Telluride Mineralogy of the Kochbulak Epithermal Gold Deposit, Tien Shan, Eastern Uzbekistan

Yongwei Lu 1, Xiaobo Zhao 1,*1, Chunji Xue 1,2, Bakhtiar Nurtaev 3, Yiwei Shi 1, Yangtao Liu 1 and Shukrat Shukurov 3

1 State Key Laboratory of Geological Processes and Mineral Resources, School of Earth Sciences and Resources, China University of Geosciences, Beijing 100083, China; yiwei-shi@email.cugb.edu.cn (Y.S.); yangtaoliu@email.cugb.edu.cn (Y.L.)
2 The National 305 Project Office of Xinjiang, Urumqi 830000, China
3 Institute of Geology and Geophysics, University of Geological Sciences, Ministry of Mining Industry and Geology of the Republic of Uzbekistan, Tashkent 100041, Uzbekistan; nurtaevb@gmail.com (B.N.); shuxrat2200@mail.ru (S.S.)
* Correspondence: xiaobozhao@cugb.edu.cn

Abstract: The Kochbulak gold deposit is situated on the northern slope of the Kurama range of eastern Uzbekistan and is one of the largest Tellurium-rich epithermal gold deposits in the world. Based on a detailed field and petrological investigation, three stages of mineralization can be classified, including, from early to late, quartz–pyrite vein stage, quartz–telluride–sulfide–sulphosalt–native gold stage, and pyrite–chalcopyrite vein stage. Abundant tellurides, including tellurobismuthite, rucklidgeite, tetradymite, altaite, volynskite, and hessite, have been well recognized in the second (main) mineralization stage. Based on the mineral assemblages and petrogenetic occurrence, the sequence of tellurides in the second mineralization stage can be approximately identified as altaite+calaverite+native tellurium, calaverite+native gold, Bi-telluride (e.g., tellurobismuthite and rucklidgeite)+petzite+native gold, Ag-Bi telluride (e.g., volynskite), and Ag-telluride (e.g., hessite)+native gold. By depicting the Log f(Te₂)-Log f(S₂) relationship diagram of the Kochbulak gold deposit under 250 °C and 200 °C, the Log f(S₂) value ranges from −14.7 to −8.6 and from −16.7 to −10.9, respectively, with Log f(Te₂) value varies from −12.3 to −7.8 under 250 °C and ranges from −13.8 to −11.2 under 200 °C.

Keywords: tellurides; epithermal gold deposit; physicochemical condition; Kochbulak; Uzbekistan

1. Introduction

Tellurium (Te) is one of the critical mineral resources that have broad applications in the high-technology industry. The main hydrothermal Te mineralization includes independent tellurium deposits (Dashuigou and Kankberg, etc.) and associated Te-rich epithermal gold deposits [1]. However, the occurrence of telluride minerals and their formation conditions in high-grade Te-rich epithermal gold deposits are still poorly understood. The Kochbulak Te-rich epithermal gold deposit, located in the eastern part of Uzbekistan, has a proven and indicated mineral resources of 160 tons Au and 400 tons of Ag [2], with ore grades ranging from 3 to 74.4 g/t for gold and from 3 to 1340.1 g/t for Ag [3]. The deposit contains a variety of Au ± Ag, Pb, Bi, Hg, Sb, and Cu telluride minerals with relatively coarse grains and diverse types, while the average content of tellurium in gold ore can reach 101.6 ppm [3]. Thus, the Kochbulak deposit provides a rare opportunity to explore the occurrence of telluride mineralogy and its enrichment conditions in an epithermal environment.

Previous studies have carried out preliminary mineralogical investigations on the Kochbulak deposit. In particular, Kovalenker et al. (1997) discussed the fluid source of the Kochbulak gold deposit through fluid inclusions, gas and ion chromatography, and sulfur isotope investigations [2]. Plotinskaya et al. (2006) described the Au-Ag tellurides in
the Kochbulak deposit and the adjacent Kairagach gold deposit [4]. In addition, Aripov et al. (2005) discussed the tendency of vertical zonation of Au, Ag, Te, and Se in different orebodies of the Kochbulak deposit [3].

This paper provides an up-to-date mineralogical description of tellurides of the Kochbulak epithermal gold deposit based on systematic petrological, scanning electron microscope (SEM), and electron microprobe analysis (EMPA). The thermodynamic phase diagram is used to constrain the physical and chemical conditions for the stable coexistence of tellurides with other ore minerals, as well as key thermodynamic parameters that caused changes in the activity of telluride complexes of the Kochbulak gold deposit. The relationship between gold and telluride and its implications for the genesis of high-grade Te-rich epithermal gold deposits has also been discussed.

2. Geological Background

The Kochbulak epithermal gold deposit is located on the northern slope of the Kurama range of the Tien Shan orogenic belt, which represents the world’s second-largest gold province (Figure 1) [5–7]. In particular, an array of Late Paleozoic epithermal gold deposits is well preserved in the province [8–10]. The geological processes of the Kurama district involved the Late Paleozoic continental arc volcanism, accompanied by the tectonic reworking of the consolidated fold belt [11,12].

![Figure 1. Sketch tectonic map of the western Tien Shan showing locations of major gold deposits (modified from [6,11]).](image)

Widespread Middle–Late Carboniferous and Early Permian volcano-plutonic rocks, including andesite–dacite, rhyolite, subvolcanic rocks, granite, granodiorite, and diorite, are exposed in the Kurama district (Figure 2) [11]. The Middle Carboniferous Karamazar granodiorite complex intrudes into the Ordovician–Silurian breccia and schist, Devonian–Lower Carboniferous carbonate rocks, as well as the Middle Carboniferous Minbulak and Akcha volcanic formations [11]. The typical feature of volcanic activity during the Middle Carboniferous is lava outflows along fissures and the accumulation of tuff and block lava. In addition, central volcanic structures are widely observed in the Nadak (C2-3), Oyasai, and Kyzylmura (C3-P1) formations, with acidic rocks being more abundant in the latter two formations.
3. Deposit Geology

The Kochbulak gold deposit is mainly hosted by andesite, dacite, and tuff of the Middle–Upper Carboniferous Nadak Formation [3]. Igneous rock mass and dike swarm are widely presented in the deposit area. An array of granite porphyry, granodiorite porphyry, and quartz porphyry dikes, and subvolcanic bodies commonly strike northeast or east, with granodiorite porphyry exposed in a small area in the southeast of the ore field and are significantly cut by fault structures (Figure 3). Local dike swarms and individual dikes of diabase, felsite, andesite, and shoshonite often strike the northeast (Figure 3).

The Kochbulak deposit is controlled by the intersection of deep faults of the orthogonal system, with a series of high-angle faults striking northwest and fewer faults striking east or northeast. Gold orebodies mostly occur in high-angle and low-angle faults, as well as in volcanic pipes, and are concentrated in the central uplifted fault blocks (Figure 3a). Low-angle (15–40°) to nearly horizontal faults are in contact with tuff layers and andesite–dacite and are also related to lava flows or subvolcanic intrusions of andesite or trachyandesite [3].
Figure 3. (a) Geological map of the Kochbulak gold deposit. (b) Cross-section of the Kochbulak gold deposit (modified after [13]).
According to the morphological structure, the orebodies can be divided into three types: e.g., high-angle discordant veins, low-angle coordinated veins and vein zones, and steep lensed to pipe-shaped orebodies [3]. The discordant veins are the most abundant and are controlled by northeast-striking high-angle faults, represented by quartz veins that are 1–2 m thick and tens to hundreds of meters long or quartz veinlets in silicified and sericitized volcanic rocks. This type of vein has variable dip angles and horizontally non-variable mineral compositions. The second type can reach a thickness of 2–3 m and is located within an extended thick layer (up to 10–30 m) of veinlets of metasomatic silicification. The coordinated veins are related to low-angle faults in contact with volcanic layers. In addition, the steep lensed to pipe-shaped orebodies are almost vertically extended and are hosted in steeply inclining hydrothermal explosive breccia (Figure 3b).

Based on the structure and texture of orebodies and the crosscutting relationship of ore veins, three mineralization stages have been recognized (Figure 4a). The mineral composition and main characteristics of each stage are described as follows.

![Figure 4](image)

**Figure 4.** (a) Typical hydrothermal gold ore of the Kochbulak deposit showing the crosscutting relationship of the three mineralization stages. (b) Miarolitic texture of quartz. (c) Crusty texture developed in the second (main) mineralization stage. (d) Breccias in the second (main) mineralization stage.

Stage I is represented by quartz–pyrite veins. Silicification and sericitization are the most intense during this stage, reflecting the characteristics of planar alteration formed by post-volcanic hydrothermal activity. The main feature of this stage is the fine-grained cryptocrystalline smoke-gray to yellow-brown quartz. Quartz has a high euhedral extent and miarolitic texture (Figure 4b), which filled many leached cavities along with transparent quartz, dolomite, barite, and fine crystals of some ore minerals. The main ore mineral is pyrite, and the quartz contains native gold and tellurides [4]. The typical feature of gold
mineralization in this stage is the separation and combination of multiple round pyrite particles with primary gold [3].

Stage II is the main mineralization stage and is characterized by quartz–telluride–sulfide–sulphosalt–native gold. The main features of this stage are ivory euhedral fine-grained quartz and xenomorphic quartz. The quartz-filled leached cavities of the first stage or filled cracks. In addition, crusty texture and banded texture are also well developed in hydrothermal quartz (Figure 4c). The mineral assemblages of this stage are dominated by quartz and sulfides (e.g., pyrite and sphalerite), which precipitate at the beginning of the stage and are followed by sulphosalts and Au-Ag tellurides [3]. Stage II interpenetrates mineral assemblages of Stage I and contains breccia from the first stage (Figure 4d).

Stage III represents the late-stage pyrite–chalcopyrite veins. These veins crosscut the mineral assemblages of Stage I and Stage II (Figure 4a).

Gold in the Kochbulak deposit occurs predominantly as fissure gold, gold inclusions, and gold grains whose sizes vary from 1 to 700 µm, and the purity of gold ranges from 0.326 to 1.000, with an average fineness of 880 [3]. Gold is closely associated with minerals such as pyrite, chalcopyrite, tellurides, and quartz. In the cylindrical orebodies, native gold and tellurides are the most abundant, with gold grades reaching as high as thousands of ppm, while tellurides crystallized in grains sized up to 10–15 cm across [6].

The hydrothermal alteration of the Kochbulak deposit shows features of zonation around orebodies. From the inner core to the outside, silicification, argillization, and propylitization develop in sequence [2]. Among these, argillization is temporally related to volcanism, and shallow propylitization is the earliest alteration process of the deposit. From top to bottom, hydrothermal alterations include argillization (containing alunite), beresitization, and potassic alteration [3]. It is consistent with the typical zonation of epithermal gold–silver deposits. In addition, chloritization, carbonation, and atypical adularization and alunitization can also be seen. The assemblage of hydrothermally altered minerals within the Kochbulak deposit is characterized by sericite+carbonate (ankerite–dolomite)+quartz+pyrite. Moreover, the altered wall rocks can be divided into two distinct types: quartz–sericite ± feldspar type near the high- and low-angle veins and vein zone and quartz–boehmite ± alunite type in tubular veins [3].

4. Samples and Analytical Methods

Three typical ore samples were selected from mining adit for comprehensive petrological studies. Three polished thick sections were examined under the optical and scanning electron microscopes (SEM). Optical microscopic observation was carried out at the Resources Exploration Laboratory, China University of Geosciences (Beijing, China). The microscope BX51 is a research-level upright polarizing microscope with both transmitted and reflected lights, which was made by the Olympus Corporation in Tokyo, Japan.

Electron microprobe analysis (EPMA) was conducted at the electron microprobe laboratory of the Institute of Mineral Resources, Chinese Academy of Geological Sciences. The testing instrument is JXA-8230, produced by JOEL Company in Tokyo, Japan, with 20 kV of accelerating voltage, 20 nA of current, 2–3 µm of beam spot diameter, 10 s of peak counting time, 5 s of high background counting time, 5 s of low background counting time. The standard samples are 53 types of minerals from the U.S. SPI Supplies, and standardization was carried out by the ZAF method [12].

5. Results

5.1. Mineralogy of Tellurides

Tellurides of the Kockbulak deposit occur closely with quartz or tetrahedrites as fine grains and often coexist with native gold and sulfides (e.g., pyrite, chalcopyrite, and galena). Based on EMPA data (Table 1), reflection photomicrographs (Figure 5), backscattered electron (BSE) images, and corresponding energy spectra (Figure 6), detailed descriptions of some typical tellurides in the Kochbulak deposit are provided as follows.
Table 1. EMPA (wt.%) data of represented telluride minerals from the Kochbulak gold deposit.

<table>
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<th>Mineral</th>
<th>Sample No.</th>
<th>Se</th>
<th>Bi</th>
<th>Te</th>
<th>Mo</th>
<th>Au</th>
<th>Pb</th>
<th>Sb</th>
<th>Ag</th>
<th>S</th>
<th>Total</th>
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(1) Tellurobismuthite (Bi₂Te₃): The reflection color is light pink, and in the BSE image, it is grayish white, darker than the color of altaite, but lighter than volynskite (Figure 5e). Tellurobismuthite has a highly euhedral appearance and occurs as regular strips, approximately 174 µm in length. Tellurobismuthite is spatially related to volynskite and occurs as inclusions within altaite (Figure 5e). Occasionally, it coexists with altaite and hessite, enclosed within tetrahedrite (Figure 5f). It can also disperse in pyrite and tetrahedrite, presenting in an irregular shape (Figure 5a). According to the results of EMPA, the tellurobismuthite shows Te concentrations from 46.28% to 46.39% and Bi concentration of 44.8%–47.16%, with minor amounts of Ag, Se, and S (Table 1). Impurity Sb is commonly
presented in tellurobismuthite, such as \((\text{Bi}_{0.78}\text{Sb}_{0.86})_2\text{Te}_3\). Compared with standard tellurobismuthite \((\text{Bi}_2\text{Te}_3\): Bi 52.20%, Te 47.80%), isomorphous substitution between Sb and Bi is more likely.

**Figure 5.** BSE images of typical tellurides of the Kochbulak gold deposit. (a) Tellurobismuthite, pyrite, tetrahedrite, and chalcopyrite. (b) Rucklidgeite, pyrite, and chalcopyrite. (c) Tetradymite, pyrite, tetrahedrite, and galena. (d) Altaite, tetrahedrite, and chalcopyrite. (e) Altaite, tellurobismuthite, and volynskite. (f) Altaite, tellurobismuthite, hessite, and tetrahedrite. Py = pyrite, Ccp = chalcopyrite, Teb = tellurobismuthite, Td = tetrahedrite, Rkl = rucklidgeite, Gn = galena, Ttr = tetradymite, Alt = altaite, Vol = volynskite, Hes = hessite.

**Figure 6.** Photomicrographs and paragenetic relationship of typical tellurides of the Kochbulak gold deposits. (a) Tellurobismuthite, altaite, tetrahedrite, and chalcopyrite. (b) Rucklidgeite, pyrite, and chalcopyrite. (c) Tellurobismuthite and volynskite in altaite. (d) Altaite, tetrahedrite, and chalcopyrite. (e) Altaite, tellurobismuthite, and hessite in tetrahedrite. (f) Altaite, tellurobismuthite, and volynskite in tetrahedrite. Py = pyrite, Ccp = chalcopyrite, Td = tetrahedrite, Rkl = rucklidgeite, Alt = altaite, Teb = tellurobismuthite, Vol = volynskite, Hes = hessite.

(2) Rucklidgeite \((\text{PbBi}_2\text{Te}_4\): The reflection color is a very weak rose tint and is light gray in BSE images (Figure 5b). It is mainly in xenomorphic appearance, coexisting with chalcopyrite. It also presents as droplet-shaped within tetrahedrite, which may be
relevant to melt involvement in concentrating Au [14]. According to the EMPA results, the rucklidgeite has a Te concentration of 46.1%, a Bi concentration of 41.04%, and a Pb concentration of 11.25%, with trace amounts of Ag and Se (Table 1).

(3) Tetradymite (Bi$_2$Te$_2$:S): Tetradymite is relatively rare and has a small particle size. It appears bright white in the BSE image, and its forms are mainly elliptical and irregularly granular, with particle sizes ranging from 12 to 32 µm. Tetradymite occurs as inclusions in tetrahedrite or accreting with tetrahedrite and filling cracks in pyrite (Figure 5c). Tetradymite also coexists with Bi-sulfosalts, Au-Ag telluride, and native gold [6]. According to EMPA results, the tetradymite has a Te concentration of 54.45%–56.21%, and a S concentration of 3.26%–3.68%, with trace amounts of Ag and Se (Table 1).

(4) Altaite (PbTe): Altaite is frequently observed in the samples. The reflection color is white with a weak turquoise tint, and in the BSE image, it appears as light gray–white grains (Figure 5d). It has a relatively euhedral form and varies in size. Some grains are associated with chalcopyrite and encapsulated in tetrahedrite, while others coexist with tellurobismuthite or altered tetrahedrite and form an etching structure. According to EMPA results, the altaite shows a Te concentration of 35.69%–39.23% and a Pb concentration of 63.04%–53.75%, with minor amounts of Ag, Se, and Bi (Table 1).

(5) Volynskite (AgBiTe$_2$): A significant amount of volynskite was detected in the samples. The reflection color is pale purplish, and in the BSE image, it appears as gray (Figure 5e). Its shape is mostly irregular, coexisting with tellurobismuthite, or occurs as inclusions in altaite. According to EMPA results, volynskite often contains impurities Sb and Pb, for instance, Ag$_{1.29}$(Bi$_{0.37}$Sb$_{0.44}$)Te$_2$. Compared with standard volynskite (AgBiTe$_2$: Te 44.61%, Bi 36.53%, Ag 18.86%), isomorphous substitution is more likely.

(6) Hessite (AgTe$_2$): The reflection color is dark gray, and in the BSE image, it appears as dark gray and is darker than the color of tellurobismuthite (Figure 5f). Particle size is about 47 µm, and the formation of altaite restricts the growth of hessite apparently. Hessite is contained in tetrahedrite, together with tellurobismuthite and altaite. Moreover, hessite also coexists with native gold and chalcopyrite, or petzite, lillianite, and tetradymite [3].

Other telluride minerals of the Kochbulak deposit recognized in the literature and our study include Au-Ag tellurides calaverite (AuTe$_2$), cukennerite (Au$_3$AgTe$_8$), petzite (Ag$_3$AuTe$_2$), sylvanite (AgAuTe$_4$), montbrayite ((Au,Ag,Sb,Bi,Pb)$_{23}$(Te,Sb,Bi,Pb)$_{38}$), kostovite (CuAuTe$_4$), empressite (AgTe), and stützite (Ag$_{5-x}$Te$_2$); Bi tellurides joséite (Bi$_4$Te$_5$), sulphotsumoite (Bi$_1$Te$_2$S), and tsumoite (BiTe); Cu tellurides vulcanite (CuTe), richardite (Cu$_2$Te), and weissite (Cu$_2$Te); other tellurides include nagyágite ([Pb$_3$(Pb,Sb)$_3$S$_6$](Au,Te)$_3$), coloradoite (HgTe), frohbergite (FeTe$_2$), goldfieldite, melonite (NiTe$_2$), tellurantimony (Sb$_2$Te$_3$), tellurite (TeO$_2$), and native tellurium [3,4].

5.2. Paragenetic Succession and Mineral Chemistry

Based on the mineral assemblages and mineral habits, the mineral paragenetic sequence in the Kochbulak deposit can be inferred (Figure 7). Among these, the sequence of mineral assemblages of the second (main) mineralization stage is altaite+calaverite+native tellurium, calaverite+native gold, Bi telluride (e.g., tellurobismuthite and rucklidgeite)+petzite+native gold, Ag-Bi telluride (e.g., volynskite), and Ag-telluride (e.g., hessite)+native gold [4].

In Figure 6a, some of the altaite grains are replaced by the latter tellurobismuthite, indicating that altaite forms earlier than tellurobismuthite. Also, due to the highly euhedral appearance of tellurobismuthite, it may formed in a relatively early stage. Volynskite often coexists with tellurobismuthite in a xenomorphic form, suggesting that volynskite deposited later than tellurobismuthite (Figure 6c,f). In addition, mineral assemblages of volynskite, Bi-telluride, and petzite can be found in the Kochbulak deposit [4]. Based on the observation of tetradymite coexisting with late-stage galena and pyrite (Figure 5c), it is speculated that the formation of tetradymite was relatively late.
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![Figure 7. Paragenetic sequence of the Te-rich Kochbulak gold deposit.](image)

Most of these tellurides have straight contact. And some of them (such as altaite and rucklidgeite) appear droplet-shaped, which may indicate crystallization at eutectic points from the melts [15].

6. Discussion

6.1. Tellurides Genesis Conditions

When the temperature is high, pyrite is expected to be precipitated from the ore-forming fluids, consuming a large amount of iron and sulfur. It can be observed that most
of the native gold in the Kochbulak deposit precipitated during the early quartz–pyrite vein stage (Stage I), which may account for the high initial $f(S_2)/f(\text{Te}_2)$ ratios at the beginning of this stage of hydrothermal activity. This process may also be responsible for sulfides and native gold precipitation at first, resulting in an enrichment of Te in the remaining fluids. Subsequently, the $f(S_2)$ gradually decreased, whereas the $f(\text{Te}_2)$ increased, and tellurides began to be precipitated. As $f(\text{Te}_2)$ increases, bismuth, tsumoite, and tellurobismuthite stabilize successively, as in the following reactions [16]:

$$4\text{BiTe} + \text{Te}_2(\text{g}) = 2\text{Bi}_2\text{Te}_3$$

(1)

It is speculated that the formation of altaite requires less tellurium fugacity so that it precipitates prior to other tellurides. Simultaneously, altaite can stable over a wide range in $f(\text{Te}_2)-f(S_2)$ [16].

On the basis of previous research, the principle reaction of rucklidgeite precipitation is as follows [16]:

$$\text{PbTe} + \text{Bi}_2\text{Te}_3 = \text{PbBi}_2\text{Te}_4$$

(2)

From the early to late paragenetic sequence, the content of Ag in native gold and tellurides gradually increased, and the main minerals in the mineral assemblages changed from Au-telluride to Ag-telluride, reflecting a decrease in temperature and $f(O_2)$, accompanied by an increasing pH. Hessite is often used as a sign for late-formed mineral paragenetic assemblages [4].

When native Au and Ag-tellurides precipitated, there was a significant decrease in $f(\text{Te}_2)$, while the $f(S_2)$ remained largely unchanged [4]. As $f(S_2)/f(\text{Te}_2)$ increased, sulfotellurides of bismuth began to precipitate compared to tellurides containing only Bi and Te, as described in the following reaction [16]:

$$2\text{Bi}_2\text{Te}_3 + S_2(\text{g}) = 2\text{Bi}_2\text{Te}_2\text{S} + \text{Te}_2(\text{g})$$

(3)

According to the previous fluid inclusion studies, the temperature of Stage II ore-forming fluids related to the formation of tellurides is in the range of 270 °C to 130 °C. The mineral assemblages of tellurides and sulfosalt rich in gold and silver generally crystallize at 250–200 °C [2]. We select 250 °C as the upper limit estimation for precipitation of tellurides and depict the Log $f(\text{Te}_2)$-Log $f(S_2)$ relationship diagram of the Kochbulak deposit under 250 °C conditions (Figure 8) [2,4].

The range of $f(S_2)$ is constrained from $-14.7$ to $-8.6$ due to the coexistence of pyrite and chalcopyrite. Tellurium exists in the form of native tellurium and calaverite because Te is initially saturated, and it determines $f(\text{Te}_2) > -7.8$. Even more, native tellurium only exists in mineral assemblages that do not contain galena. This is because the altaite–galena assemblages may buffer $f(\text{Te}_2)/f(S_2)$ and limit $f(\text{Te}_2)$ to increase. Therefore, the lower limit of $f(\text{Te}_2)$ for the Stage II ore-forming fluids is probably $-12.3$.

When the temperature drops to 200 °C, pyrite and chalcopyrite still coexist [16], with $f(S_2)$ ranging from $-16.7$ to $-10.9$. The $f(\text{Te}_2)$ can be estimated to vary from $-13.8$ to $-11.2$, based on the observed coexistence of altaite, tellurobismuthite, and hessite, stable existence of native gold, and a gradual decrease in $f(\text{Te}_2)$ during deposition (Figure 9).
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6.2. Implications for Mineralization

The occurrence of tellurides appears to be closely related to the epithermal gold mineralization of the Kochbulak deposit [2,4]. A significant amount of Au-telluride or Au- and Ag-tellurides have been precipitated during the initial phase of the Stage II (main) veins. In contrast, the Bi- and Pb-tellurides dominate the late phase of the Stage II veins.
and are spatially and temporally associated with native gold. The precipitation of Bi- and Pb-tellurides might have reduced the concentration of tellurium in the fluids, which promotes the precipitation of gold and eventually results in the precipitation of native gold with relatively high fineness.

The role of active tectonics has inspiring significance for gold mineralization. Mineralization is dominantly controlled by fault structures, and gold with high grades is especially enriched in the high-grade ore pipes at fault intersections. Cook et al. (2005) proposed that such a tectonic setting is optimal for the development of sustained fluid throttling [18].

Moreover, the genetic mechanism usually indicates mantle-sourced alkaline magmas in subduction settings, the key source for which is the melting of Te-rich sediments [15,18]. The supporting bases include the Kochbulak telluride-bearing deposit, which is hosted by calc–alkaline volcanics.

7. Conclusions

(1) The main tellurides of the Kochbulak deposit include tellurobismuthite, rucklidgeite, altaite, volynskite, hessite, and tetradymite.

(2) The sequence of mineral assemblages in the main mineralization stage is altaite+calaverite+native tellurium, calaverite+native gold, Bi-telluride (e.g., tellurobismuthite and rucklidgeite)+petzite+native gold, Ag-Bi telluride (e.g., volynskite), followed by Ag telluride (e.g., hessite)+native gold.

(3) At 250 °C, Log ƒ(S2) of ore-forming fluids ranges from −14.7 to −8.6, with Log ƒ(Te2) value varying from −12.3 to −7.8. Whereas at 200 °C, Log ƒ(S2) ranges from −16.7 to −10.9, with Log ƒ(Te2) varying from −13.8 to −11.2.

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References


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