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THE MURUNTAU GOLD DEPOSIT, TAMDY MOUNTAINS, UZBEKISTAN

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Abstract - The Muruntau mine, Uzbekistan, is localised in a shear zone related to upper Carboniferous to lower Permian accretion of the Kazakhstan-North Tien Shan and Karakum-Tarim tectonic plates. The gold ore was deposited syntectonically in an extensional step-over along a northwest-striking, left-lateral fault zone under ductile to transitional-brittle conditions. The host rocks are carbonaceous shales, siltstones, sandstones, and chert. Early stage alteration was quartz-albite-biotite-chlorite-oligoclase with some pyrite and gold. The predominant period of gold-sulfide deposition accompanied a later K-feldspar, phlogopite, muscovite, Mg-Chlorite, and Fe-Mn carbonate alteration. Later veinlets contain tourmaline, and the latest stage of alteration was calcite veinlets with pyrite, TiO_2 and rare-earth element minerals.

1. INTRODUCTION

The Muruntau mine, Uzbekistan, is one of the world's largest lode gold deposits. It was discovered in 1957 at the site of ancient workings where copper and gold (?) were mined. It is located on the southeastern edge of the Tamdy Mountains (Tamdytau) in the Kyzylkum Desert, about 400 kilometres west of Tashkent, the capital of Uzbekistan (Figure 1). Muruntau is a shear zone-hosted syn-deformation/syn-igneous intrusion gold deposit formed in the depth-dependent brittle-ductile transition zone along a crustal-scale, left-lateral fault zone (Drew and Berger, 1996). It is a similar deposit style to those in the Allegheny, California (Böhlke, 1989) and Yilgarn block, Australia region (Groves *et al.*, 1989). The purpose of this paper is to describe the tectonic setting and structural localisation of the Muruntau deposit and describe the physical characteristics of the deposit.

2. REGIONAL GEOLOGIC SETTING

The Muruntau gold deposit is located at the western end of the Tien Shan fold and fault belt that extends from Mongolia on the east to the Kyzylkum desert. In the desert northwest of the Tien Shan mountain system, the D_4 fold and thrust belt is bounded to the north by a suture zone (Figure 1) resulting from the late Carboniferous to lower Permian accretion of the Karakum-Tarim plate on the south and the Kazakhstan-North Tien Shan on the north (Akhber and Mushkin, 1976). Regional-scale D_4 left-lateral, strike-slip faults "peel" off of the suture zone and strike west-northwest into the Kyzylkum desert and control the localization of the hypo/mesothermal shear-zone style gold deposits.

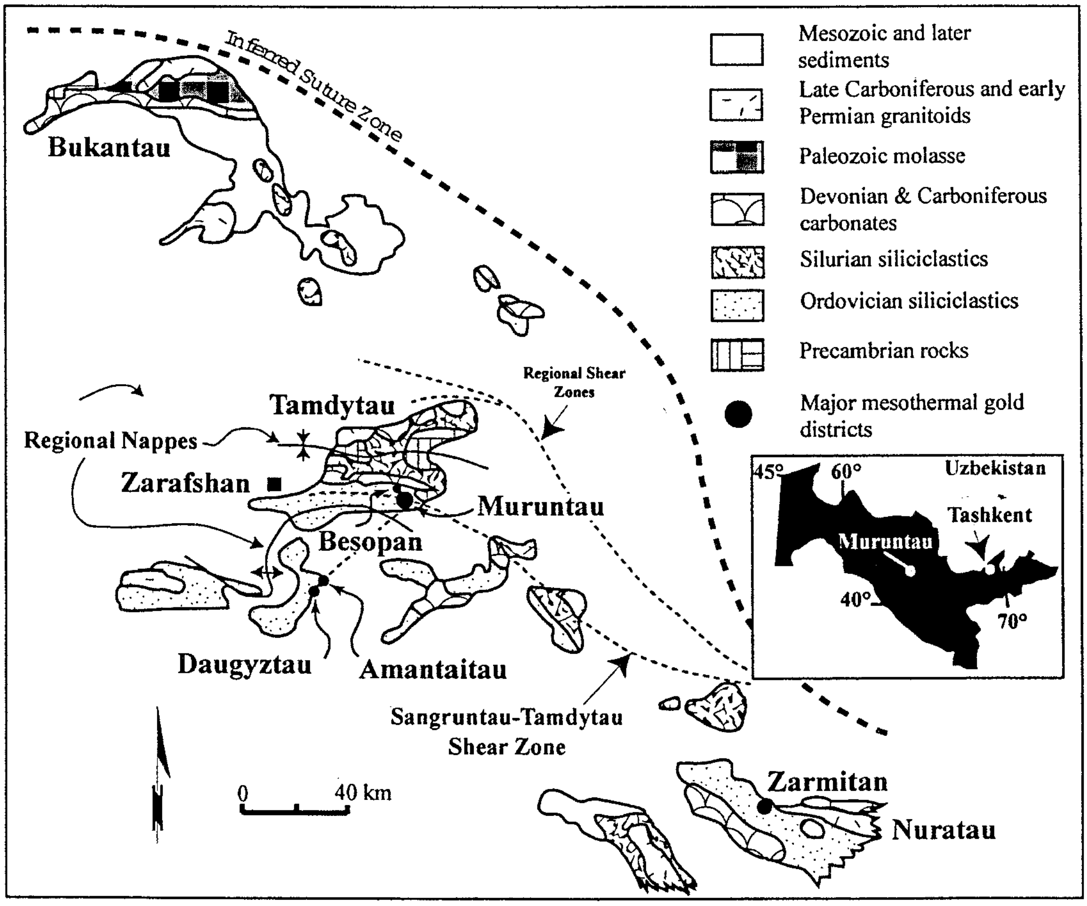

Figure 1. Generalized geologic map of the Kyzylkum desert region, Uzbekistan, showing the locations of the principal hypo/mesothermal gold districts. The inferred locations of the Late Carboniferous D_4 suture zone and selected nappes and regional shear zones is for reference. Muruntau is located approximately at N41°31', E64°35'.

Compressional deformation related to the latest Carboniferous to Early Permian continent to continent collision (D_4) is characterized by south-verging thrust faults and regional-scale nappes (Drew and Berger, 1996). Two of these nappes transect the Tamdy Mountains, a synform in the central part of the range and an antiform along the southern margin (Figure 1). Following compression, oblique convergence resulted in transpressional deformation south of the suture zone. One of these, the Sangruntau-Tamdytau, transects the southern flank of the Tamdy Mountains and follows the northern limb of the antiformal nappe (Figure 1). The activation of a southwest-striking strike-slip fault, the Muruntau-Daugyztau fault zone (D_5), and its interaction with the Sangruntau-Tamdytau fault zone changed the strike of the eastern nose of a domal structure along the antiformal nappe and resulted in a Z-shaped fold (F_5) near the southeastern tip of the Tamdy Mountains. A left-stepover was forced in the Sangruntau-Tamdytau fault system at its intersection with the Muruntau-Daugyztau fault zone, and the Muruntau open-pit mine is within this extensional duplex.

Riphean to Vendian chert, mafic volcanic, carbonaceous shale, and dolomite, the Taskazgan Suite, are the oldest rocks in the Tamdy Mountains. They crop out in the core of a dome along the anticlinal nappe west of Muruntau and in the Tamdy Mountains north and northwest of Muruntau. Overlying the Taskazgan Suite is the Besopan Suite, the main ore host for hypo/mesothermal gold deposits in the region. The Besopan Suite is a Cambrian to Ordovician sequence divided into four units, bS_1 to bS_4. Unit bS_1 consists of ferruginous sericite-chlorite mica schists, carbonaceous beneath the zone of oxidation, derived from the metamorphism of siltstone with some sandstone and clay. Some siliceous volcanic rocks also occur. Unit bS_2 is metasandstone with some coarser siliciclastic material. Unit bS_3, the main ore host at Muruntau, consists of phyllitic to schistose carbonaceous metasiltstone, metasandstone, calcareous metasandstones, and metatuff. The uppermost unit, bS_4, is a quartz-clay sandstone with metasiltstone, argillite, and lenses of gritstone.

Prior to the deformation related to the upper Paleozoic accretionary event, the Taskazgan and Besopan suites were metamorphosed and deformed (D_1). Schistose and phyllitic (S_1) and crenulation (F_1) fabrics developed. D_2 deformation produced kilometer- to meter-scale isoclinal folds (F_2) which are overturned to the east and north. There is a well-developed S_2 axial-plane cleavage associated with the folding. Subsequently, D_3 thrusts tectonically transposed the F_1 and F_2 folds into a number of imbricate northerly-verging thrust plates (D_1-D_3 may be Ordovician). South-verging Carboniferous to early Permian thrust faults, regional nappes, and transpression (D_4) were developed during and following accretion. Some of the F and S fabrics were transposed during D_4 deformation. All of D_{1-3} tectonic fabrics as well as D_4 transposed fabrics were important in controlling the deposition of gold-bearing quartz veinlets at Muruntau.

During D_4 deformation, Silurian–Devonian carbonates and an ophiolite complex were thrust over the Besopan and Taskazgan suites. These rocks are eroded away above the Muruntau deposit, although remnant outliers are above the Miutenbai area (Figure 2).

Post-D_4 accretion granites are widespread in the Kyzylkum desert region. In the Tamdytau, a composite granite/alaskite intrusion crops out about 25-km northwest of Muruntau. Another intrusion crops out about 10-15 km southeast of Muruntau, the Sardarin granite (Kotov and Poritskaya, 1992). Swarms of dikes are prevalent along the Sangruntau-Tamdytau shear zone, including within the Muruntau mine, and vary from felsite to syenodiorite to lamprophyre. The intrusions are ≈286 Ma and the dikes are on the order of 273Ma (Kostitsyn, 1994).

3. GEOLOGY OF THE MURUNTAU DEPOSIT

The Muruntau orebodies are localized in the basal part of the bS_3 unit of the Besopan Suite along the Sangruntau-Tamdytau shear zone. In contrast to the underlying bS_2 and overlying bS_4 units, in the vicinity of the Muruntau mine unit bS_3 is a relatively homogeneous, carbonaceous and ferruginous metasiltstone (it is referred to locally as the "Variegated Besopan due to oxidation of outcrops). The carbonaceous content varies from 0.5-3.0% (P. Mukhin, written communication, 1998). As noted above, there is a layer-parallel S_1 schistosity, F_2 isoclinal folds, and imbricate D_3 thrust faults related to the earlier Paleozoic deformation. There is a well-developed axial-plane cleavage (S_2) related to the F_2 isoclinal folding. Also as noted previously, a D_4 antiformal nappe was developed during the Late Carboniferous ("Hercynaian") followed by strike-slip faulting.

Unit bS_3 was contact metamorphosed prior to hydrothermal alteration. The metamorphism is related to the emplacement of granitic rocks at depth. A 4-km deep drill hole (SG-10) 1.5 km southeast of the Muruntau pit (Figure 2) intersected granitic dikes with a distinct penetrative fabric (P. Mukhin, written communication, 1998) that links the emplacement of the granite to D_4 deformation on the Carboniferous Sangruntau-Tamdytau shear zone. The altered part of unit bS_3 is bounded by shear zones (cf. Mukhin et al., 1988) and overall has a lenticular geometry.

3.1 Gold resource

The amount of contained gold at Muruntau has not been announced, but may be on the order of 140-150,000,000 troy ounces (N. Kurbanov, personal communication, 1991). Average mill-head grade is 3 g/t Au and somewhere on the order of 64 tons Au is produced each year (Engineering and Mining Journal, September 1995). Total sulfide content of the ore is 0.5–1.5% (Borodaevskaya and Rozhkov, 1977). The principal ore mineral at Muruntau is native gold. Pyrite is the most abundant sulfide with significant arsenopyrite and some marcasite and pyrrhotite. Other minerals reported from the deposit include scheelite, gold-bismuth tellurides and selenides, molybdenite, wolframite, bismuthinite, native bismuth, magnetite, and ilmenite (Khamrabaev, 1969; Borodaevskaya and Rozhkov, 1977).

The mine is an open-pit operation, using conventional shovels and trucks. The ore is trucked to in-pit crushers and from there by belts to trains which transport the ore 6-8 km to the mill and refinery facility. Low-grade (<2-3 g/t Au) ores are trucked to stockpiles and subeconomic grade material to waste dumps.

3.2 Geometry of the orebodies

In plan view, the ores in the pit form thick, irregular zones of silicification generally elongated northeast-southwest to the north of the South Fault (Figure 2). This geometry reflects the complex fracture patterns in the host rocks due to D_{1-5} stages and styles of deformation. Their elongation is parallel with the extensional direction within the stepover. The orebody shapes are due to their development in permeabilities related to S_2 axial-plane fractures and D_4 Paleozoic folding that accompanied the strike-slip deformation. The folded, imbricate D_3 thrust surfaces form sinuous traces along the trend of the Sangruntau-Tamdytau shear zone. Because of their intrinsic permeability, some of the D_3 thrust surfaces are mineralized within the shear zone (Figure 2).

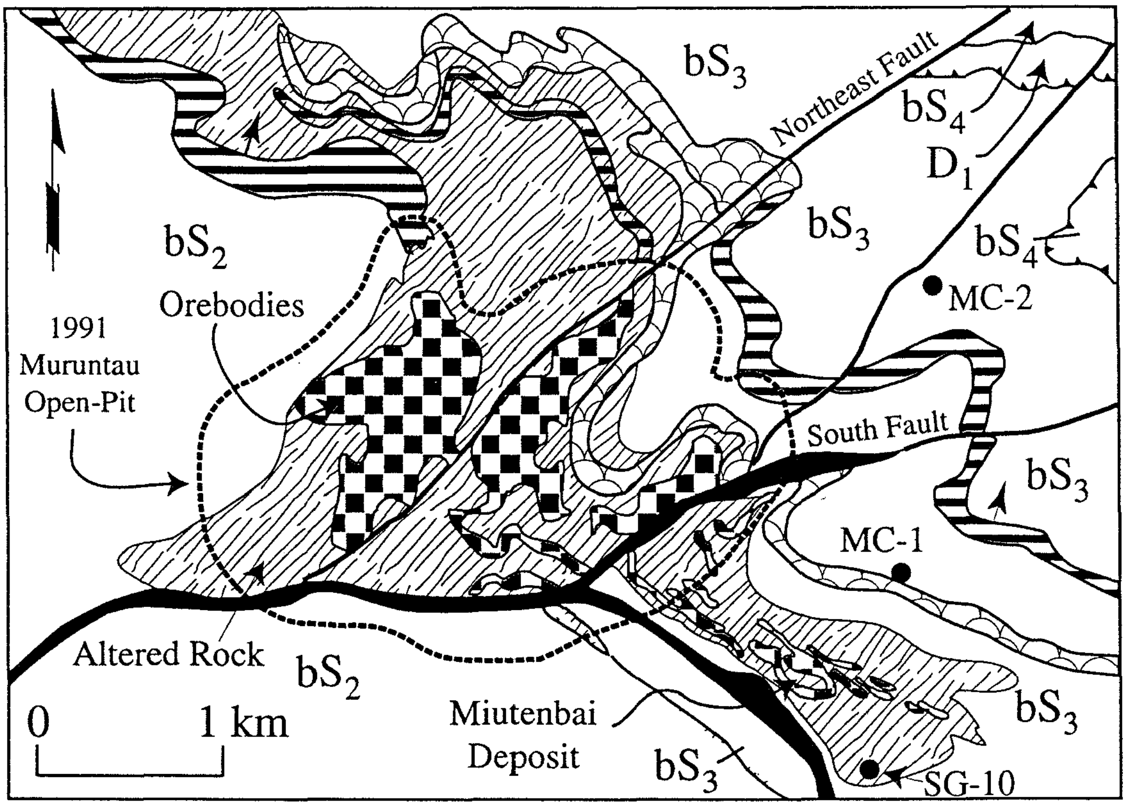

Figure 2. Plan map of the Muruntau ore field showing the altered and ore-bearing rocks. D_3 thrust planes (stripes and semicircles) form sinuous zones with long axes northwest-southeast. The bold, horizontal stripes indicate the thrust zones with incipient quartz-gold mineralization. Geologic unit D_1 in this figure is early Devonian carbonate rocks. The South and Northeast faults are part of the Muruntau-Daugyztau fault zone. Drill holes MC-1, MC-2, and SG-10 are shown for reference. (Modified from N. Kurbanov, written communication, 1991)

Figure 3 is a cross-section through the Miutenbai (Figure 2) portion of the Muruntau ore field. The eastward-dipping, stockwork orebodies were formed within the D_3 imbricate thrust faults. All of the orebodies (>2-3 g/t Au) are enclosed within a rind of hydrothermal alteration (discussed below). The ore-controlling fault system forms an upward-branching negative flower structure, and the paragenetically later, through-going "Central Veins" were formed along these faults.

3.3. Hydrothermal alteration

3.3.1. *Early-stage evolution of the ore-forming system*

The Muruntau deposit is along the D_4 Sangruntau-Tamdytau shear zone, is structurally complex, and records a protracted history of syndeformation mineralization. Initial hydrothermal activity

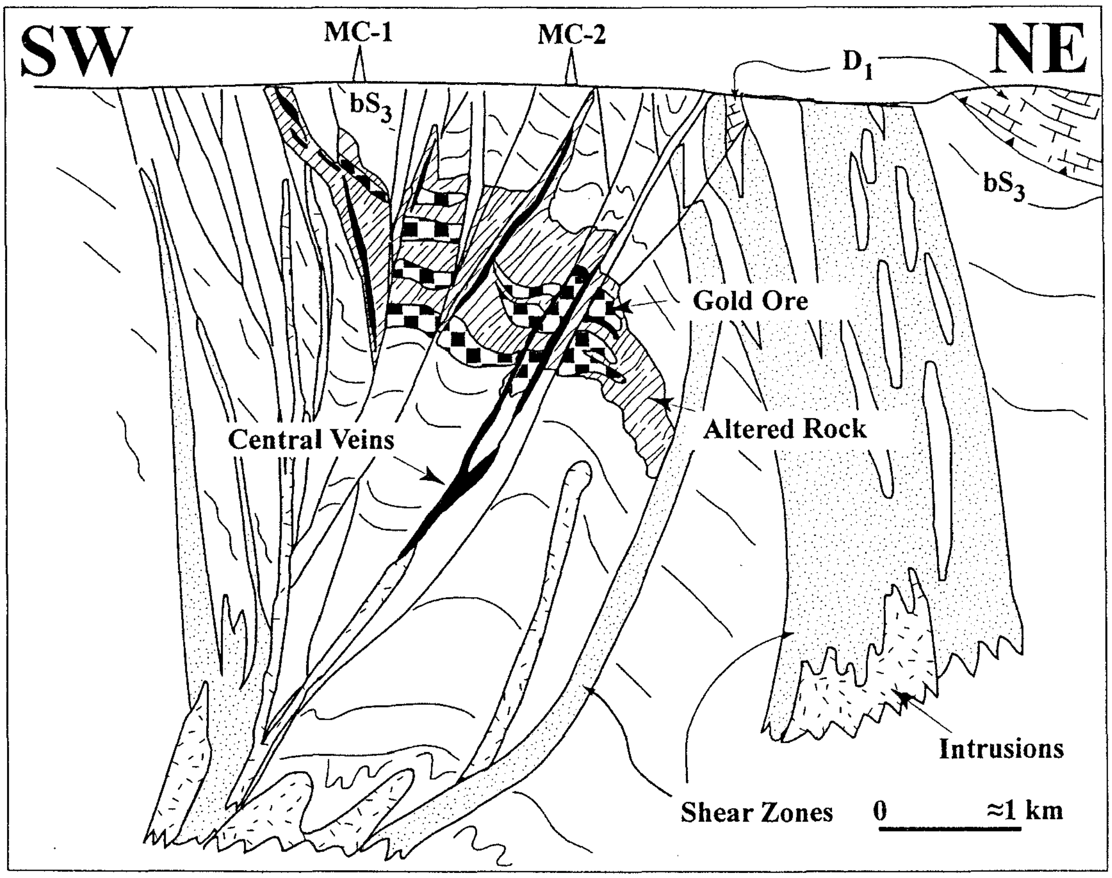

Figure 3. Northeast-southwest cross-section in the vicinity of the Miutenbai deposit (Figure 1). The stockwork gold ores (checkered pattern) are surrounded by a rind of hydrothermal alteration. The main faults make up an upward-branching flower structure that controls the Central Veins. D_1 in this illustration is early Devonian carbonate rock. Drill holes MC-1 and MC-2 are shown for reference (Figure 2). (Modified from D. Azghirey, unpublished data, 1991)

in the vicinity of the mine began prior to the development of the left-stepover across the Muruntau-Daugyztau fault zone. This early-stage mineralization extended from south of the Muruntau open pit (Miutenbai deposit) to the Besopan deposit (Figure 1) 4 km northwest of the mine. The primary permeability controlling this stage of the system appears to be the D_3 subparallel, imbricate, intraformational thrust planes and D_4 partings in the host rock which contain synkinematic veins and veinlets that vary from millimeters to centimeters in thickness. They are often folded and boudinaged. There are some meter or more thick flat veins that occur along dilatant fractures parallel to the partings; they are commonly boudinaged. In thin section, all of these veins and veinlets display crack-seal growth habits.

The early-stage alteration forms a long, linear zone along the shear zone and, in general, makes up a lens of mineralization. Mukhin et al. (1988) refer to this zone as the "Muruntau Lens". It is superimposed on a spotted schist the texture of which is attributed to contact metamorphism (Marakushev and Khokhlov, 1992) that immediately preceded the more pervasive hydrothermal alteration. The spots consist predominantly of biotite and chlorite set in a matrix of predominantly plagioclase, calcic andesine to labradorite, quartz. Sillimanite and cordierite occur in the contact metamorphic assemblage at depth. The overprinting early-stage hydrothermal assemblage consists of quartz + albite + phlogopite + chlorite + oligoclase with linear, subparallel zones of quartz veins and veinlets. The primary and contact metasomatic minerals were replaced by the hydrothermal assemblage. Alteration began during protracted ductile deformation within the rock matrix in as much as some quartz and albite are elongated in the plane of the S_1 schistosity. Early-stage phlogopite is very fine-grained where it grew along grain boundaries and is coarser along cleavage planes. Pyrite and gold were deposited during this stage of alteration, but most of the early-stage auriferous zones (≈0.1–2 g/t Au) are subeconomic. Drew and Berger (1996) refer to this stage as a period of incipient, through-going "Mother Lode"-style vein formation. Fluid-inclusion filling temperatures are 350°-400°C during this stage (Berger et al., 1994).

3.3.2. *Intermediate-stages of ore formation*
The development of the extensional stepover along the Sangruntau-Tamdytau shear zone was accompanied by the refocusing of hydrothermal activity to within it. This terminated the continued development of the "incipient" Mother Lode-style veins north of the Muruntau pit.

Phlogopite with pyrite±arsenopyrite in en echelon microveins is widespread. The veinlets have selvages of muscovite, magnesian chlorite, quartz, phlogopite, K-feldspar, and minor Fe-Mg carbonate. The veinlets commonly display crack-seal textures and stepped fracturing is also common. The veinlets crosscut schistosity and cleavage, consistent with a change in the principal stress trajectories accompanying the development of the extensional stepover. Some of the microveins are predominantly pyrite + arsenopyrite with thin phlogopite selvages. Gold accompanies the sulfides.

The next intermediate substage of mineralization, veins of quartz + K-feldspar + muscovite + ankeritic carbonate + sulfides, heralds the main period of gold deposition. The veinlets crosscut the phlogopite veins and locally the ankeritic carbonate pervades and replaces the rock matrix. Through-going, Mother Lode-style veins were also formed during this stage; they are referred to as the "Central Veins" by the mine staff (Figure 3). These high-angle veins are large, up to several meters thick with strike lengths of hundreds of meters, and contain the highest grades of gold in the deposit. The gold is native and may be seen interstitial to quartz grains and within pyrite and arsenopyrite. Small quantities of coeval galena, sphalerite, and chalcopyrite occur in the Central Veins.

Silicic dikes intrude the deposit after the formation of the Central Veins (Figure 3), either concurrent with the intermediate stages of mineralization or immediately preceding the final stage. Veins that crosscut the dikes and other assemblages are made up of quartz + K-feldspar + dolomitic carbonate + tourmaline + pyrite. The tourmaline is dravite, and occurs as segregations within the veins, as discrete microveins, and as the matrix of breccias which include clasts of gold-bearing quartz-vein material.

3.3.3. *Final stage of mineralization*
The final stages of veining include calcite with some pyrite, TiO_2, monazite, and bastnaesite(?). Calcite also pervasively alters the rock matrix in places. This stage occurs throughout the mine, is not auriferous, and is the last stage of the system.

There is a later stage of alteration that consists of intense quartz-sericitization along spatially restricted brittle faults (e.g., South Fault). This alteration is referred to as "sericitolites" by Kotov and Poriskaya (1992). Its temporal relation to the Muruntau hydrothermal system is unknown.

4. CONCLUSIONS

Muruntau is a very large gold deposit because of several coinciding factors. The three foremost factors are as follows:

(1) The development of significant permeabilities within the ferruginous host rocks during an earlier Paleozoic ("Caledonian"– Ordovician?) deformation followed by their modification and "opening up" during a Late Carboniferous to Early Permian deformation ("Hercynian"). These include D_1 Caledonian schistosity (S_1) and axial-plane cleavage (S_2), and D_4 Hercynian transposed cleavage. All of which are important controls on the stockwork nature of the orebodies. The S_2 axial-plane cleavage resulted in closely spaced tabular veins in the stockwork zone that are referred to as "banded" veins, and D_3 imbricate thrust faults provided avenues of enhanced permeability within the $D_{4\text{-}5}$ Sangruntau-Tamdytau shear zone.

(2) A large ductile-brittle shear zone— the northwest-striking, left-lateral Sangruntau-Tamdytau —which was forced to step extensionally across the northeast-striking Muruntau-Daugyztau shear zone. The D_5 stepover "opened up" the available permeabilities into planes that were hydraulically conductive.

(3) Continued intrusive activity in the vicinity over a long period of time provided a heat source that focused fluid flow into the extensional duplex and may also have provided chemical components to the hydrothermal fluids. High-grade through-going veins, the Central Veins, developed later in the paragenesis and contain a substantial proportion of the gold in the deposit.

Outside the Muruntau mine, there are numerous deposits of gold along the Sangruntau-Tamdytau shear zone varying in size from 1 to >50 tons of contained gold. Arsenic and gold are anomalous along much of the trace of the shear zone (cf. Khamrabaev, 1969; Drew and Berger, 1996). However, the combination of favorable permeabilities in the large extensional stepover and the immediate proximity of a long-lived heat source were requisite for the formation of the "giant" Muruntau deposit.

5. ACKNOWLEDGMENTS

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