore belts in Russia are the Sadon ore belt in the North Caucasus, with vein-type Pb and Zn deposits, and the East Transbaikalian belt, with the Spassky and Au-bearing Novo-Shirokinsky deposits; comparable in significance is the Karamazar belt, near the Tajikistan–Uzbekistan border.

The North Caucasus (North Ossetia) base-metal belt comprises not only ordinary but also large and medium-size Pb–Zn deposits. Thus, an opportunity exists to compare the geology and structure of large and relatively modest deposits and to reveal the causes of the localization of large Pb and Zn ore reserves.

The Sadon deposit, which has been mined since 1890, is largely exhausted. More than a million tons of both metals have been produced here, along with Cd and Ag as by-products. More than 40 t of silver have been recovered at the smelter in the vicinity of the town of Vladikavkaz.

GEOLOGY OF THE SADON BASE-METAL BELT

The Sadon belt is traced along the Digora–Ossetia intrusive–tectonic uplift, which extends in the near-latitudinal direction, gradually plunging eastward. Middle Paleozoic granitic rocks and small horsts of Proterozoic chlorite–quartz, chlorite–sericite–quartz, and amphibole schists crop out in the western and central segments of the belt, making up the lower structural stage, which hosts the bulk (up to 80%) of the highest grade base-metal ore. In the north, these crystalline rocks are overlain by Lower Jurassic (Pliensbachian) andesitic and dacitic lavas and less abundant tuffs, which, in turn, underlie a Lower–Middle Jurassic sandstone sequence. The Jurassic rocks compose the upper structural stage, which hosts the remainder of economic ore (Tibilov, 1969). The greatest thickness of volcanics is reached in the central, likely the most mobile, segment of the belt,

approximately 40 km long. In the west, in the territory of the Fasnal Uplift, and in the east, close to the Fiagdon Uplift, the thickness of volcanic rocks abruptly decreases to 100–200 m and then they disappear. At the eastern, most plunging end of the belt, only the Lower–Middle Jurassic sandshale sequence occurs.

The base-metal ore mineralization most likely is late Bathonian in age. Thin (only a few tens of meters) beds of Bathonian clay mark the cessation of sedimentation and the transition to a short orogenic period and the deposition of Pb–Zn ore. Recent data (Gargatsev et al., 1994) support the aforesaid. The thick (~2 km) sequence of Upper Jurassic limestone postdated the ore deposition.

From east to west, the ore mineralization is first localized in Aalenian–Toarcian silty slates (the Dargavs–Sargom, Kakadur–Khanikom, and Kadat ore fields). Westward, the Pb–Zn mineralization is observed in Domerian sandstone, Pliensbachian andesitic and dacitic lavas and tuffs, and small horsts of Paleozoic granitoids and Proterozoic schists (the Dzhimidon, Kholst, Levoberezhny, and Arkhon ore fields and deposits). Farther to the west, the Sadon and Zgid ore fields are hosted in granitoids and locally enter into the Jurassic andesite and dacite in the north. Finally, at the western flank of the belt, in the Digora Horst, the base-metal ore is localized only in the metamorphic schists and granites of the lower structural stage (the Fasnal and Vazakhokh ore fields).

The central portion of the Digora–Ossetia Uplift, which is characterized by a two-stage structure, is transected by several oblique and branching WNW-trending faults that are spaced at 3–5 km and divide the uplift into a system of blocks, or sheets. These tectonic sheets demonstrate progressive right-lateral offset relative to one another. The central sheet, composed of rocks pertaining to both structural stages and sandwiched between the Sadon–Unal Fault in the southwest and the Diagonal Fault in the northeast, is mineralized to the greatest extent. From west to east, high-grade economic ore is known from the Zgid, Sadon, Arkhon, and Oktyabr'sky deposits. The next tectonic sheet, between the Diagonal and Dagom faults, hosts less important Pb–Zn deposits: Levoberezhny, Kholst, Dzhimidon, and Bazang. In each tectonic sheet, the ore mineralization is localized in marginal parts of transverse uplifts, being related to NNE- and NE-trending systems of shear splays of bending or branching ore-controlling boundary faults (Rypinsky et al., 1969; Nekrasov, 1980; Konstantinov et al., 2003).

In the eastern part of the belt, where only Jurassic rocks crop out, the character of ore localization is different. The deposits are confined here to near-latitudinal shear zones, and the ore is hosted in steeply dipping NW- and WNW-trending fractures conjugated with these zones (the Kakadur–Khanikom, Kadat, and other deposits). In the upper structural stage, the ore-bearing fractures inherit the bends of plastic shale and thus cre-

ate structural traps for orebodies. Indeed, in some segments of the ore belt, the NW-trending faults and orebodies gradually become near-latitudinal and ENE-trending and then again return to their previous orientation.

It may be suggested that the vertical range of ore formation in the central portion of the ore belt (1.5–3.5 km from the former ground surface) was the most favorable for and susceptible to the changing conditions of ore deposition (Nekrasov, 1980), and the main body of ore was deposited precisely here in the form of the Sadon and Zgid deposits.

The following structural elements are most promising for ore localization: (1) bends of ore-controlling high-amplitude faults extending in the WNW direction; (2) the most mobile areas, between two closely spaced branches of NW- and WNW-trending faults; and (3) small horsts of granites that adjoin the ore-controlling faults in the north or are sandwiched between such faults. In case (3), the base-metal ore mineralization is hosted in the brittle granitic rocks, penetrating updip into the overlying volcanics only for 100–200 m.

The structural features mentioned above are most characteristic of the Sadon deposit, which contains large Pb and Zn reserves.

STRUCTURE OF THE SADON DEPOSIT

The deposit is related to the Sadon Fault Zone and varies in thickness from 10 m at the southern flank to 80–100 m at the opposite flank. The deformed rocks of this zone are separated at the hanging and lying walls by the Western and Eastern boundary sutures, filled with clay gouge. In granite, these faults steeply dip to the southeast, while in the overlying volcanics they bend and dip northwestward. The fault zone extends for almost four kilometers in the NNE direction from the Sadon–Unal Fault in the south. In this direction and upward, the Sadon Fault penetrates volcanic rocks, where it splits into numerous branches that are cut off by the WNW-trending Diagonal Fault (Fig. 1).

The Sadon Fault is a long-lived structural element. In some intervals, its sutures filled with clay gouge are sealed by dacitic stocks and dikes and younger eruptive breccia of Pliensbachian age. The stocks and dikes are considered to be conduits and vents of volcanic flows. In the Pliensbachian, the fault zone branching at the roof of the granitoid pluton was a horst-brachyanticline divided by fault branches into a series of narrow longitudinal sheets. The central sheet remained relatively uplifted during accumulation of volcanic flows 240 m in total thickness. The adjacent tectonic sheets subsided to a depth of 500–620 to 1000 m. The maximum total amplitude is characteristic of the most mobile Western Suture, which is interpreted as a left-lateral reverse-strike-slip fault, while the Eastern Suture is a right-lateral normal-strike-slip fault (Fig. 1). In the course of development of the Sadon Fault, the amplitude of displacements decreased and by the moment of ore depo-

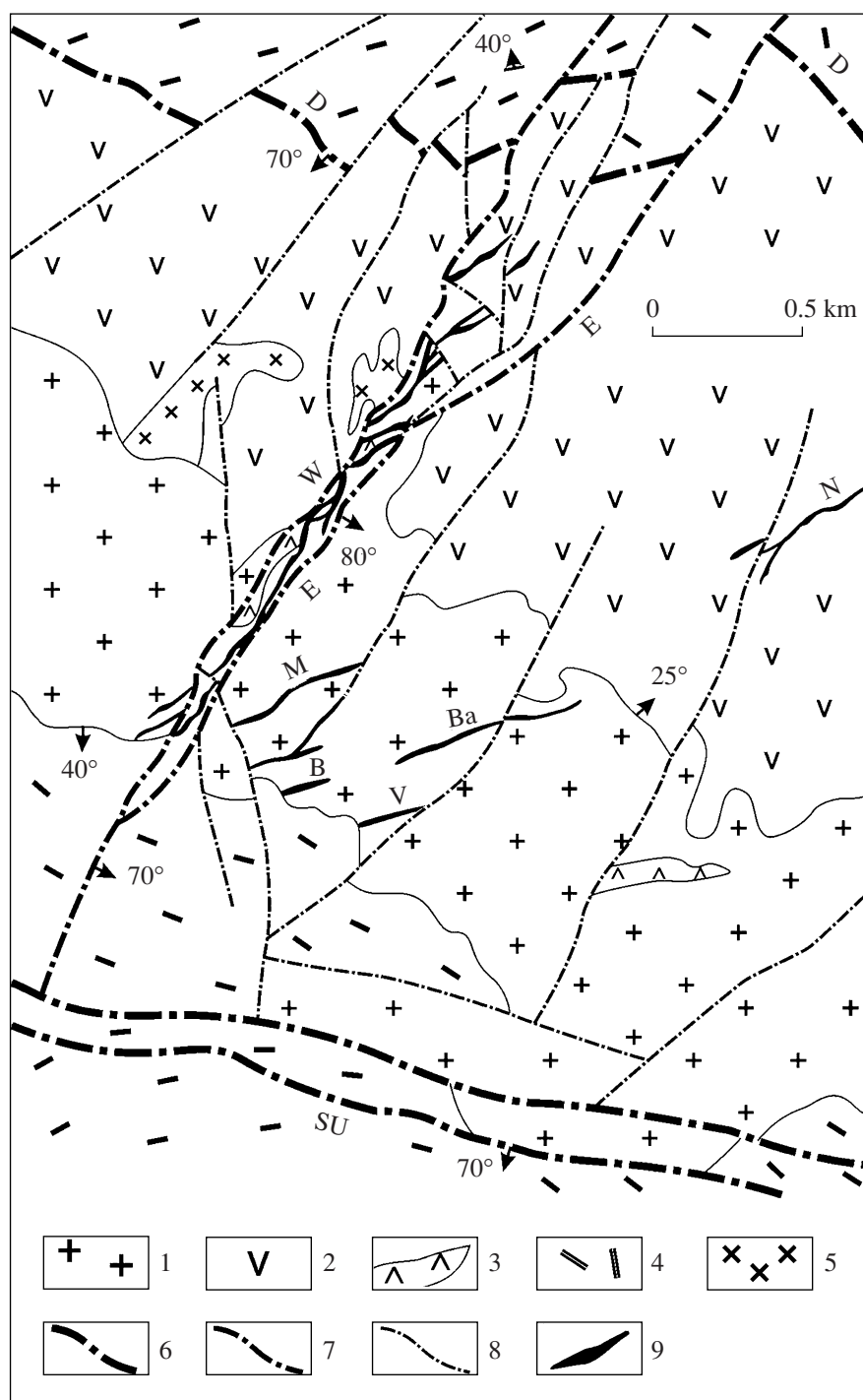


Fig. 1. Geological sketch map of the Sadon deposit. (1) Middle Carboniferous granodiorite and granite; (2) Early Jurassic andesite and dacite (lavas and tuffs); (3) Early Jurassic dacite and albitophyre; (4) Lower-Middle Jurassic sequence of shale and subordinate sandstone; (5) Middle Jurassic quartz diorite; (6) regional ore-controlling faults (letters in figure): SU, Sadon-Unal, and D, Diagonal; (7) tectonic sutures filled with clay gouge in the ore-bearing Sadon Fault Zone (letters in figure): W, Western, and E, Eastern; (8) other faults; (9) ore zones and vein-type base-metal orebodies (letters in figure): M, Multiple-Veined, B, Bitarov, Ba, Bachit, V, Vertical, and N, Nogkau.

sition diminished to a few meters (Nekrasov, 1980). For example, the separation of a vein that offsets from the Eastern Suture does not exceed 1.5–2.0 m in plan view (Fig. 2).

The ore mineralization is largely localized between the Western and Eastern sutures in the form of en echelon orebodies within a segment that extends for 2000 m in the lateral direction and from 500–550 masl in gran-

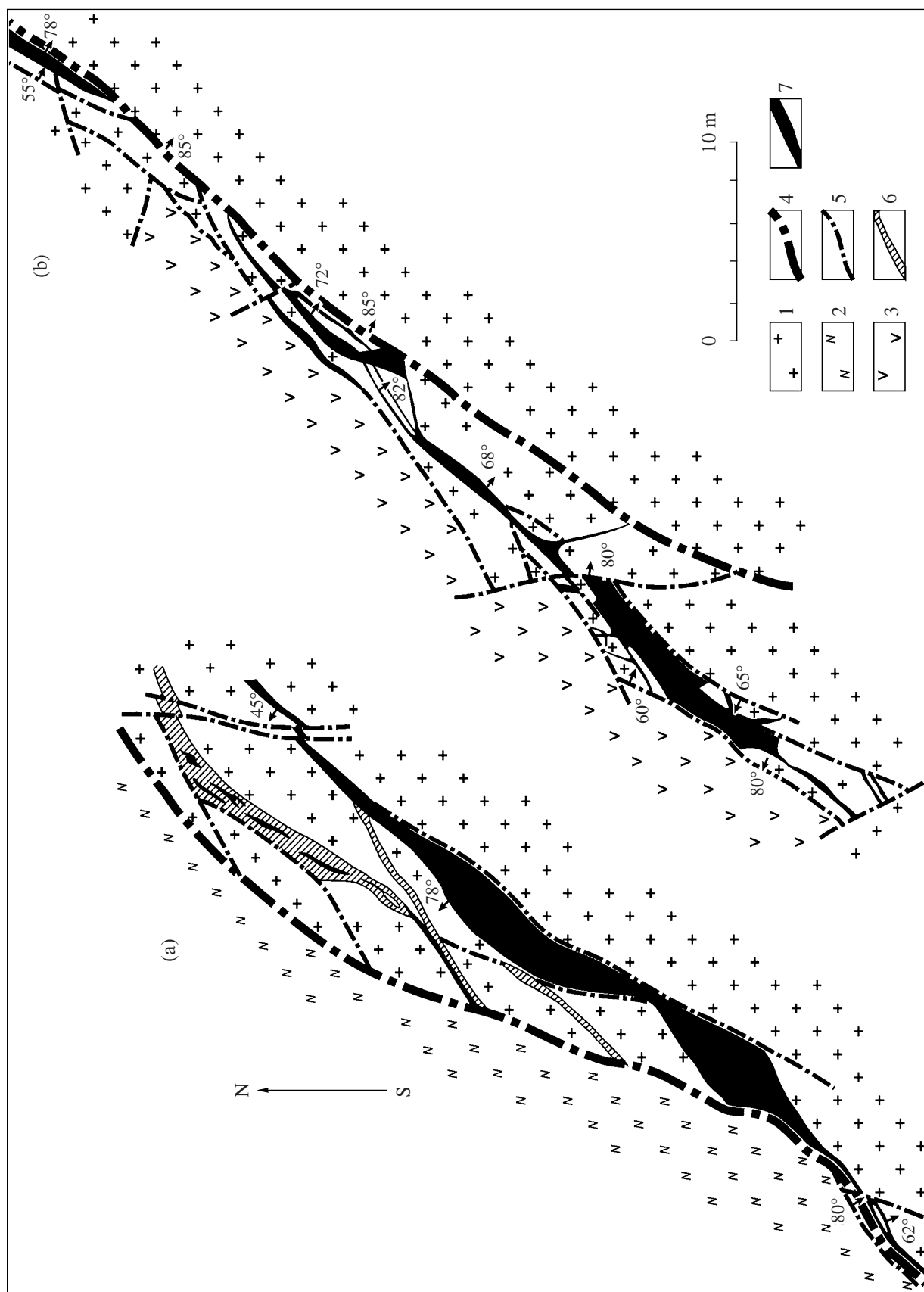


Fig. 2. Sketches of ore veins and veinlets that illustrate relationships of ore-bearing fractures and orebodies with the (a) Western and (b) Eastern tectonic sutures filled with clay gouge in the Sadon Fault Zone (plan view). (1) Granite, (2) subvolcanic dacite, (3) andesite and dacite flows, (4) tectonic sutures filled with clay gouge, (5) other shear fractures, (6) older pyrite-quartz veins and veinlets, (7) younger pyrite-galena-sphalerite ore veins and veinlets.

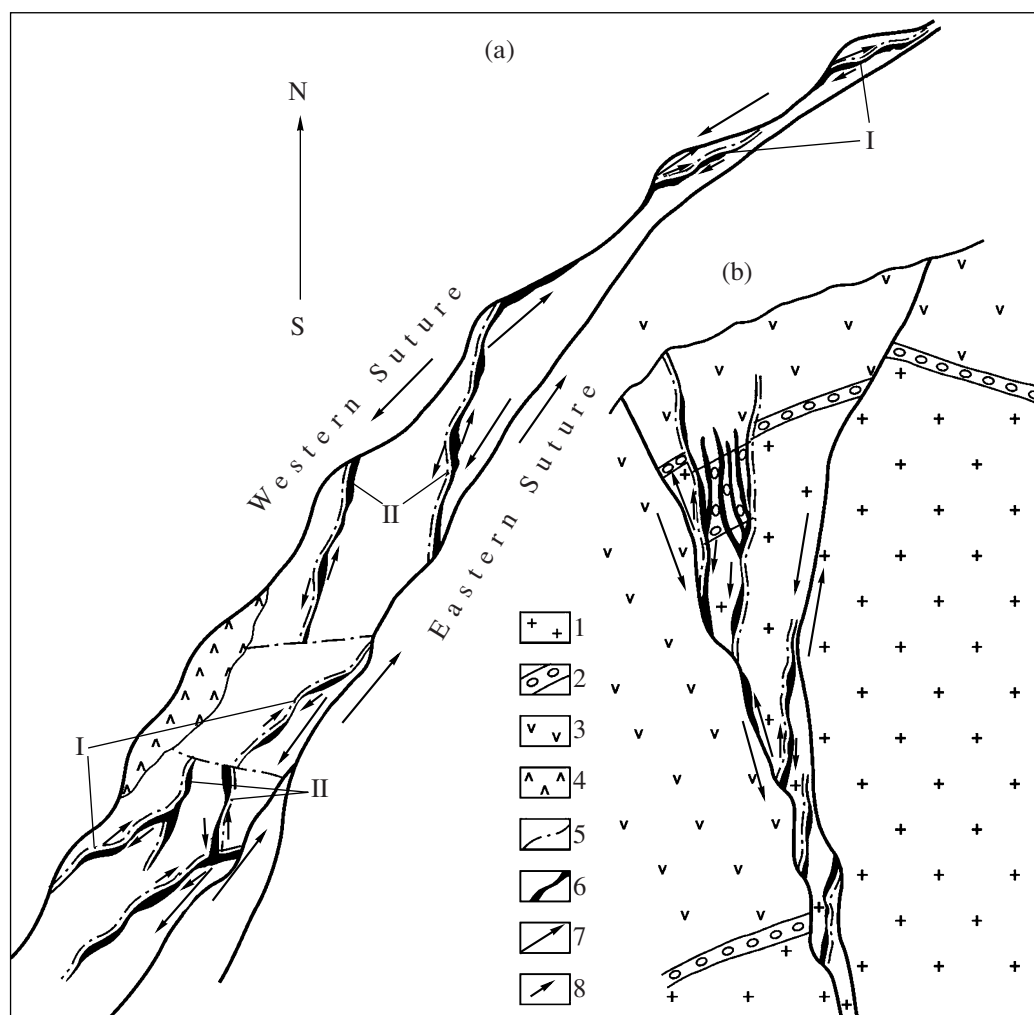


Fig. 3. A scheme illustrating directions of suggested intramineral movements in the ore-bearing Sadon Fault Zone: (a) plan view and (b) section. (1) Granite, (2) basal conglomerate, (3) andesite and dacite flows, (4) subvolcanic dacite and albitophyre dikes, (5) slip plane with premineral clay gouge, (6) ore vein, (7) direction of intramineral movement along sutures of the Sadon Fault, (8) direction of intramineral movement along other faults. I and II are systems of auxiliary shear fractures.

ites (as supported by drilling) to 1820 masl in volcanics. Thus, the vertical range of ore mineralization reaches approximately 1300 m.

The orebodies hosted in granite are tabular or slightly lenticular (Fig. 2) and composed of quartz, quartz–siderite–galena–sphalerite, and galena–sphalerite mineral aggregates. Veins are commonly 1–2 m thick, with swells reaching 10 m near the roof of granite, where the veins locally give way to stockworks and systems of veinlets, as well as systems of closely spaced thin and persistent veins in bodies of eruptive breccia.

In the overlying volcanic rocks, the thickness of orebodies decreases markedly and they grade into thin isolated veins and veinlets. A discontinuous unit of basal conglomerate is incorporated into the fault zone as separate tectonic blocks. Veins that enter these blocks are transformed into relatively thick (up to 18 m or greater) systems of closely spaced high-grade pyrite–sphalerite–

galena veinlets. From the uppermost level of ore mineralization to the level of 1600 masl, galena is predominant in veins and veinlets; the Pb/Zn ratio is maintained at 3/1. At 1400–1200 masl, this ratio is close to unity. At a greater depth, the ore largely consists of sphalerite, and by 900–700 masl, the Pb/Zn ratio equals 1/(4–6).

At deep levels of the deposit (1100–950 m), a zone of thin pyrite–pyrrhotite–galena–sphalerite–quartz veins and veinlets offsets in the ENE direction from the Eastern Suture of the Sadon Fault near its junction with the Sadon–Unal Fault. These are the Maisky, Bitarov, Bachit, Nuzal, and other veins (Fig. 1). Almost all these veins are hosted in granite and pinch out, penetrating into the overlying volcanics. As a rule, these veins extend for 100–200 m and have a thickness no greater than one meter. Only the Bachit Vein is traced for 500–700 m. The zone of the above-mentioned veins marks

the system of older auxiliary shears of the Eastern Suture sealed by minerals of the first generations.

The localization of ore mineralization in the Sadon Fault Zone is controlled by the morphology of the Western Suture, from which most ore veins and veinlets spread, and by the shear systems in the deformed zone between both sutures.

The tectonic surface of the Western Suture, which is accompanied by ore mineralization hosted in granite, conglomerate, and basal volcanic units, steeply plunges to the southeast. The fault surface is complicated by alternating sockets (Fig. 3) with moderately convex northwest sides. Each socket controls a swell of the fault zone, and almost every swell hosts an orebody that offsets from the Western Suture.

The uppermost segment of the suture, which mainly cuts volcanic rocks at the northeastern flank, is crimped to the least extent. The sockets of the suture surface are isometric here and spaced at 100–150 m from one another. The number of sockets decreases with depth; in granite, they are spaced at a distance of 200–300 m from one another in the lateral direction and 150–250 m down the dip. At deep levels, their lateral spacing increases to 300–500 m and they become oval-shaped, elongated down the dip, and steeply declining to the northeast. At the deepest levels (600–900 masl), only four sockets are retained, elongated down the dip.

The orebodies are confined to the auxiliary shears that extend in swells of the deformed zone. The mineralized auxiliary shears of two systems emerge from the southwestern boundary of each socket and from the bend of the Western Suture and its low-angle segments. The shears steeply dip to the northwest and west, striking in the NE and less frequently the NNE directions (Fig. 3). Veins and veinlets largely fill the NE-trending shears but locally sharply bend, filling the fractures of the second system. The alternation of near-vertical swells of substantially galena–sphalerite veins oriented in the northeastern direction (Figs. 1, 3) clearly indicates that the veins were formed in the process of left-lateral reverse–strike-slip faulting. The amplitude of intramineral movements is measured in units from decimeters up to a few meters (Fig. 2).

The tectonic surface of the Eastern Suture is more flat. At the flanks, it smoothly bends, imparting a trough shape to this fault that plunges to the southeast. At a depth, this fault is accompanied by a zone of auxiliary shears of the second, near-meridional system. The shears are filled with quartz–sulfide veins and veinlets composed of early pyrite and pyrrhotite together with prevalent sphalerite.

GEOLOGY AND STRUCTURE OF DEPOSITS IN THE EAST KARAMAZAR DISTRICT, NORTHERN TAJIKISTAN

In the Kurama metallogenic zone, vein-type, substantially lead deposits are localized in the East Kara-

mazar ore district, where they are largely hosted in Permian–Triassic volcanic rocks, whereas base-metal skarn deposits (the Kansay and Altyn-Topkan ore fields, in particular) are predominant in the southwestern Karamazar, where Upper Devonian and Lower Carboniferous limestone is widespread.

Similarly to the Sadon belt, in the eastern Karamazar, the main ore-controlling function belongs to systems of extended and steeply dipping faults (Wolfson et al., 1972; Babakhodjaev et al., 2001). The latitudinal Bashtavak Fault is the main tectonic line. A series of NE-trending faults—Iron, Kanjol, Tary-Ekan, Eastern, and Jusalyasay—offset from the Bashtavak Fault to the southwest, toward the East Karamazar district.

The latter two faults are traced to the NE and SW from another near-latitudinal fault, the Turquoise Fault, which extends to the south of the Bashtavak Fault. The overwhelming majority of vein-type deposits are hosted in relatively narrow and short fault zones of the second order conjugated with the aforementioned larger faults. The second-order faults control the localization of separate zones, areas, and occurrences of veined barite- and fluorite–quartz–galena mineralization.

Like the Sadon belt, the East Karamazar ore district is characterized by a two-stage structure. The lower structural stage is composed of large Middle Carboniferous granodiorite plutons that crop out along the western and eastern boundaries of the district. Cambrian–Ordovician gabbro–diorite–plagiogranite intrusions are locally retained in the uplifted blocks. Middle Devonian–Lower Carboniferous limestone, less abundant dolomite, and volcanics are the country rocks.

The upper structural stage consists of a vast cover of Permian and Early Triassic volcanic rocks, largely silicic in composition, that embraces the entire northern and central portions of the ore district.

The small (<100–200 kt of Pb and Zn) vein-type deposits—Zambarak, Tary-Ekan, and Kanjol—are spatially related to the NE-trending Tary-Ekan and Kanjol faults (Wolfson et al., 1972; Badalov, 1985). The Karatash-Kotan deposit is related to the Eastern Fault, and the Chukur-Jilga deposit, to the junction of the fault bearing the same name with the transverse Lead Fault. The Kanimansur deposit, medium-size with respect to Pb and Zn reserves and enriched in Ag, is localized at the intersection of a NE-trending fault of the same name of the second order with a swarm of quartz porphyry, syenite porphyry, and dolerite dikes that extends in the ENE direction (Safonov et al., 2000; Faiziev, 2003). In contrast to the Sadon deposit, the ore-bearing faults at all East Karamazar deposits are not directly conjugated with regional ore-controlling faults. Of the deposits listed above, only the Kanjol deposit is hosted in granitoids of the lower structural stage, while the remainder reside in volcanics of the upper structural stage. The Pb–Zn ore mineralization followed the emplacement of the youngest basic dikes at the Permian–Triassic boundary.

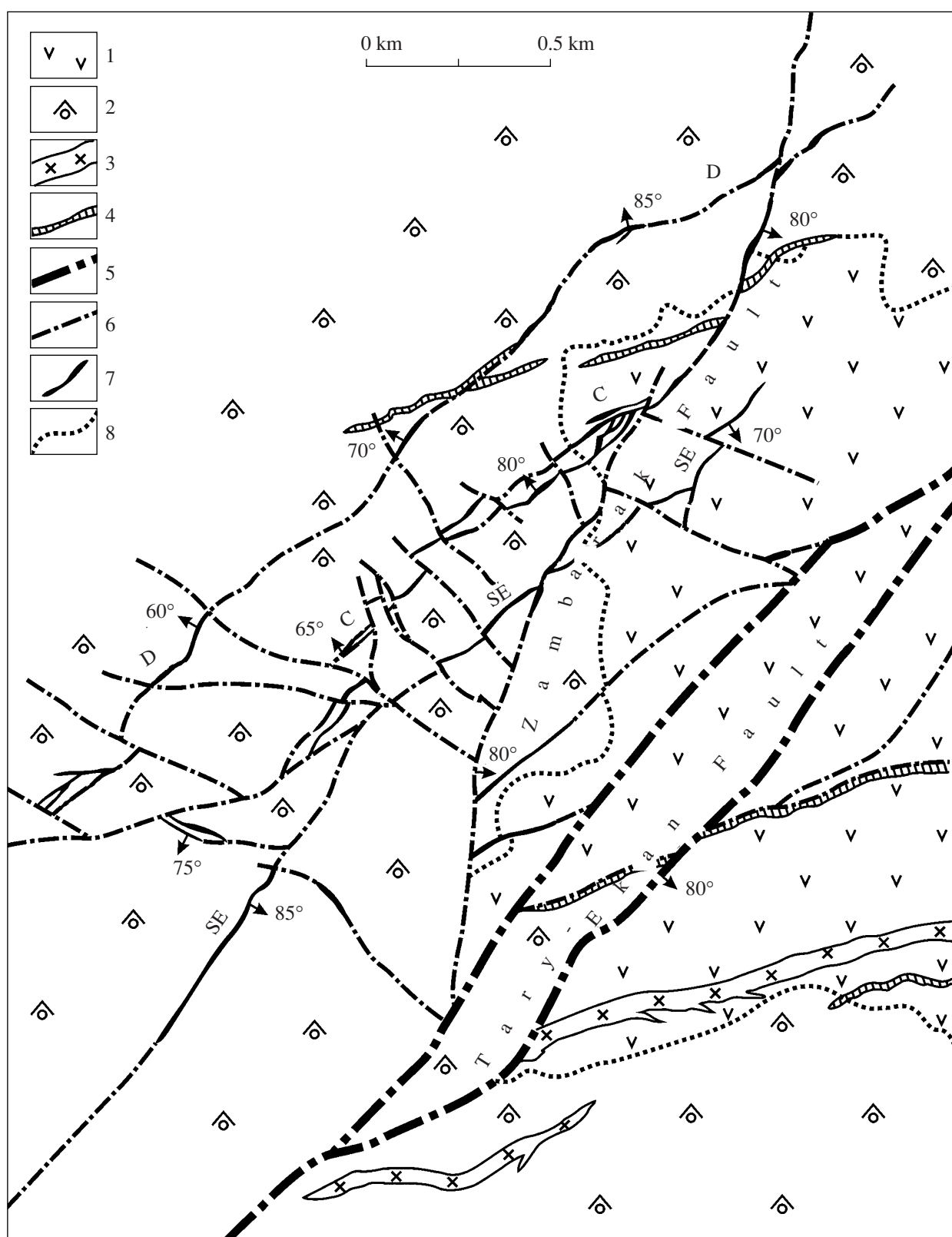


Fig. 4. Geological sketch map of the Zambarak deposit. (1) Early Permian quartz porphyry and albitophyre (lavas and tuffs); (2) Late Permian quartz porphyry and felsite, occasionally spherulitic or fluidal banded, and subordinate tuffs; (3) Late Permian–Early Triassic composite dikes with quartz porphyry cores and dolerite margins; (4) dolerite dikes; (5) the ore-controlling Tary-Ekan Fault and its branches; (6) other faults; (7) quartz–barite–galena veins; (8) contacts of lava flows. Ore zones (letters in figure): D, Davdara; C, Central; SE, Southeastern.

The Zambarak deposit is a striking example of ordinary vein-type deposits. Its localization is controlled by a short fault of the same name of the second order that extends in the northern direction from the regional Tary-Ekan Fault. The Zambarak Fault steeply dips to the southeast, extends in the near-meridional direction, and bends to the NNE approximately one kilometer from the Tary-Ekan Fault. Three ore-bearing fracture zones and related orebodies extend away from the bend. The Central and Davdara zones, steeply dipping to the northwest, show a right-lateral displacement by a few tens of meters, while the Southeastern zone, which plunges to the southeast, underwent a left-lateral displacement by the same distance (Fig. 4). These structural relationships likely indicate that the ore-bearing fractures are pinnate shears related to the Zambarak Fault and that premineral normal faulting prevailed over strike-slip faulting (Nekrasov, 1959). The ore mineralization is hosted in spherulitic rhyolite; quartz porphyry; and, to a lesser extent, in silicic pyroclastic rocks.

The structure of all ore zones is similar. Each ore zone is a series of closely spaced thin crush zones and slip planes accompanied by barite–galena and less frequent quartz–barite–galena veins and veinlets. The zones are dissected by transverse faults into numerous tectonic blocks. The extent of veins within the blocks varies from a few tens of meters to 300 m. The number of veins in neighboring blocks often is different. The occurrence of barite–galena veinlets and even large veins in transverse faults, as well as ore pockets at the junctions of longitudinal and transverse faults, clearly shows that the transverse fractures served as tectonic limits during orebody formation. The transverse fractures are the most numerous near and within the footwall of the Zambarak Fault, where they are regarded as the oldest auxiliary shears (Fig. 4). The extent of ore zones that spread outward from the Zambarak Fault varies from 800 m to 2.0–2.5 km (the Davdarak Zone is discontinuous). The vertical range of ore mineralization is 300–350 m.

The northeastern segments of the ore zone are mineralized to the greatest extent. A few relatively thick (up to 1.5–2.0 m) barite–galena veins in the Central ore zone, retaining their general northeastern orientation, sharply bend in some places, following the near-latitudinal ore-bearing shears. Entering these shears, the veins pinch out to veinlets 3–10 cm thick. These relationships testify to the formation of ore veins in the process of intramineral right-lateral strike-slip faulting.

GEOLOGY AND STRUCTURE OF LARGE FOREIGN LEAD–ZINC DEPOSITS OF VEIN TYPE

At the known vein-type Pb and Zn deposits outside of Russia, the large reserves of these metals are also established in fault zones that transect both the lower and upper structural stages. For example, at the Bohutín deposit in the Příbram ore field, Czech Republic; the Hecla and Nellie deposits in the Coeur d'Alene ore belt

in the United States; Montevecchio, Sardinia; Freiberg, Germany; Mpanda, Tanzania; Taolin, China; etc., the ore-bearing faults are developed in gneiss, granite, quartzite, metasandstones, and other relatively brittle rocks of the lower structural stages. Separations along these faults reach many hundreds of meters and even more than a kilometer (Malakhov, 1957). Similar ore-bearing faults that host large base-metal reserves were established in rocks of the upper structural stage, for example, at the Zlatá Baňa deposit in Slovakia (Divinec et al., 1989); the Ag- and Au-bearing Guanajuato deposit and Santa-Bárbara, La Colorada, and other deposits in Mexico; the Casapalca and Quiruvilca deposits in Peru; the Creed deposit in the United States; the Toyoha deposit in Japan; and others. The total amplitude of displacements along the Veta Madre Fault at the Guanajuato deposit in Mexico is 1400 m (Vassalo Morales et al., 1982).

The faults, including their branches and sutures, are marked by dikes and stocks at the deposits hosted in both structural stages, in particular, at the Bohutín deposit in the Příbram ore field (Malakhov, 1957). The faults in the upper structural stage also control the position of steeply dipping subvolcanic intrusions, as was established in the ore-bearing Sierra Fault Zone at the Guanajuato deposit and in fault zones at the Santa Bárbara deposit in Mexico (Scott, 1964), the Quiruvilca deposit in Peru (Bartos, 1987), the Zlatá Baňa deposit in Slovakia (Divinec et al., 1989), and elsewhere.

The geological setting shows that the faults arose long before the deposition of base-metal ore, so that the fracture pattern of the large base-metal deposits experienced long-term premineral preparation. Relatively thick fault zones of complex structure enclose elongated blocks of lenticular and rhomb-shaped outline. Each of these blocks is distinguished by its style of deformation, several systems of boundary faults different in age, and relatively rare premineral faults. The ore veins and veinlets are hosted selectively within ore-bearing fault zones of one or two directions, occasionally penetrating beyond their limits along auxiliary shear fractures. In particular, Ag- and Au-bearing Pb–Zn ore mineralization hosted in the Veta Madre Fault Zone (Gross, 1975; Vassalo Morales et al., 1982) is traced continuously for 5 km along the strike and for 750–900 m down the dip. At the Toyoha deposit in Hokkaido Prefecture (the main vein-type deposit of Japan), the major Ag-bearing Pb–Zn ore veins are confined to thick crush zones more than 1.5–2.0 km in extent. These zones also control the localization of dike-shaped volcanic conduits. The contacts of Neogene volcanic flows are displaced along these crush zones for a few hundred meters, indicating that the main displacements at this deposit, as at other vein-type deposits, occurred at the premineral stage of formation of the fracture pattern.

The quartz–calcite–fluorite–base-metal ore at the Santa Bárbara deposit in Mexico is hosted in two thick

and extended (>(5–6) km) crush zones of NNE direction and in a connecting NW-trending diagonal fault; all fault zones dissect Cretaceous–Oligocene limestone and shale. A swarm of rhyolitic dikes was traced along the western ore-bearing fault. Occasionally dikes enter the fault zone, which existed before the emplacement of dikes. The extended vein-type orebodies are localized in both the major fault zones and the connecting NW-trending fault. For example, the Segovedad–Alexandria and Bronces Seca veins extend for almost two kilometers, while the San Rafael, Clarines, and some other veins are no less than one kilometer long (Scott, 1964). The considerable length of ore veins is caused by the formation of extended and alternating bends in the host crush zones. Owing to the multiple rejuvenations, the total displacement is as great as hundreds of meters. From the onset of mining in 1913 up to the present, no less than 550–600 kt of lead, more than 1300 kt of zinc, and about 4500 t of silver have been produced at this deposit. In good years, the annual production rate reached 1450 kt of ore. The residual reserves are estimated at 530–650 kt Pb + Zn and no less than 1200 t Ag.

CONCLUSIONS

(1) The large vein-type Pb–Zn deposits related to thick fault zones are of major economic importance. As a rule, these fault zones are directly connected with regional ore-controlling faults. The vein-type ore mineralization hosted in ore-bearing faults bears a through character: it appears in the lower structural stage, penetrates into the upper stage, and embraces a considerable vertical range.

(2) The following main attributes of large Pb and Zn deposits should be noted.

The ore-bearing faults started to form before the emplacement of igneous rocks or synchronously with stocks and dikes. During the long-term development, the fault zones were rejuvenated many times, and in some cases, their total amplitudes exceed 1000–1500 m. The displacements wane to a few meters or less by the period of ore deposition.

The long-term premineral preparation results in the formation of relatively thick zones of moderately deformed rocks. These zones are combinations of elongated lenticular and rhomb-shaped tectonic blocks deformed to various degrees. These zones are separated by thin zones of brecciation, tectonic sutures filled with clay gouge, and slip planes. It is these fractures and, especially, crush and breccia zones, oriented as a rule obliquely to the planes of master ore-bearing faults, that host the ore veins, veinlets, and pockets. The orebodies concentrate in fault zones, and only a very small percentage of Pb–Zn ore is contained beyond the deformed zones.

The ore-bearing faults suppress the transverse fractures that commonly constrain the ore mineralization. Therefore, the ore mineralization may be traced for sev-

eral kilometers along the strike and for a kilometer (occasionally for 1.5–2 km) down the dip almost without breaks. In the upper structural stage, the vertical range of ore mineralization commonly reaches only a few hundred meters, approaching a kilometer in exceptional cases. The ore-bearing faults often split upward into a fan of branches. As a result, the veins and veinlet zones grade upward into thick stockwork zones.

A certain group of large gold deposits (with reserves no less than 100 t Au) is also localized in fault zones. The ore-bearing faults at large gold deposits have much in common with those at Pb and Zn deposits: they originate long before the ore mineralization, they undergo long-term premineral preparation, and the younger ore mineralization concentrates in already existing faults and penetrates along them down to a depth of two kilometers or deeper.

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