Setting of the giant Muruntau Gold Deposit: Implications for ore genesis

A.R. WILDE[1] AND D. GILBERT[2]

[1]Department of Earth Sciences,
P.O.Box 28E Monash University,
Victoria 3800, Australia

[2]BHP World Minerals
550 California St
San Francisco CA 94104

Abstract: The Muruntau gold deposit is situated in the Kyzyl Kum Desert of Uzbekistan. It is currently being mined in the world's largest open pit gold mine with production believed to be of the order of two million ounces per annum. The open pit measures about 3.5 by 2.5 km and extends to a depth of 350m. The gold ore resource in the Muruntau deposit, including production, is about 170 million ounces of gold (Anonymous, 1996). This paper presents a summary of the deposit geology and its regional geological setting. Information used in this paper has been generated from observations made on two visits to the mine and its environs, and a review of the Russian- and English-language literature.

Discovery History

The giant Muruntau Gold deposit was discovered in 1958. The area was a source of turquoise since the days of the Silk Road. It was not until the nineteen fifties, however, that the Muruntau area was systematically explored, initially for uranium. A huge gold and arsenic geochemical anomaly, (see Drew *et al.*, 1996) detected during systematic geochemical sampling and 1:200,000 scale geological mapping of the area indicated the Muruntau deposit. Auriferous quartz veins were subsequently found in surface exposures at the site of the current open pit. Mining commenced on the deposit in 1967, and production has been continuous ever since.

Tectonic Setting

The Kyzyl Kum area is underlain by three main tectonic units (Fig. 1). The oldest (basement) consists of metamorphosed and folded Lower Palaeozoic carbonaceous and sulphidic clastic rock referred to as the Besopan Formation. The Besopan Formation was metamorphosed and deformed during the Lower Palaeozoic Caledonian orogeny. After erosion and exhumation it became basement to an unconformable cover sequence of Devonian to Early Triassic carbonate and clastic sediments and volcanic rocks referred to herein as Cover Sequence 1.

Cover Sequence 1 has been divided into a lower carbonate-dominant section reflecting passive margin sedimentation. The upper part is marked by a change to terrestrial evaporitic facies in the Karatau Range (Cook *et al.*, 1997; Lapointe *et al.*, 1997) and extrusion of alkalic andesites in the so-called "Valerianovsky volcanic belt". These andesites have been intersected in petroleum wells and are inferred at depth from aeromagnetic data (see Drew *et al.*, 1996). Palynological data from overlying sediments suggest that these volcanic rocks are pre-Triassic in age consistent with Carboniferous K-Ar dates (Burshtein, 1998). Alkalic chemistry suggests deposition in a rift environment (Y. Savchuk, *pers. comm.*, 1998).

Cover Sequence 1 was intruded by granites during the Late Carboniferous Hercynian orogeny. Some authors infer a major Carboniferous collisional suture beneath the sedimentary rocks of Cover Sequence 2 (Fig. 1). There is, however, little evidence of active subduction here during this time.

Cover Sequence 2 (Syr Daria or Kyzyl Kum Basin) comprises over 2 km of mainly terrestrial sedimentary rocks which unconformably overlie Cover Sequence 1 and Hercynian intrusions. Sedimentation during the Jurassic was confined to narrow NW- and NNE-trending basins. During the Cretaceous and Tertiary, however, sedimentation extended beyond these narrow basins and covered rocks of the basement and Cover Sequence 1 throughout the Kyzyl Kum region (Fig. 1).

Lithologies

Basement

The Lower Palaeozoic Besopan Formation basement outcrops as a number of inliers, comprising perhaps 15%

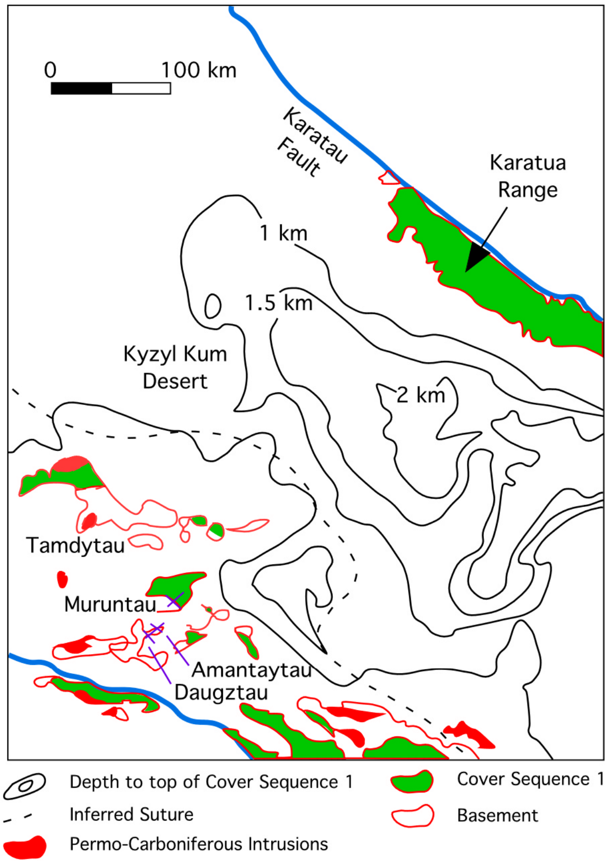

Figure 1. Regional geological setting of the Muruntau Deposit, based on Soviet regional metallogenic mapping.

of the Kyzyl Kum area (Fig. 1). These inliers form low ranges of hills which trend west-north-west. The Besopan Formation consists of metamorphosed mudstones, siltstones and sandstones. It has been divided into four units, termed Besopan 1, 2, 3 and 4, based on colour variation and the ratio of coarse to fine-grained clastic sedimentary rocks. Besopan 1 is the oldest, and Besopan 4 the youngest. The lithological succession in the Besopan Formation is difficult to define precisely, because of repetition and omission of units caused by isoclinal folding and major thrust faults (e.g. Drew *et al.*, 1996).

Besopan 3 ("Variegated Besopan") is the main gold host at Muruntau. It is represented by green to red (hematitic) phyllites in surface exposures but is extremely carbonaceous at depth (Y. Savchuk, pers. comm., 1996). The Besopan 2 consists of similar lithologies to the overlying Besopan 3, namely phyllite and meta-sandstone. Marakushev and Khoklov (1992) show that the two units are identical petrochemically. The main difference may be caused by variation in the abundance of carbon and in the sulphide minerals between Besopan 2 and Besopan 3.

A distinctive black siliceous layer occurs within the Besopan 3. The layer is a few metres thick and can be traced as discontinuous surface exposures extending more than 15 km west from the deposit. A sample of the siliceous layer (collected 10 km west from the Muruntau open pit) contains elevated palladium (0.1 ppm), V and Hg as well as abundant fine-grained carbon as patches and veins. Inclusions of carbonate in quartz suggest in the sample that this horizon may be a siliceous replacement of a carbonate-bearing shale horizon (Gilbert, 1995).

Cover Sequence 1

Unmetamorphosed Devonian to Carboniferous carbonate-dominant rocks overlie the meta-clastic rock of the Besopan Formation with angular unconformity. Comparable sequences are exposed in the Karatau Range of southern Kazakhstan about 200 km north of Muruntau (Fig. 1). Here the sequence consists of a variety of Devonian and Carboniferous carbonate rocks and breccias interpreted as having an evaporitic origin modified by karstic collapse (Lapointe *et al.*, 1997). The depositional environment is interpreted to be a migrating shelf to platform transition reflecting fluctuating sea levels (Fig. 2; Cook *et al.*, 1997, Lapointe *et al.*, 1997; Cook *pers. comm.*, 1998) .

The late Carboniferous of the Karatau Range is marked by a major change to a shallow-marine terrestrial (evaporitic) facies (Fig. 2). Petroleum exploration drill-holes north-west of Muruntau intersected folded Late Permian to Early Triassic red-brown sandstones and mudstones, black mudstone and tuffaceous sandstones which overlie gray-colored porphyritic andesite lavas (Burshtein, 1998).

Cover Sequence 2

The Jurassic of Cover Sequence 2 comprises unfolded terrestrial sediments which include sandstone, siltstone, mudstone and coal. The environment of deposition is interpreted as fluvial, alluvial and lacustrine (Burshtein, 1998). The Cretaceous of Cover Sequence 2 comprises hematitic siltstone, mudstone and conglomerate. Lenses of anhydrite occur in the upper parts. The Early Cretaceous rocks are terrestrial in origin but a marine influence is apparent in the upper part of the section (Burshtein, 1998).

Granites

Granites comprise less than 10% of the Palaeozoic bedrock exposures in the Kyzyl Kum region. Aeromagnetic data indicate that they could be more extensive beneath sedimentary rocks of Cover Sequence

2 (Savchuk *et al*., 1991). Savchuk *et al.* (1991) recognise an older Bokalinsk Suite and younger Nuratinsk suite. The Bokalinsk Suite outcrops rarely and comprises only 5% of outcropping intrusions. The Nuratinsk Suite is predominantly composed of granite and granodiorite and comprises 95% of exposed intrusions in the Kyzyl Kum region. It is spatially and probably temporally associated with tin mineralisation in the region. Granites of this suite intrude folded sedimentary rocks of the Basement and Cover Sequence 1.

Two intrusive bodies and dykes of several compositions are known in the vicinity of the Muruntau deposit. One of the intrusive bodies, the Sardarin Pluton, is 12 km south of the Muruntau deposit, but is apparently not exposed. Its extent has been determined from drilling and from interpretation of airborne magnetic data. The other intrusive body, the Murunski Pluton, is composed of a medium-grained alaskite, and was intersected beneath the deposit in an exploratory diamond drill hole at a depth of 4 km (Kostitsyn, 1996). Contact metamorphism about the pluton is manifested as biotite porphyroblasts and locally, as andalusite and cordierite porphyroblasts (Kotov and Poritskaya, 1992; Drew *et al.*, 1996). Hornfels has been observed in the drill holes beneath the Muruntau deposit.

The Sardarin Pluton yielded a Rb-Sr isochron of 286 ± 1.8 million years and initial ratio of 0.7078 (Kostitsyn, 1996). The Murunski Pluton yields an identical isochron of 287 ± 1.8 million years (Permo Carboniferous) and initial $^{87}Rb/^{87}Sr$ ratio of 0.716.

Major deformation events

Caledonian (Silurian) Deformation

The Basement is strongly folded and pelitic rocks have a well-developed axial planar cleavage. Isoclinal folds with east-striking axial planes overturned to the north have been described (e.g. Kotov and Poritskaya, 1992). Such isoclinal folding is interpreted to have occurred prior to deposition of Cover Sequence 1, which exhibits open folds with vertical axial planes. The east-west trending fold visible west of Muruntau (Fig. 3) is believed to be of Caledonian age.

Metamorphic grade of the Basement did not exceed greenschist facies over much of the region. Rb - Sr dating of metamorphic micas has yielded a Caledonian (Early Devonian) cooling age of 401 ± 11 million years (Kostitsyn, 1996). This age is consistent with the unmetamorphosed nature of unconformable Cover Sequence 1.

Hercynian (Late Carboniferous) Deformation

There is evidence of a deformation event during the Hercynian (late Carboniferous) in this region. North of Muruntau, Devonian and Carboniferous carbonate rocks are thrust over the top of the older basement rocks (Fig. 3; Drew *et al.*, 1996). The age of this thrusting is therefore Carboniferous or younger. Drew *et al.*, (1996) consider that the contact between the Besopan 3 and 4 is marked by a Carboniferous shear zone, the Sangruntau-Tamdytau shear zone.

A thrusting event at this time helps to explain the change at the top of the Carboniferous (in the Karatau range) from shallow marine to terrestrial. The widespread intrusion of granitic intrusions also occurred at this time, possibly in response to crustal thickening by thrusting.

Permo-Triassic Deformation

Alexeiev *et al.*, (1997) have documented a major Permo-Triassic deformation event in the Karatau Range, north of Muruntau (Fig. 1). This event is synchronous with the major unconformity between Cover Sequences 1 and 2. The main manifestation of this event is the giant Karatau Fault (Fig. 1) which has right-lateral displacement of 150 km and related steeply-plunging Z-shaped folds (Alexeiev *et al.*, 1997). A parallel structure occurs about 50 km south of Muruntau (Fig. 1). Outcrops of the basement and Cover Sequence 1 throughout the region are elongate in the direction of strike-slip faulting (i.e. NW) as are the principal magnetic trends.

A second set of faults trends NE and ENE (Fig. 3). A fault of this orientation, the Muruntau-Daugyztau fault, is spatially and probably temporally associated with mineralisation at Muruntau (Fig. 3). The age of this and parallel structures is clearly Carboniferous or later.

Figure 3 shows NE-trending anticlinal and synclinal axes paralleling, and probably related to, major strike-slip faults. These folds are open with a wavelength of approximately 1 km and the axes plunge shallowly north-eastwards. Much of the gold at Muruntau is located within the axial zone of the syncline.

Late Mesozoic and Tertiary Deformation

Localised open fold sets with an interpreted post-Tertiary age are superimposed on the Hercynian deformation. These folds occur in Tertiary exposures about 50 km to the south-west of the Muruntau deposit. A further 70 to 100 km of right-lateral movement occurred along the Karatau fault during the late Mesozoic and early Tertiary (Alexeiev *et al.*, 1997).

Muruntau gold deposit

Geometry of the Mineralisation

The geometry of the Muruntau deposit was controlled by three main factors: presence of the carbonaceous and

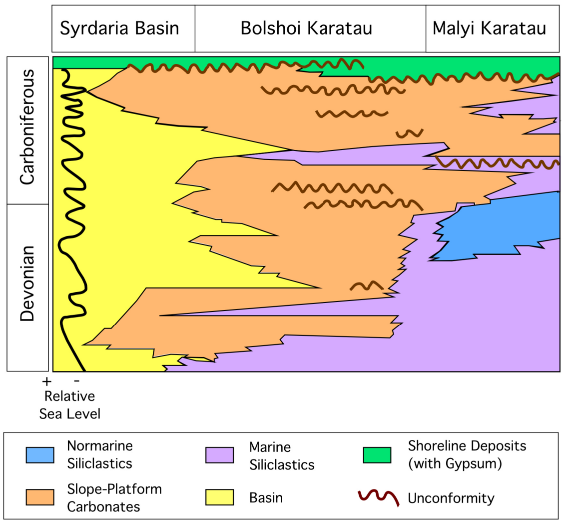

Figure 2. Depositional profile of the Karatau Range, Kazakhstan (from Cook et. al., 1997).

sulphidic Besopan 3 unit; proximity to the ENE-trending Muruntau-Daugyztau Fault and presence of an ENE-trending fold axial zone on the north side of the fault. Drew *et al.* (1996) have argued that another control is the presence of a Carboniferous thrust fault at the top of the Besopan 3 unit. Thus the orebody is to some degree stratabound within the Besopan 3 horizon but is also structurally-controlled by small-scale folding and fractures related to the Muruntau-Daugyztau fault zone and its related folding. Interpretation of the ore geometry is complicated by some post-ore movement on the Muruntau-Daugyztau Fault.

Gold occurs in sub-vertical quartz-sulphide veins and irregular quartz vein stockworks which cut hydrothermally-altered clastic host-rocks. The veins and vein stockworks are most intense within a few hundred metres of the major north-easterly trending Muruntau-Daugyztau strike-slip fault (Fig. 3). Several large sub-vertical quartz-gold veins (the Central Veins) form the core of the mineralisation and contain the highest gold grades seen at Muruntau. These veins are undeformed and trend ENE and easterly. They can be several metres thick.

Mineralised veins such as the Central Veins and stockworks postdate earlier, boudinaged and isoclinally folded quartz veins. The early veins are typically thin (a few cm) and usually parallel to the dominant cleavage of the host phyllites.

Ore Mineralogy and Paragenesis

Gold is associated with pyrite and arsenopyrite, which comprise a few volume percent of the ore. The sulphide minerals often occur as veinlets in altered host-rocks and as isolated clots within quartz veins. Pyrite grains sometimes enclose small pyrrhotite grains suggesting that some pyrite may have replaced pyrrhotite (Gilbert, 1995). Rare chalcopyrite, sphalerite and molybdenite were observed in a number of low-grade stockpiled ore samples. Gold has been observed as minute inclusions in pyrite (Gilbert, 1995) and intimately intergrown with antimony sulphide (Schandl, 1997).

The deposit is anomalous in tungsten which occurs as scheelite. According to Uspenskiy and Aleshin (1993) tungsten is confined to shallow-dipping stratabound zones which are cut by later discordant gold ore zones. Grades are generally sub-economic (typically hundreds of ppm) but can reach 0.5%. Uspenskiy and Aleshin (1993) provide evidence that scheelite occupies fractures in early folded quartz veins and also occurs as veinlets with pyroxene and amphibole selvages.

Tungsten veins are cut by auriferous arsenopyrite veinlets, suggesting that the tungsten pre-dates gold mineralisation. In the open pit, tungsten-bearing zones are observed to be cut by gold ore zones, which are related to the large discordant quartz veins (Central Veins; Uspenskiy and Aleshin, 1993).

A distinctive silver-rich gold and base-metal sulphide assemblage occurs in the region about the Muruntau deposit. Samples from the Cosmanachi silver mine, 16 km west from Muruntau, consist of galena, sphalerite, tetrahedrite, pyrargyrite, millerite, an unidentified silver sulphide, a silver sulphide-telluride mineral, lead silver antimony sulphide and others (Gilbert, 1995). These minerals overprint early arsenopyrite and pyrite (Gilbert, 1995) suggesting that the silver-rich mineralising event is later than the main gold event. Secondary minerals include chalcocite, covellite, lead arsenate and stolzite (lead tungstate).

Hydrothermal Alteration

Gold-coeval hydrothermal alteration at the Muruntau deposit is very extensive. The alteration, which consists of quartz, albite and biotite ("metasomatite") overprinting and replacing the regional and contact metamorphic assemblages, extends in a lens-shaped area with dimensions of approximately 8 km by 2 km about the gold mineralisation at Muruntau, in the so-called "Muruntau Lens" (Fig. 3); (e.g. Marakushev and Kokhlov, 1992; Kotov and Poritskaya, 1992). There is some petrographic evidence that much of this alteration consists of layer-parallel replacement of carbonate-bearing units (Gilbert, 1995; Schwandl, 1997). The modal mineral composition of the alteration is illustrated in Figure 4.

The albite-stable alteration ("metasomatite") is overprinted by sericite and chlorite related to the main ore depositing phase (Kotov and Poritskaya, 1992).

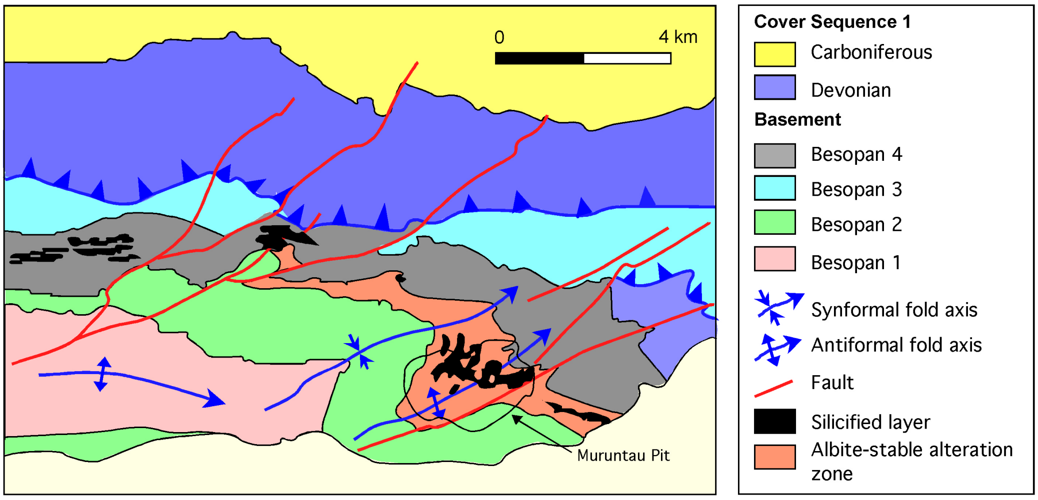

Figure 3. Geology of part of the Tamdytau Mountains showing the setting of the Muruntau deposit, based on compilation of Soviet mapping by Drew (1993).

Sericite and chlorite is limited in extent relative to the earlier alteration, being confined to narrow vein selvages of a few millimetres extent (Kotov and Poritskaya, 1992) and pervasive replacement of feldspar.

A ubiquitous alteration phase is pale-coloured dravitic tourmaline (Gilbert, 1995). Microprobe analysis reveals that these dravites are rich in V (up to 2.7% V_2O_3), Mg and Na (Gilbert, 1996). Carbonaceous material is locally abundant in the pit. Petrographic determinations on stockpiled ore samples reveal an average of 4% by volume and locally as much as 50% (Schandl, 1997). Marakushev and Khokhlov (1992) describe carbon "fronts" but the relationship between carbon "fronts" and gold is not well understood at this time.

Age of the Hydrothermal System(s)

One of the most controversial aspects of the Muruntau orebody is its age. Alteration replaces and exploits a pre-existing cleavage and also overprints contact metamorphic andalusite and cordierite associated with the buried alaskite pluton beneath the deposit (Kotov & Poritskaya, 1992; Drew *et al.*, 1996). These observations strongly suggest that alteration was considerably later than peak deformation, and post-dates the thermal event accompanying the emplacement of the adjacent granite. Kostitsyn (1993, 1996) provides three Rb-Sr mineralisation ages: 257.6 ± 2.2, 230.2 ± 3.5 and 219.4 ± 4.2 million years (Permian to Triassic). All these ages are significantly younger than the crystallisation age of the Murunski intrusive, 4 km beneath the Muruntau deposit.

Genesis

Gold deposition is inferred to have occurred during a major period of strike-slip movement and terrestrial basin formation that spanned the Late Permian and Early Triassic. The event is marked by a profound change in sedimentary depositional environments from a marine carbonate shelf-type sedimentation in the Late Palaeozoic to non-marine terrigenous, saline to hypersaline depositional settings in the Jurassic and Cretaceous characterized by the "red-beds" of Cover Sequence 2 (Syr Daria Basin). This change can be observed through much of Central Asia.

Mineralisation was emplaced within the pre-existing metamorphic aureole of a buried Permo-Carboniferous felsic intrusive. Isotopic data indicate that mineralisation occurred about 30 million years later than cooling of the intrusion below its Rb-Sr closure temperature (Kostitsyn, 1996). The intrusion and its metamorphic aureole probably controlled the subsequent development of the

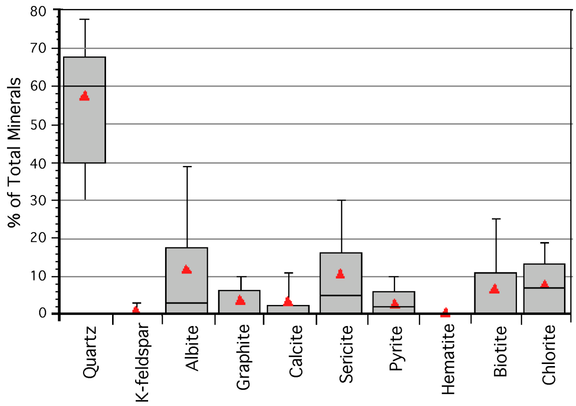

Figure 4. Modal mineralogy of 64 samples from Muruntau (Schandl, 1997; I.P. Zarevich, unpub. data).

ore-forming hydrothermal cell because of the permeability variation imposed on the host succession by the intrusion and its metamorphic halo. The aureole and the intrusive could have acted as a brittle and dilatant block, generating a more strongly fractured zone containing more dilatant fractures than the adjacent more ductile host-rocks. It is not clear however, if the intrusion could have remained a source of a thermal anomaly focussing a hydrothermal cell for over 50 million years after emplacement.

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