Original Article

Re–Os Geochronology on Molybdenites from the Donggebi Mo Deposit in the Eastern Tianshan of the Central Asia Orogenic Belt and its Geological Significance

Chunming Han,1 Wenjiao Xiao,1 Guochun Zhao,2 Min Sun,2 Wenjun Qu3 and Andao Du3

1State Key laboratory of Lithospheric Evolution, Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing, 2Department of Earth Sciences, The University of Hong Kong, Hong Kong and 3National Research Center of Geoanalysis, Beijing, China

Abstract

The Donggebi Mo deposit is located in the eastern section of the Eastern Tianshan Orogenic Belt, Central Asia Orogenic Belt. Rhenium and osmium isotopes of molybdenites from the Donggebi porphyry Mo deposit have been used to determine the timing of mineralization and the source of osmium and, by inference, ore metals. Molybdenite was collected mainly from a granite porphyry stock, which is characterized by moderate to strong silicification. Rhenium concentrations in molybdenite samples are between 10 and 63 μg g⁻¹. Analysis of eight molybdenite samples yields an isochron age of 234.3 ± 1.6 Ma (2σ) with an initial 187Os of 0.04 ± 0.45 (MSWD = 0.25). The data support the hypothesis that a significant part of the metals and magmas have a mixed (crust + mantle) origin. Based on the geological history and spatial-temporal distribution of the granitoids, it is proposed that the Mo deposits in the eastern part of the East Tianshan Orogenic Belt were related to a post-collision extensional setting in the Early Mesozoic.

Keywords: Central Asia Orogenic Belt, Donggebi, Eastern Tianshan, Mo deposit, Re–Os isotope.

1. Introduction

The Eastern Tianshan metallogenic belt in northwestern China forms a significant part of the Central Asian Orogenic Belt, which bears one of the most important porphyry Cu ± Au ± Mo metallogenic provinces in the world (Seltmann & Porter, 2005; Fig. 1). The province also contains post-collisional metallic mineral deposits formed between 280 and 240 Ma.

Donggebi is the largest, and economically the most important, deposit in the East Tianshan belt with total Mo metal reserves of 0.5 Mt (Huang et al., 2011a). It was discovered in 2008 and explored during the period 2009–2010; construction of the now-operating mine began in 2011. Since the discovery of the deposit, many studies have been conducted that have addressed the geology and geochemistry of the deposit (Tu et al., 2011; Wang, 2011; Huang et al., 2011a, b), and
the ore-forming granite porphyry (Yang et al., 2011; Deng, 2012).

In the present study, we carried out Re–Os dating on molybdenum from the Donggebi deposit in order to determine the timing of mineralization. We also discuss the source of the metals in order to understand the geodynamic environments and processes that controlled the ore formation.

2. Geological setting

The Eastern Tianshan belt contains a number of Paleozoic terranes that accreted between the Siberian and Tarim cratons, and underwent complex tectonic evolution (Coleman, 1989; Xiao et al., 2004; Zhang et al., 2004; Zhou et al., 2004; Dong et al., 2006). The belt is divided into three tectonic zones (North, Central, and South Zones), which are separated to the north by the

Fig. 1 Schematic map of the Central Asian Orogenic Belt (modified after Seltmann and Porter, 2005; Shen et al., 2010), showing principal porphyry copper deposits. The number of the mineral deposits in the Figure corresponds with Table 1.

Fig. 2 Simplified geological map of the eastern Tianshan, NW China. Numbers of deposits: (1) Tuwu Cu–Mo–Au–Ag deposit; (2) Yandong Cu–Mo–Au–Ag deposit; (3) Huangshan Cu–Ni deposit; (4) Huangshandong Cu–Ni deposit; (5) Hulu Cu–Ni deposit; (6) Xiangshan Cu–Ni deposit; (7) Tudan Cu–Ni deposit; (8) Tulaergen Cu–Ni deposit; (9) Baishiquan Cu–Ni deposit; (10) Tianyu Cu–Ni deposit; (11) Kangguer Au deposit; (12) Shijingtian Au deposit; (13) Mazhuangshan Au deposit; (14) Matoutan Au deposit; (15) Baishan Mo–Re deposit; (16) Jinwozi Au deposit; (17) Xiaorequanzi Cu–Zn deposit; (18) Donggebi Mo deposit
Aqikekudouke fault and to the south by the Kawabulak fault (Li et al., 2003; Chai et al., 2008). The North Zone, situated north of the Aqikekudouke fault, which contains several tectonic units, including the Tousuquan-Danhu arc, Kangguertag forearc/intra-arc basin and Yamansu forearc/arc (Xiao et al., 2004). It hosts a number of magmatic Cu–Ni sulfide deposits, such as Xiangshan, Huangshan, Huangshandong, Hulu, and Tulaergen, as well as the Donggebi Mo deposit (Fig. 1; Table 1).

The tectonic history of the Tianshan orogen is considered to have been associated with the evolution of the ancient Tianshan ocean between the Tarim craton and the Junggar-Kazakhstan block (Allen et al., 1993; Carroll et al., 1994). The orogen is separated from the Tarim craton by the Kangguer ductile suture zone, and extends west to Gansu Province. The main structures of East Tianshan are characterized by a series of approximately east–west-trending faults, including the regional-scale Kalamaili-Maiqinwula, Kangguer, Yanmansu, Aqikekudouke, and Middle Tianshan faults, and many small-scale faults (Fig. 2; He et al., 1994; Mao et al., 2002). Of these faults, the Kangguer fault is the most prominent one which consists of mylonite, tectono-clastic rocks, tectonic lenses, and breccia, and which not only forms the boundary between the Kazakhstan-Juanggar block and the Tarim craton, but also an important structural zone along which major magmatic activities and associated ore mineralization took place (He et al., 1994). Much of the magmatism in East Tianshan belt occurred in the Paleozoic (Ma et al., 1997), and formed in a convergent continental margin environment during the early period of the Middle Carboniferous. Two chains of diorite–granodiorite–adamellite suites were emplaced in the north and south Jueluotage area (Allen et al., 1993; He et al., 1994; Chen et al., 1999). The Yandong, Tuwu, Linglong, Chihu, Sanchakou, and Hongshan stocks in the northern part of the area consist predominantly of dioritic porphyry, plagiogranitic porphyry, quartz dioritic porphyry, granodioritic porphyry and granitic porphyry, whereas the Lingtietan, Chilongfeng, Shaquanzi, Shabei, and Baishan stocks in the southern part of the area are composed primarily of dioritic porphyry, quartz dioritic porphyry, granodiorite porphyry, and granitic porphyry (He et al., 1994). In the northern part of the area, the Xiaopu pluton yielded a Rb–Sr isochron age of 312.1 Ma, and the Qi’eshan pluton yielded a single-zircon U–Pb age of 308.5 Ma (Han et al., 2002).

Following the contractional deformation at the convergent stage, extensional faulting took place along the ductile shear zone in the north Kangguer area (He et al., 1994). The extension was associated with widespread emplacement of mafic-ultramafic complexes in the Huanshan-Jiangerquan region, including the Tudun, Erhongwa, Xiangshan, Huangshan, Huangshandong, and Hulu plutons, and the formation of a number of magmatic-type copper-nickel sulfide deposits (He et al., 1994; Ma et al., 1997). Of these plutons, SIMS zircon U–Pb ages of the Xiangshan and Hulu plutons have been reported as 308.9 ± 10.7 Ma and 320 ± 38 Ma, respectively (Li et al., 1998); the Xiangshan pluton yielded a single-zircon age of 285 ± 1.2 Ma (Qin, 2000); and the Huangshandong pluton yielded a Re–Os isochron age of 282 ± 20 Ma (Mao et al., 2002).

3. Donggebi Mo deposit

The Donggebi porphyry Mo deposit, located ~110 km south (41°55′00″N, 93°20′15″E) of Hami city, is situated 2 km north of the Yamansu fault. The host rocks are composed of metasedimentary rocks of the Lower Carboniferous Gandun Formation. They consist of meta-sandstone, meta-sandy mudstone, meta-argillaceous sandstone, meta-mudstone, meta andesite, tuff and hornfels. The stratigraphic units trend WNW and dip ENE with an angle of 50–75°. The sedimentary rocks are metamorphosed by deeper-seated intrusive rocks (Ma et al., 2012).

Some granite porphyries occur as dikes in the mineralized area. Unmineralized biotite granite is present northwest of the mining area. The Donggebi intrusion is composed of porphyritic granite and granite porphyry. The coarse-grained porphyritic granite contains 2–9% orthoclase, 6–51% plagioclase, 20–35% quartz, and 1–3% biotite, with minor amounts of muscovite and sericite. Plagioclase crystals are often replaced by granular saussurite and fine-grained clay minerals. The granite porphyry contains 30% orthoclase, 40% plagioclase, 25% quartz, and 5% biotite, with minor amounts of apatite, muscovite and chlorite. Orthoclase crystals range from 0.5 to 1 mm in size. Alteration minerals include saussurite, sericite, and chlorite. A zircon SHRIMP U–Pb age 227.6 ± 1.3 Ma recently obtained on porphyritic granite (Huang et al., 2011b) indicates that the porphyritic granite intruded after Mo mineralization. A stratabound-fracture zone is recognized, which hosts the main mineralization trending NE, and dipping south with an angle of 30–60° (Fig. 3).
Table 1 Characteristics of the principal porphyry Cu–Mo deposits in the Central Asia Orogenic Belt

| Ore deposits | Location         | Main economic elements                  | Host rocks and ages (Ma) | Mineralization and ages (Ma) | Grade (g/t), reserve/utility | Reference                                                                 |
|--------------|------------------|----------------------------------------|--------------------------|------------------------------|----------------------------|--------------------------------------------------------------------------|
| Baogutu(1)   | Xinjiang, NW China | Cu–Mo–Au                               | Diorite and quartz diorite; SHRIMP U–Pb 325.1 ± 4.2 Ma | Molybdenite Re–Os isochron 310.1 ± 3.6 Ma | Cu 0.063 Mt, 0.28%; Mo 0.018 Mt, 0.011% Au 1.46; 0.1 g/t; | Song et al. (2007); Shen et al. (2010)                                      |
| Tuwu-Yandong(2) | Xinjiang, NW China | Cu–Mo–Au                               | Plagiognegranite porphyry; SHRIMP U–Pb 333 ± 2 Ma and 334 ± 2 Ma | Molybdenite Re–Os isochron 322.7 ± 2.3 Ma | Cu 4.65 Mt, 0.67%; Au 18 t, 0.15 g/t; | Rui et al. (2002); Liu et al. (2003)                                          |
| Wunage-Nushan(3) | Inner Mongolia, NE China | Cu–Mo                               | Adamellite porphyry; Single zircon U–Pb 188.3 ± 0.6 Ma | Molybdenite Re–Os isochron 178 ± 10 Ma | Cu 2.23 Mt, 0.67%; Mo 0.26 Mt, 0.019%; | Qin et al. (1999); Li et al. (2007)                                            |
| Duobao-Shan(4) | Heilongjiang, NE China | Cu–Mo                               | Granodiorite; SHRIMP U–Pb 479.5 ± 4.6 Ma | Molybdenite Re–Os isochron 50.6 ± 14 Ma | Cu 2.44 Mt, 0.47%; Mo 0.11 Mt, 0.016%; | Zhao et al. (1997); Cui et al. (2008)                                        |
| Erdenet(5)    | North Mongolia   | Cu–Mo–Au                               | Diorite, granodiorite porphyry; Rb-Sr isochron 252 ± 11 Ma | Molybdenite Re–Os isochron 240.6 ± 0.6 Ma | Cu 9.18 Mt, 0.3-0.6%; Mo 0.27 Mt, 0.012%; | Berzina and Solntsov (1999); Watanabe and Stein (2000); Berzina et al. (2005) |
| Tsagaan-Suvarga(6) | South Mongolia | Cu–Mo                               | Syenogarnite, subordinate, Granodiorite; Biotite K–Ar 256–339 Ma | Molybdenite Re–Os isochron 370.4 ± 0.8 Ma | Cu 1.30 Mt, 0.54%; Mo 0.04 Mt, 0.19%; | Gerel (1998); Lamb and Cox (1998); Watanabe and Stein (2000) |
| Oyu Tolgoi(7) | South Mongolia   | Cu–Au                                | Quartz monzodiorite; SHRIMP U–Pb 362 ± 2 Ma and 378 ± 3 Ma | Molybdenite Re–Os isochron 372 ± 2 Ma and 373 ± 1.2 Ma | Cu 20.57 Mt, 0.83%; Au 790 t, 0.32 g/t; | Cooke et al. (2005); Wainwright et al. (2005); Khashgerel et al. (2009) |
| Kharmagtai (8) | South Mongolia   | Cu–Au–Mo                             | Quartz-diorite dikes; Monzodiorite and diorite porphyry stocks | Molybdenite Re–Os isochron 506 ± 14 Ma | Cu 2.29 Mt, 0.35% | Shin et al. (2005); Kirwin et al. (2005)                                      |
| Boshekul(9)   | Kazakhstan       | Cu–Mo                                | Tonalite and granodiorite; Rb-Sr isochron 481 ± 23 Ma | Molybdenite Re–Os isochron 240.6 ± 0.6 Ma | Cu 1.27 Mt, 0.72%; Mo 0.14%; Au 0.28 g/t; | Kudryavtsev (1996) |
| Samarsk(10)   | Kazakhstan       | Cu–Au                                | Quartz monzontite; Devonian | Molybdenite Re–Os isochron 370.4 ± 0.8 Ma | Cu 1–2%; Mo 0.0036%; Au 0.4–1 g/t; | Zhukov et al. (1997); Heinhorst et al. (2000); Huang et al. (2007) |
| Borly(11)     | Kazakhstan       | Cu–Mo                                | Granodiorite; granodiorite porphyry | Molybdenite Re–Os isochron 506 ± 14 Ma | Cu 0.60 Mt, 0.38% | Cooke et al. (2005); Wainwright et al. (2005); Khashgerel et al. (2009) |
| Kounrad(12)   | Kazakhstan       | Cu–Mo–Au                             | Granodiorite and tonalite | Molybdenite Re–Os isochron 506 ± 14 Ma | Cu 7.90 Mt, 0.61%; Mo 0.0035%; Au 0.017 g/t; | Kudryavtsev (1996); Zhukov et al. (1997); Heinhorst et al. (2000); Sehlmann and Porter (2005) |
| Sayak(13)     | Kazakhstan       | Cu–Mo–Au                             | Granitoid; Biotite K–Ar 304–329 Ma | Mo 0.01%; Au 0.70 g/t; | Cu 12.50 Mt, 0.39%; Mo 0.01%; Au 0.22 g/t; | Heinhorst et al. (2000); Cooke et al. (2005) |
| AKtaga(14)    | Kazakhstan       | Cu–Mo                                | Granodiorite and diorite 300 | Mo 0.01%; Au 0.22 g/t; | Cu 1.64 Mt, 0.52%; Mo 0.005%; Au 0.005 g/t; | Zhukov et al. (1997); Huang et al. (2007); Shen et al. (2010) |
| Koksai(15)    | Kazakhstan       | Cu–Mo–Au                             | Granodiorite and papiornkite porphyry | Mo 0.01%; Au 0.22 g/t; | Cu 1.4 Mt, 0.17%; Au 45.6; 0.63 g/t; | Cooke et al. (2005); Cai and Li (1995) |
| Taldy Bulak(16) | Kazakhstan     | Cu–Mo–Au                             | Dacite stock | Mo 0.51 Mt, 0.115%; | Cu 10.64 Mt, 0.39%; Au 1.374; 0.51 g/t; | This study |
| Kal'makyr(17) | Uzbekistan       | Cu–Au                                | Diorite, monzodiorite, 321–330; granodiorite, 306–311 | Mo 0.51 Mt, 0.115%; | Cu 10.64 Mt, 0.39%; Au 1.374; 0.51 g/t; | Cooke et al. (2005) |
| Donggebi (18) | Xinjiang, NW China | Mo                                  | Granite porphyry | Mo 0.51 Mt, 0.115%; | Cu 10.64 Mt, 0.39%; Au 1.374; 0.51 g/t; | This study |

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In total, five orebodies have been identified, and they are distributed in the contact zone between the porphyritic granite and metasedimentary rocks of the Lower Carboniferous Gandun Formation. Individual orebodies vary from 280 m to 850 m in length and 10 m to 65 m in thickness. In the dipping direction, the explored orebodies extend over 320 m below the surface (Fig. 4). The main orebodies trend NE and dip east at about 30°.

The ores are characterized by veinlet-disseminated and brecciated structures. Principal metallic minerals are molybdenite and pyrite with minor quantities of chalcopyrite, galena, magnetite, scheelite, and wolframite. The gangue minerals include orthoclase, plagioclase and quartz, with lesser amounts of calcite, muscovite, and chlorite. The size of molybdenite ranges from 0.03 mm to 3 mm.

Several stages of hydrothermal alteration are recognized at Donggebi based on chemical and mineralogical analyses. The highest Mo contents occur in zones with complex hydrothermal overprinting. A potassic alteration (K-feldspar + secondary biotite) affected the entire mineralized area. It involved microcline grown in the matrix around and between biotite and plagioclase. Minor disseminated pyrite and magnetite, and veinlets of magnetite ± pyrite are present in the potassic alteration zones.

Light-colored, white, irregular, phyllic (quartz-sericite/muscovite) alteration zones, overprint potassic alteration where sericite/muscovite together with

Fig. 3 Geological map of the Donggebi Mo deposit (after Deng, 2012).
fine-grained quartz have replaced feldspar. Euhedral pyrite is common in this zone. Minor chalcopyrite occurs with disseminated molybdenite. Silicification with fine-grained quartz is associated with stockwork quartz veins and veinlets with chalcopyrite, pyrite, molybdenite, and magnetite. The biotitization zone is weakly developed and related minor Mo orebodies are hosted in this zone; the biotitization is related to late-stage vein composed of quartz and biotite.

According to mineral assemblages and crosscutting relationships of the ore veins, five mineralization stages are identified (Fig. 5). Stage I is characterized by K-feldspar and quartz veins, and wolframite also formed during this stage (Fig. 6a, b). Stage II is an assemblage consisting of quartz, magnetite, and a little molybdenite (Fig. 6c, d). Stage III (main mineralization stage) consists of molybdenite, chalcopyrite, and pyrite, with minor galena and sphalerite (Fig. 6e, f). Stage IV is marked by the formation of calcite and gypsum (Fig. 6g, h). Stage V is characterized by the presence of supergene assemblage, consisting of limonite and malachite.

4. Analytical method

Re–Os isotopic analyses were performed at the National Research Center of Geoanalysis, Chinese Academy of Geosciences. The details of the chemical procedure have been described by Du et al. (1995), Shirey and Walker (1995), Stein et al. (1997), and Markey et al. (1998). They are briefly described here.

The carious tube (a thick-walled borosilicate glass ampoule) digestion technique was used. The weighed sample was loaded in a carious tube through a long thin-neck funnel. The mixed $^{190}$Os and $^{185}$Re spike solution and 2 mL of 10 N HCl and 6 mL of 16 N HNO₃ were added while the bottom part of the tube was frozen at $-80$ to $-50^\circ$C in an ethanol–liquid nitrogen slush; the top was sealed using an oxygen-propane torch. The tube was then placed in a stainless-steel jacket and heated for 10 h at 230$^\circ$C. Upon cooling, the bottom part of the tube was kept frozen, the neck of the tube was broken, and the contents of the tube were poured into a distillation flask and the residue was washed out with 40 mL of water. Separation of osmium by distillation and separation of rhenium by extraction were performed based on the analytical method from Du et al., (1995). A TJA PQ-EXCELL ICP-MS
(Varian Company, Palo Alto, USA) was used for the determination of the Re and Os isotope ratio.

Average blanks for the total carious tube procedure were ca. 10 pg Re and ca. 1 pg Os. The analytical reliability was tested by repeated analyses of molybdenite standard HLP-5 from a carbonate vein-type molybdenum-lead deposit in the Jinduicheng-Huanglongpu area of Shaanxi Province, China. Fifteen samples were analyzed over a period of 5 months. The uncertainty in each individual age determination was about 0.35% including the uncertainty of the decay constant of $^{187}$Re, uncertainty in isotope ratio measurement, and spike calibrations. The average Re–Os age for HLP-5 is 221.3 ± 0.3 Ma (95% confidence limit, Stein et al., 1997). Median age and mean absolute deviation were 221.34 ± 0.12 Ma. The average Re concentration was 283.71 ± 1.54 μg g$^{-1}$. The average Os concentration was 657.95 ± 4.74 ng g$^{-1}$.

5. Results

The concentrations of Re and Os and the osmium isotopic compositions of molybdenite from the Donggebi Mo deposit are shown in Table 2. The total Re and Os concentrations of molybdenite range from 10 to 63 μg g$^{-1}$ and 26 to 155 μg g$^{-1}$, respectively. Model ages for the deposit were calculated assuming that the initial abundance of $^{187}$Os is zero. Isochron ages for all samples from the Donggebi Mo deposit were calculated using Isoplot Model 3 with 2% input error.
The numbers within the brackets in Table 2 are measurement errors, and correspond to the last digit of analytical data in front of the brackets.

A regression analysis was applied to eight analytical data of molybdenite, which yields an isochron age of 234.3 ± 1.6 Ma (2σ) with an initial 187Os of 0.04 ± 0.45 (MSWD = 0.25) (Fig. 7), identical to the mean age (234.4 ± 1.2 Ma, ± 0.50% 2σ, n = 8) calculated from the single sample age determinations (Fig. 8). Model ages for individual analyses range from 233.7 ± 3.2 to 235.6 ± 3.4 Ma (Table 2).

### Table 2 Re–Os isotopic data for molybdenite from the Donggebi Mo deposit, eastern Tianshan

| No. samples | Weight (g) | Re (μg g⁻¹) | Measured 2σ | Measured 187Re (μg g⁻¹) | Measured 2σ | Measured 187Os (μg g⁻¹) | Measured 2σ | Model age (Ma) | Measured 2σ |
|-------------|------------|-------------|-------------|-------------------------|-------------|--------------------------|-------------|---------------|-------------|
| DGB-12      | 0.02052    | 33.12       | 0.27        | 20.82                   | 0.17        | 81.37                    | 0.72        | 234.1         | 3.4         |
| DGB-11      | 0.05004    | 41.97       | 0.31        | 26.38                   | 0.19        | 103.8                    | 0.90        | 235.6         | 3.4         |
| DGB-13      | 0.05056    | 10.92       | 0.09        | 6.862                   | 0.056       | 26.87                    | 0.26        | 234.6         | 3.5         |
| DGB-14      | 0.05018    | 38.24       | 0.32        | 24.03                   | 0.20        | 93.91                    | 0.78        | 234.1         | 3.3         |
| DGB-15      | 0.05008    | 59.27       | 0.52        | 37.25                   | 0.33        | 146.0                    | 1.20        | 234.8         | 3.4         |
| DGB-16      | 0.05012    | 41.03       | 0.34        | 25.79                   | 0.21        | 101.0                    | 0.80        | 234.7         | 3.3         |
| DGB-17      | 0.05025    | 56.39       | 0.45        | 35.44                   | 0.28        | 138.2                    | 1.10        | 233.7         | 3.2         |
| DGB-18      | 0.05015    | 63.18       | 0.56        | 39.71                   | 0.35        | 154.9                    | 1.30        | 233.7         | 3.4         |

Enriched 190Os and 185Re were obtained from the Oak Ridge National Laboratory. Decay constant: \( \lambda (187Re) = 1.666 \times 10^{-11} \text{year}^{-1} \) (Smoliar et al., 1996). The uncertainty in each individual age determination was about 0.35% including the uncertainty of the decay constant of 187Re, uncertainty in isotope ratio measurement, and spike calibration.

6. Discussion

6.1 Age of mineralization

The Re–Os geochronology applied to molybdenite, is remarkably robust, even if overprinted by metamorphism and deformation. If molybdenite does not contain any initial or common Os, all measured Os is monoisotopic (187Os) as the product of decay of 187Re, and the isochron age then represents the depositional age of molybdenite (Suzuki et al., 1996; Brenan et al., 2000; Barra et al., 2003). For the Donggebi Mo ore deposit, the analysis of eight molybdenite samples yields an isochron age of 234.3 ± 1.6 Ma (2σ) with an initial 187Os of 0.04 ± 0.45. It is shown that the initial 187Os values from the molybdenite samples are close to zero and the Re–Os isochron ages reflect the time of sulfide deposition. The Mo mineralization of the Donggebi Mo deposit took place after regional low-grade metamorphism and folding, and was not influenced by later geological events.

The age of mineralization in the eastern Tianshan, reported by some researchers (Li et al., 1998; Mao et al., 2003; Qin et al., 2003; Han et al., 2010), is mainly of Late...
Paleozoic age (330 to 260 Ma; Table 3). Younger mineralization ages from the Indosinian epoch (Mesozoic) have rarely been reported in the literature. However, recent studies indicate that the ages of the Jinwuozi gold deposit are 228–230 Ma (Chen et al., 1999), the Au-bearing quartz vein III of the Shiyingtan gold deposit is 244±9 Ma (Zhang et al., 2003), the Xiaobaishitou W–Mo deposit (20 km northeast of Weiya) is 248 Ma (Li et al., 2004, unpublished data), and the Re–Os ages of molybdenite from the Donggebi Mo deposit in the eastern Tianshan are close to the Re–Os ages (234 Ma) of molybdenite from the Donggebi Mo deposit in the eastern Tianshan, and indicate that the Indosinian period is also an important mineralization epoch in the Eastern Tianshan Orogenic Belt.

6.2 Source of ore-forming metals and tectonic setting

In recent years, the Re contents of the molybdenites have been used to trace the source of ore materials (Mao et al., 1999, 2003, 2006; Stein et al., 2001). The Re content in molybdenites decreases gradually from the mantle source to a mixture of mantle and crust and then to the crustal source (Mao et al., 1999, 2003, 2006; Stein et al., 2001) (Table 3). In addition, Stein et al. (2001) concluded that deposits with the mantle component (mantle underplating, mantle metasomatism, melting of mafic or ultramafic rocks) have higher Re contents, whereas deposits with a crustal origin have lower Re contents associated with molybdenites. In comparison to cited publications for different locations (e.g., Mao et al., 1999, 2003, 2006; Stein et al., 2001), the relatively lower Re contents of molybdenites from the Donggebi Mo deposit that may indicate a mixed (crust+mantle) origin, but crustal components are more dominant.

In the Rb versus Y+ Nb diagram (Pearce et al., 1984; Table 4; Fig. 9), the Donggebi granitic rocks mainly show post-collisional characteristics (Pearce, 1996). The ages of the Mo mineralization (234.3 ± 1.6 Ma) and the corresponding tectonic setting of the Eastern Tianshan belt (Xiao et al., 2004) suggest that the Donggebi Mo deposits formed in the post-collisional setting.
7. Conclusions

The Donggebi porphyry Mo deposit is composed of quartz and sulfide stockwork and veinlets in the Donggebi granitoid. Hydrothermal alteration with potassic, propylitic, and phyllic assemblages are observed. Eight molybdenites from the deposit yielded an isochron age of 234.3 ± 1.6 Ma (2σ) with an initial \(^{187}\text{Os}\) of 0.04 ± 0.45 (MSWD = 0.25), model ages for individual analyses range from 233 to 236 Ma. Combined with the regional geological history, the Donggebi mineralization is concluded to have been closely related to an intracontinental extensional setting.

Table 4: Available geochronological data for ore deposits in the West China

| Name of deposit | Dated minerals/rocks | Dating method | Age/(Ma) | Data sources |
|-----------------|---------------------|---------------|----------|--------------|
| Baishan Re-Mo   | Molybdenite         | Re-Os isochron| 224.8 ± 4.5 | Zhang et al. (2005) |
| Au              | Pyrite              | Re-Os isochron| 225 ± 12  | Zhang et al. (2005) |
| ’               | Pyrite              | Re-Os isochron| 225 ± 12  | Zhang et al. (2005) |
| ’               | Molybdenite         | Re-Os isochron| 229.4 ± 1.7 | Wu et al. (2005) |
| Shuangfengshan  | Plagiogr. porphyry   | SHRIMP        | 235.7 ± 5.5 | Wu et al. (2005) |
| Au              | Quartz abrite       | Rb–Sr         | 226 ± 21  | Wu et al. (2005) |
| ’               | Quartz vein         | Rb–Sr         | 226 ± 44  | Wu et al. (2005) |
| Weiya V-Ti-Fe   | Gabbro              | Sm–Nd         | 220 ± 30  | Wu et al. (2005) |
| ’               | Magnetite           | Sm–Nd         | 220 ± 30  | Wu et al. (2005) |
| ’               | Gabbro              | U–Pb          | 233.4 ± 8.6 | Wu et al. (2005) |
| Xiaobaishitouquan | Biotite garnite    | Rb–Sr         | 244 ± 5   | Wu et al. (2005) |
| W               | Quartz vein         | Rb–Sr         | 228 ± 22  | Wu et al. (2005) |
| Nanjinshan Au   | Sericite            | Ar–Ar         | 242.8 ± 0.8 | Jiang and Nie (2006) |
| ’               | Biotite             | Ar–Ar         | 244.2 ± 0.3 | Jiang and Nie (2006) |
| Hongjianbingshan W | Muscovite         | Ar–Ar        | 216.6 ± 1.6 | Jiang and Nie (2006) |
| ’               | Greisen             | Rb–Sr         | 215.2 ± 2.8 | Jiang and Nie (2006) |

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