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Metallogenic Province Derived from Mantle Sources: Nd, Sr, S and Pb Isotope Evidence from the Central Asian Orogenic Belt

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Abstract

The Central Asian Orogenic Belt (CAOB) is one of the most important regions for Cu, Au and polymetallic and rare metallic (Li, Be, Nb, Ta) mineralization over the world. Most of the ore deposits in the CAOB are closely associated with granitoids. Available Sr, Nd, S and Pb isotopic data indicate that the metallogenic epoch and sources of the mineral deposits in the CAOB are consistent with that of the regional granites. Available data suggest that mantle sources could have played an important role in the Paleozoic to Mesozoic mineralization in the CAOB.

Key words: Central Asian Orogenic Belt, metallogenic province, mantle source, Sr, Nd, S and Pb isotopes.

Introduction

One of the basic problems in metallogeny is to explore the source of ore-forming materials. The study of the genesis of ore deposit from the view point of the source of ore-forming material provides information not only on the enrichment of ore-forming materials, but also reveals the geodynamic setting. The development of modern isotopic determining techniques provide powerful tools for such studies.

The Central Asian Orogenic Belt (CAOB) is one of the most important belts for Cu, Au and polymetallic mineralization, and also for rare metallic (Li, Be, Nb, Ta) mineralization in the world. Most of the mineral deposits are closely associated with granitoids. The purpose of this paper is to examine the signature of mantle-derived materials on the metallogeny in the CAOB, based on the comparison of ages and sources between regional granitoids and mineral deposits on the basis of available Sr, Nd, S and Pb isotopic data.

The CAOB is bounded by the Siberian and Sino-Korean Tarim cratons (Fig. 1). The Paleo-Asian ocean, which provided the framework for the CAOB, was opened at 1000 Ma, and its maximal opening occurred after or simultaneously with the first accretion-collision event at 600–700 Ma, resulting from the collision of microcontinents and the Siberian continent. The ultimate closing of the Paleo-Asian ocean occurred in the late Devonian–early Carboniferous (Dobretsov et al., 1995; Khain et al., 2002).

The CAOB is characterized by very large volumes of granitic rocks emplaced from the early Paleozoic to late Mesozoic, occupying a total area more than 5,000,000 km^2. The available geochronology of granites shows that granitic magmatism began before about 500 Ma, and reached the peak during the ultimate closing of the Paleo-Asian ocean and the collision between the Siberian and Sino-Korean-Tarim plates at the late Devonian–early Carboniferous, and continued during the extentional regime after the collision event (Hong et al., 2000). The granites thus define tectonic settings from subduction type through collision type to post-collisional extensional type. Extensive I-type, S-type and A-type granites are therefore present in this region.

Sm–Nd Isotopic Characteristics of the Granites in the CAOB

Based on available Sm–Nd isotopic data on the granites from eastern Kazakhstan, Altai, eastern and western Junggar, Alatao mountains, Tianshan mountains, Xinjiang, China, Mongolia, Transbaikalia, Russia, Inner Mongolia, northeastern China and coastal area, (Jahn et al., 2000, a,b; Hong et al., 2000), some general characteristics can be summarized as follows:

(1) The voluminous granites are characterized by

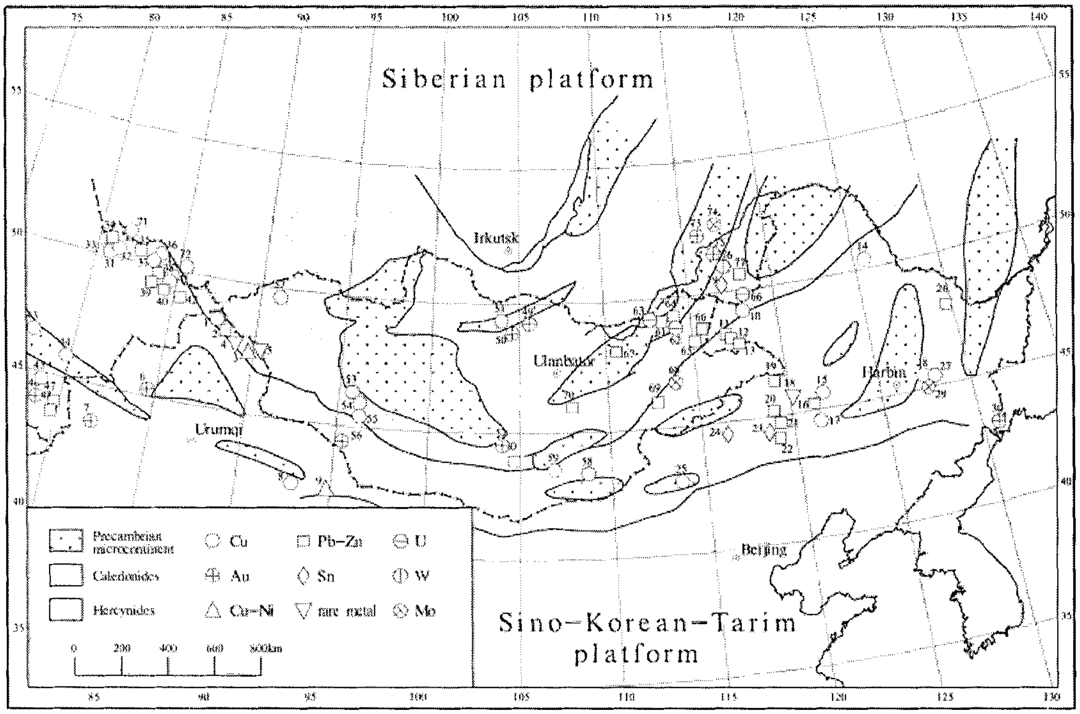

Fig. 1. Tectonic subdivision and distribution of metallic mineral deposits of the Central Asian orogenic belt. Number of the deposits in figure 1 is same to that in table 1.

positive εNd(T) values with limited variation, regardless of the intrusive age (early and late Paleozoic, and Mesozoic), tectonic settings (syn-, late-, post-, and an-orogenic) and granite type (I-, S-, A-, and M-type). This feature indicates that there is little correlation between Nd isotope signature and bulk composition, which in turn suggests restricted contribution of the ancient crustal material (Fig. 2). They are quite different from the Phanerozoic granites from the Caledonian, Hercynian and Himalayan orogenic belts, and the S-type and I-type granites from the Lachlan fold belt, Australia (Fig. 2).

Continental crust is commonly classified as either juvenile (mantle-derived) or evolved (derived at least in part from older enriched crust) on the basis of initial Nd isotopic compositions. Positive εNd is considered to reflect derivation from juvenile sources, whereas negative εNd is interpreted to reflect derivation from evolved sources (Bowring and Housh, 1995). The positive εNd values for granites in the CAOB thus suggest juvenile material derived from a depleted mantle, which is in contrast with other Phanerozoic crust-derived granites characterized by negative εNd values.

The generation of voluminous, compositionally evolved, magmas with sources dominated by primitive mantle-like materials raises obvious petrogenetic questions, but this does not have to be a single-stage process. Both assimilation-fractional crystallization (AFC) models (De Paolo, 1981) and melting- assimilation- storage- homogenization (MASH) models (Hildreth and Moorbath, 1988) can be extended to allow remelting and assimilation of juvenile addition to the crust by successive magma batches over a short time scale.

(2) The T_{DM} values of granites, regardless of their intrusive ages, vary in the range of 500–1000 Ma, with a peak at 700–800 Ma. Compared with other Phanerozoic granites over the world, they show relatively younger T_{DM} values with limited variation. This could indicate the isotopic homogeneity of sources. However, the Nd model ages for the examined granites appear to be older than the crystallization ages of the oldest granitoids (520 Ma, Kovalenko et al., 1996). This suggests that some old crustal material was involved in the granite petrogenesis. It is worthy to consider that the T_{DM} of granites are basically consistent with the ages of the maximal opening of the Paleo- Asian ocean recorded by ancient ophiolite and island-arc complex, if we consider that T_{DM} values can be raised through the hybridization of older crust. It follows that at least a part of these granites (for example, some of the early Paleozoic and early late-Paleozoic) could be related to subduction processes of the Paleo-Asian oceanic crust, and the sources of granites could be subducted oceanic crust and overlying metasomatized mantle wedge (Hong et al., 2000).

(3) Only those granites which intruded into the Precambrian microcontinents, most of which are younger than 300 Ma, show negative εNd values, older $T_{DM,}$ and remarkable scatter of their εNd and T_{DM} values over the

interval between ~200 and ~300 Ma (Kovalenko et al., 1996; Hong et al., 2000). This scatter suggests that the sources of the granites in microcontinents were isotopically heterogeneous. But compared with other typical Phanerozoic crust-derived granites over the world, they have higher εNd values and lower T_{DM}. This feature might suggest that old Precambrian crust was actively involved in the petrogenesis of the granites since about 300 Ma. The data also suggest that the source of granites was still dominated by juvenile mantle material. This is consistent with the general characteristics of the granites in the CAOB.

The ultimate closing of the Paleo-Asian ocean and collision-amalgamation between the Siberian and Sino-Korean-Tarim plates occurred in the late Devonian-early Carboniferous. It could be the most significant tectonic event during the evolution of the Paleo-Asian ocean, marking the primary formation of Laurasia supercontinent (Veevers, 1994; Dobretsov et al., 1995). Because of the significant collision event that occurred about 300 Ma ago, ancient crust was actively involved in the genesis of granites in the microcontinents, characterized by negative εNd values. A large scale extentional regime after the collision provided the tectonic setting for underplating of the mantle-derived material and delamination of lithosphere mantle, resulting in the extensive late Paleozoic-Mesozoic post-orogenic granites with positive εNd values in the CAOB.

(4) εNd values of granites gradually decreased with the decreasing age of the granites, showing a clear evolution trend of Nd isotopic composition. Particularly, Mesozoic granites younger than 200 Ma are characterized by εNd values approaching zero, a common feature for granites in microcontinents and orogenic belts (Kovalenko et al., 1996; Hong et al., 2000). It could be because enhanced recycling of the continental crust resulted from breakup and dispersal of Pangea supercontinent since 200 Ma (Veevers, 1994).

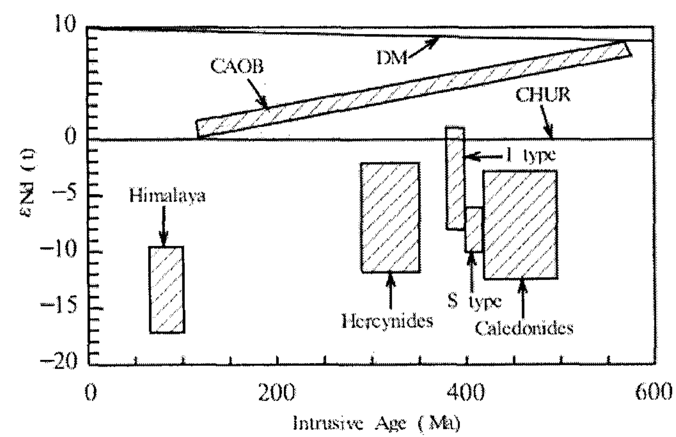

Fig. 2. εNd(T) versus intrusive age plot for the Phanerozoic granites. Data from the following areas: CAOB, from Hong et al. (2000); Caledonides, Hercynides and Himalaya, from Patchett (1992); S- and I-type granites from the Lachlan fold belt, Australia, from McCulloch and Chappell (1982).

Metallic Mineral Deposits Associated with Magmatic Rocks in the CAOB

If voluminous granites in the CAOB were derived from juvenile crust, as mentioned above, it raised the interesting possibility that the ore deposits related to magmatic rocks have close affinity to mantle-derived materials. We summarize the salient features of the major large and medium scale ore deposits related to magmatic rocks in the CAOB in table 1. The distributions of all these ore deposits are shown in figure 1. Major characteristics are summarized below:

(1) The CAOB is characterized by Cu, Au and polymetal mineral deposits, including those of Cu, Au, Mo, Ni, Pb, Zn and Ag among others. These include some of the large ore deposits over the world, for example, Aqtogay porphyry Cu deposits, Arkharly volcanogenic Au deposits, Kazakhstan; Erdenet porphyry Cu deposit, Olon-Ovoot hydrothermal Au deposit, Talin Metts Uul altered crush zone Au deposit, Mongolia; Aselei volcano-sedimentary Cu- Zn deposit, Tuwu porphyry Cu deposit, China, among others. The belt is also characterized by rare metal and radio element mineral deposits, for example, Verkhnee Espe peralkaline granite REE-Zr-Nb deposit, Kazakhstan (Heinhorst et al., 2000); Keketuohai and Kulumutu granitic pegmatite Li-Be-Nb-Ta deposits, Xingjiang; Baerzhe peralkaline granite Nb-Y-Be deposit, central Inner Mongolia, China; Strelizov volcanic U-Mo deposits, Transbaikalia, Russia and Dornot volcanic U-Mo deposits, East Mongolia. Almost all these ore deposits, including massive sulfide deposits, porphyry deposits, continental volcanic deposits, Cu-Ni-sulfide deposits, skarn deposits, hydrothermal deposits and pegmatite deposits, except black shale deposits, are closely associated with magmatism, particularly with granitoids.

(2) Although mineralization in the CAOB started in the late Proterozic (for example, Bainaimiao Cu deposit, Inner Mongolia, China, Table 1) and early Paleozoic (for example, Koktaszhal Cu-Au deposit, Baschekul Cu-Mo deposit, Kusmurum Cu-Zn deposit, Akbastau Cu-Zn deposit, Zhaisan Cu-Mo deposit, Kazakhstan, MMAJ, 1998), the peak period of mineralization occurred in the late Paleozoic and Mesozoic, which is consistent with the peak time of regional granitic magmatism. However, E150° marks the boundary of these occurrences, the mineralization on the west to it is mainly late Paleozoic, whereas the mineralization on the east to it the Mesozoic, which indicate that the former was controlled by the Paleo-

Table 1. Metallic mineral deposits associated with magmatic rocks in the Central Asian orogenic belt.

Mine	Province	Metallogenic elements	Age	Size	Type	Reference
China						
Aselei	Altai, Xinjiang	Cu, Zn	LPZ	L	V-S	Dai Zixi et al. (2001)
Keketale	Altai, Xinjiang	Pb, Zn, Ag, Cu	LPZ	L	V-S	Dai Zixi et al. (2001)
Kalatongke	Altai, Xinjiang	Cu, Ni	LPZ	M	Sul	Dai Zixi et al. (2001)
Keketuohai	Altai, Xinjiang	Li, Be, Nb, Ta	MZ	L	Peg	Wang Denghong et al. (2002)
Kulumutu	Altai, Xinjiang	Li, Be, Nb, Ta	MZ	L	Peg	Wang Denghong et al. (2002)
TuoliQiyiqiu	West Zhungaer, Xinjiang	Au	LPZ	L	Hyd	Dai Zixi et al. (2001)
Axi	West Tianshan Mountain, Xinjiang	Au	LPZ	L	Vol	Dai Zixi et al. (2001)
Tuwu	East Tianshan Mountain, Xinjiang	Cu	LPZ	L	Porp	Dai Zixi et al. (2001)
Huangshan	East Tianshan Mountain, Xinjiang	Cu, Ni	LPZ	M	Sul	Dai Zixi et al. (2001)
Wunugetushan	Deerbugan, Inner Mongolia	Cu, Mo	MZ	L	Porp	Zhao Yiming et al. (1997)
Jiawula	Deerbugan, Inner Mongolia	Ag, Pb, Zn	MZ	L	Sub-Vol	Zhao Yiming et al. (1997)
Chaganbulagen	Deerbugan, Inner Mongolia	Ag, Pb, Zn	MZ	L	Sub-Vol	Zhao Yiming et al. (1997)
Erentaolegai	Deerbugan, Inner Mongolia	Ag, Pb, Zn	MZ	L	Sub-Vol	Zhao Yiming et al. (1997)
Duobaoshan	Heilongjiang	Cu, Mo	LPZ	L	Porp	Zhao Yiming et al. (1997)
Lianhuashan	Xilinhaote, Inner Mongolia	Cu, Ag	MZ	M	Hyd-Porp	Zhao Yiming et al. (1997)
Mengentaolegai	Xilinhaote, Inner Mongolia	Zn, Pb, Ag	MZ	L	Hyd	Zhao Yiming et al. (1997)
Budunhua	Xilinhaote, Inner Mongolia	Cu	MZ	M	Porp-Hyd	Zhao Yiming et al. (1997)
Baerzhe	Xilinhaote, Inner Mongolia	Nb, Y, Be	MZ	L	Alk	Zhao Yiming et al. (1997)
Chaobuleng	Xilinhaote, Inner Mongolia	Fe, Cu, Zn, Bi	MZ	M	Skn	Zhao Yiming et al. (1997)
Haobugao	Xilinhaote, Inner Mongolia	Pb, Zn, Cu, Ag	MZ	L	Skn	Zhao Yiming et al. (1997)
Baiyinnuo	Xilinhaote, Inner Mongolia	Pb, Zn, Cu, Sn	MZ	L	Skn	Zhao Yiming et al. (1997)
Dajing	Xilinhaote, Inner Mongolia	Ag, Pb, Zn, Cu, Sn	MZ	L	Hyd	Zhao Yiming et al. (1997)
Huanggang	Xilinhaote, Inner Mongolia	Sn, Fe	MZ	L	Skn	Zhao Yiming et al. (1997)
Maodeng	Xilinhaote, Inner Mongolia	Cu, Sn	MZ	M	Hyd	Zhao Yiming et al. (1997)
Bainaimiao	Wenduermiao, Inner Mongolia	Cu	PT-EPZ	L	Vol	Nie Fengjun et al. (1993)
Cuihongshan	Zhangguangcailing, Heilongjiang	Pb, Zn	LPZ	L	Skn	Song Shuhe (1992)
Gongpengzi	Zhangguangcailing, Heilongjiang	Cu, Zn	MZ	M	Skn	Song Shuhe (1992)
Bailing	Zhangguangcailing, Heilongjiang	Cu, Zn	MZ	M	Skn	Song Shuhe (1992)
Wangdaoling	Zhangguangcailing, Heilongjiang	Mo	MZ	M		Song Shuhe (1992)
Xiaoxinancha	Jilin-West Liaoning	Au	LPZ	M	Hyd	Song Shuhe (1992)

Table 1. *Contd.*

Mine	Province	Metallogenic elements	Age	Size	Type	Reference
Kazakhstan						
Beryzovskaya	Altai	Cu	LPZ	L	V-S	Dai Zixi et al. (2001)
Belouzovskoe	Altai	Cu, Zn, Pb	LPZ	L	V-S	Dai Zixi et al. (2001)
Nikoraevskaya	Altai	Cu, Zn, Au, Ag	LPZ	L	V-S	Dai Zixi et al. (2001)
Artemievskoe	Altai	Zn, Pb, Cu, Au, Ag	LPZ	L	Hyd	MMAJ, (1998)
Chekmar	Altai	Zn, Pb, Cu, Au, Ag	LPZ	L	Hyd	MMAJ, (1998)
Leninogorsk	Altai	Cu, Zn, Pb, Au, Ag	LPZ	L	V-S	Dai Zixi et al. (2001)
Tishinskiy	Altai	Cu, Zn, Pb, Au	LPZ	L	V-S	Dai Zixi et al. (2001)
Novo-Leninogorskoe	Altai	Zn, Pb, Cu, Au, Ag	LPZ	L	Hyd	MMAJ, (1998)
Obruchevskoe	Altai	Zn, Pb, Cu, Au, Ag	LPZ	L	Hyd	MMAJ, (1998)
Maleevskoe	Altai	Zn, Pb, Au, Ag	LPZ	L	V-S	Dai Zixi et al. (2001)
Zyryanovskaya	Altai	Cu, Zn, Pb	LPZ	L	V-S	Dai Zixi et al. (2001)
Mayskoe	Altai	Zn, Pb, Cu	LPZ	L	Hyd	MMAJ, (1998)
Sayakskaya	Balkhash	Cu, Mo, Au, Ag	LPZ	L	Skn	Dai Zixi et al. (2001)
Aqtogay	Balkhash	Cu, Mo, Au, Ag	LPZ	L	Porp	Dai Zixi et al. (2001)
Koksai	Balkhash	Cu, Mo, Au, Ag	LPZ	L	Porp	Dai Zixi et al. (2001)
Arkharly	Balkhash	Au	LPZ	L	Vol	Dai Zixi et al. (2001)
West Tekel	Balkhash	Zn, Pb	LPZ	M	Hyd	MMAJ, (1998)
Tekel	Balkhash	Zn, Pb	LPZ	M	Hyd	MMAJ, (1998)
Mongolia						
Boroo	North Mongolia	Au		M	Hyd	MMAJ, (1998)
Bumbat	North Mongolia	Au		M	Hyd	MMAJ, (1998)
Erdenet	North Mongolia	Cu, Mo	PZ	L	Porp	MMAJ, (1998)
Olon-Ovoot	South Mongolia	Au	LPZ	M	Hyd	MMAJ, (1998)
ArZuumGol	Gobi-Altai	Cu, Pb, Ag		M	Hyd	MMAJ, (1998)
Shar-tal	Gobi-Altai	Cu, Zn, Pb, Co		M	Hyd	MMAJ, (1998)
Ungii Nuur	Gobi-Altai	Cu, Ag, Zn, Co, Ni			Hyd	MMAJ, (1998)
Talin Metts Uul	Gobi-Altai	Au	LPZ	L	A.C.Z.	Nie Fengjun et al. (2000)
Otol	Gobi-Altai	Cu	LPZ	S	Hyd	Dai Zixi et al. (2001)
Tsagaan-Suvraga	South Mongolia	Cu, Mo, Au	LPZ	L	Porp	MMAJ, (1998)
Shuten-khanbogd	South Mongolia	Cu, Au, Ag	LPZ	M	Mass	MMAJ, (1998)
Khartolgoi	South Mongolia	Pb, Sb, Zn, Ag	PZ	L	Skn	MMAJ, (1998)
Ulaan	East Mongolia	Zn, Pb, Cu, Au, Ag	MZ	M	Hyd	MMAJ, (1998)
Dornot	East Mongolia	U, Mo	MZ	L	Vol	Xiang Weidong et al. (1998)
Gurburak	East Mongolia	U, Mo	MZ	L	Vol	Xiang Weidong et al. (1998)
Mkhar	East Mongolia	Zn, Pb, Ag	MZ	M	Hyd	MMAJ, (1998)
Tsav	East Mongolia	Pb, Zn, Cu, Ag, Au	MZ	L	Hyd	MMAJ, (1998)
Bayan Uul	East Mongolia	Pb, Zn, Au, Ag	MZ	M	Hyd	MMAJ, (1998)
Ondorhaan	East Mongolia	Pb, Zn, Ag	MZ	M	Hyd	MMAJ, (1998)
Arlunnuur	East Mongolia	Mo,W	MZ	L	Hyd	Zhao Yiming et al. (1997)
Tumurtiin	East Mongolia	Zn, Pb	MZ	M	Skn	MMAJ (1998)
Tumurtiin South	East Mongolia	Zn, Pb, Cu, Ag, Mo	MZ	M	Skn	MMAJ (1998)
Russia						
Zminogorskiy	Altai	Cu	LPZ	L	V-S	Dai Zixi et al. (2001)
Crasnoiarskiy	Altai	Cu	LPZ	M	Hyd	Dai Zixi et al. (2001)
Darason	Argun	Au	MZ	L	Hyd	Zhao Yiming et al. (1997)
Tslekan	Argun	Mo	MZ	L	Hyd	Zhao Yiming et al. (1997)
Balei	Argun	Au	MZ	L	Hyd	Zhao Yiming et al. (1997)
Bugdain	Argun	W, Mo	MZ	L	Hyd	Zhao Yiming et al. (1997)
Noion-Talog	Argun	Pb, Zn, Ag	MZ	L	Vol	Xiang Weidong et al. (1998)
Strelizov	Argun	U, Mo	MZ	L	Vol	Xiang Weidong et al. (1998)
Scherlovogor	Argun	Sn, W	MZ	L	Grs-Hyd	Xiang Weidong et al. (1998)

Abbreviation: 1. Deposit type: A.C.Z.–Altered crush zone, Grs–Grseisen, Hyd–Hydrothermal, Mass–Massive, Peg–Pegmatite, Porp–Porphyry, Skn– Skarn, Sul–Cu-Ni sulfide, Sub-Vol–Subvolcanogenic, Vol–Volcanogenic, V-S–Volcano-sedimentary. 2. Deposit size: L–Large, M–Medium, S–Small; 3. Geologic age: LPZ–Late Paleozoic, MZ–Mesozoic, PT–Proterozoic, PZ–Paleozoic.

Asian oceanic tectonic domain, whereas the latter was strongly impressed by the Pacific oceanic tectonic domain. It is important to note that the distribution of continental volcanic Au deposits is restricted in the Mesozoic- Cenozoic circum Pacific oceanic and Tetys belts, but the late-Paleozoic continental volcanic Au deposits were discovered in the CAOB, for example, Axi, Xinjiang, China (Table 1); Kochbulak, Uzbekistan (MMAJ, 1998). These deposits have been fundamental to mineral economy and theoretical studies on metallogeny (Tu Guangzhi, 1999).

(3) From the view point of metallogenic element association, Cu, Au and polymetallic mineralization are distributed over whole region in the CAOB, but the characteristics of mineralization varies widely in different regions from west to east. The mineralization in Altai, eastern Kazakhstan is characterized by Cu, Au deposits, including a series of large and very large ore deposits. In Xinjiang, China, it is characterized by Li-Be-Nb-Ta mineralization (for example, Keketuohai and Kulumutu) and Cu-Ni deposits (for example, Kalatongke and Huangshan). In eastern Mongolia-Argun, it is characterized by Cu, Pb, Zn, Ag deposits, and Cu-Sn association (for example, Huanggang, Maoden, Dajing and Haobugao, Inner Mongolia, China), U-Mo association (for example, Strelizov, Russia and Dornot, Mongolia) and Nb-Y-Be association (for example, Baerzhe, Inner Mongolia, China). The Xilinhaote- Ganzhuermiao Sn-Cu polymetallic mineralization zone, located in the southern Da Hinggan Mountains, is the sole Sn-mineralization zone ever found in north China, the Huanggang Sn deposits in which is the only known largest scale Sn deposits in north China. Comparing with the famous tin deposits in south China, for example, Dachang, Guangxi, Gejiu, Yunnan and Qitianling, Hunan, the Huanggang deposit is characterized by association with Cu. An identical situation exists in the W-Sn deposits, Argun-Heilongjiang mineralization zone, Russia, for example, the Bugdain and Seherlovogor deposits (Zhao Yiming and Zhang Dequan, 1997). Cu, Au, Ni are the typical metallogenic elements in the metallogenic province derived from the mantle, whereas W, Sn, U represent the typical association in metallogenic provinces derived from the crust. Sn-Cu and U-Mo mineralization in the eastern part of the CAOB could have resulted from different metallogenic sources.

(4) The distribution of ore deposits in the CAOB is also characterized with spatially concentrated specific tectono-magmatic zones, for example, Altai, Balkhash-Ili, Argun-Heilongjiang, Xilinhote-Ganzhuermiao among others.

Isotopic Characteristics of Metallic Mineral Deposits

Sr and Nd isotope composition of ore-bearing rocks associated with the metallic mineral deposits are compiled in table 2. The inferences drawn from the data are as follows:

(1) Most of initial Sr isotipe ratio (I_{Sr}) of ore-bearing rocks are below 0.706, and most of εNd values are positive, which are consistent with the general characteristics of regional granitoids as mentioned in a previous section. These feature indicate that the ore-bearing rocks were almost all derived from mantle sources. Even I_{Sr} values of the fluid inclusion have similar isotopic characteristics, which indicate that ore-bearing fluids preserve the mantle derived nature inherited from magmatic sources. Although some granitoids related to W, Sn and rare-metallic mineratization have higher I_{Sr} values (0.711–0.728), they still have higher and even positive εNd values, which suggest the marked influence of mantle-derived materials. Only some of the ore-bearing rocks which occur in microcontinent show negative εNd values, for instance, Bainaimiao Cu-deposit, Inner Mongolia, China, and some rare metal, W-Sn deposits, Transbaikalia, southern Gorny Altai, Russia. These data are also consistent with the characteristics of granitoids in the regions.

(2) Ore-bearing rocks, particularly granites associated with W, Sn and rare metal mineralization, are generally strongly fractionated, but their isotopic characteristics are consistent with regional granites without the influence of magmatic fractionation and mineralization.

(3) Although the duration of metallogeny in the CAOB spans a large spectrum, the Sr, Nd isotopic system of the ore-bearing rocks are seen to be within a narrow arrange, even their chemical compositions have a large arrangements. We interpret this to indicate that all ore-bearing rocks have isotopically similar sources from the early Paleozoic to Mesozoic. Similar to the regional granitoids, εNd values of the ore-bearing rocks show gradual decrease with the decreasing age of the rocks. Particularly, the Mesozoic ore-bearing rocks younger than 200 Ma are characterized by εNd values approaching zero, indicating that the ore-bearing rocks had origin similar to regional granitoids, both of which were derived from the mantle, and influenced by continental recycling process after about 200 Ma.

S and Pb isotope composition of nonferrous and precious metallic ore deposits in northern Xinjiang and Xinggan Mountains, China are presented in table 3 and table 4, respectively. Sulfur and lead isotopes are usually used as important tracers to discuss sources of hydrothermal fluid and metallogenic elements for ore deposits.

Most of ore-deposits in northern Xinjiang and Xinggan mountains are characterized by a narrow range in sulfur isotope composition, with $\delta^{34}S$ values of sulfides ranging from 1.5‰ to 4.3‰ (Fig. 3), average approaching to zero

Table 2. Sr and Nd isotope of the ore-bearing rocks in the Central Asian orogenic belt.

	Mine	Ore-bearing rocks	Age (Ma, determining method)	I_{Sr}	εNd	Reference
Xinjiang, China						
Altai	Ashele -Cu-Zn	altered dacitic breccia tuff	290.8±5 (Rb-Sr)	0.7087		Li Huaqing et al. (1998)
		dacite porphyry	296±10 (Rb-Sr)	0.7061	+2.5-+4.4	Li Huaqing et al. (1998)
		sub-rhyolite porphyry	294±38 (Rb-Sr)	0.7063	+4.4	Li Huaqing et al. (1998)
		jaspilite	378.3±39 (Rb-Sr)	0.7086	+1.52-+1.9	Li Huaqing et al. (1998)
		granodiorite	360±11 (Rb-Sr)	0.7060	+0.9-+1.2	Li Huaqing et al. (1998)
		spilite			+6.7-+8.1	Li Huaqing et al. (1998)
	Suoerkuduke -Cu-Mo	altered andesite	288.3±17.6 (Rb-Sr)	0.7046±4	+5.4-+5.9	Li Huaqing et al (1998)
	Duonalasayi -Au	tonalite	289±5 (U-Pb)	0.7069-0.7079		
		quartz-diorite porphyry	371±22 (Pb -Pb)			Li Huaqing et al. (1998)
		plagiogranite dyke	352.5±40 (Rb-Sr)	0.7058-0.7074		Li Huaqing et al. (1998)
		fluid inclusion of quartz vein	269.0±13 (Rb-Sr)	0.7043±1		Li Huaqing et al. (1998)
	Saidu-Au	biotite-granite	275.87±21 (Rb-Sr)	0.7076±1		Li Huaqing et al. (1998)
		fluid inclusion of quartz vein	272±19 (Rb-Sr)	0.7116±3		Li Huaqing et al. (1998)
	Saerbulake -Au	rhyolite porphyry	292.1±7.3 (Rb-Sr)	0.7033±19		Li Huaqing et al. (1998)
		fluid inclusion of quartz vein	285±43 (Rb-Sr)	0.7051±1		Li Huaqing et al. (1998)
	Kalatongke -Cu-Ni	basic-ultrabasic rocks	297.7±11 (Sm-Nd)		+6.0	Li Huaqing et al. (1998)
	Keketale -Pb-Zn	metarhyolite breccia tuff lava	358.0±9.9 (Rb-Sr)	0.70790±75		Zhou Gang et al. (1998)
	Shangkelan -Nb-Ta-Be	myscovite-albite granite	181±9.2 (Rb-Sr)	0.70494±65		Chen Fuwen et al. (1999a)
		fluid inclusion	177±17 (Rb-Sr)	0.70494±65		Chen Fuwen et al. (1999a)
		myscovite-albite granite	176.1±12.9 (Rb-Sr)	0.70483±1365		Zhang Qianfeng et al. (1994)
	Dahalasu -Nb-Ta	biotite syenogranite	221.7 (Rb-Sr)	0.7064		Wang Zhonggang et al. (1998)
	Jiangjunshan -Nb-Ta	amazonite-bearing granite	227 (Rb-Sr)	0.7110		Wang Zhonggang et al. (1998)
West Zhungaer	Hatu-Au	tuff	320±56 (Rb-Sr)	0.7054±1		Li Huaqin et al. (1998)
		syenoganite	285±11 (Rb-Sr)	0.7059±2		Li Huaqin et al. (1998)
		alkali-feldspar granite	298±4 (Rb-Sr)	0.7062±9		Li Huaqin et al. (1998)
		fluid inclusion of quartz vein	290±1 (Rb-Sr)	0.7048±1		Li Huaqin et al. (1998)
			288±12 (Rb-Sr)	0.7050±1		Li Huaqin et al. (1998)

Table 2. *Contd.*

	Mine	Ore-bearing rocks	Age (Ma, determining method)	I_{Sr}	εNd	Reference
East Zhungaer	Buerkesidai -Au	andesite	347 (Rb-Sr)	0.7037	+7.96	He Bochu et al. (1994)
		alkali-feldspar granite	314 (Rb-Sr)	0.7046	+5.65	He Bochu et al. (1994)
		diabase porphyry	329 (Rb-Sr)	0.7037	+6.06	He Bochu et al. (1994)
		quartz-albite porphyry	294±5 (Rb-Sr)	0.70454±47		Wang Denghong et al. (2002)
	Taste-Au	amphibole monzogranite	320.3±8.6 (Rb-Sr)	0.70454±47		Zhou Gang et al. (1999)
	Sareshcke-Sn	peralkaline	290±11 (U-Pb)		+7.31	Bi Chengsi et al. (1993)
		granite	290±11 (U-Pb)		+6.43	this paper
			290±11 (U-Pb)		+3.73	this paper
	Beilekuduke-Sn	biotite granite	313±18 (U-Pb)		+6.79	this paper
	Hongtujingzi-Sn	biotite granite	297.3±3.8 (U-Pb)		+7.51	this paper
					+5.84	this paper
	Kamusite-Sn	biotite granite	276.6±4.6 (U-Pb)		+8.52	this paper
					+5.42	this paper
	Ganliangzi-Sn	peralkaline granite	307±20 (Rb-Sr)	0.70232±854		Chen Fuwen et al. (1999b)
		fluid inclusion of quartz vein	305±25 (Rb-Sr)	0.70766±145		Chen Fuwen et al. (1999b)
West Tianshan mountain	Axi-Au	andesite	345.9±9 (Rb-Sr)	0.7057±14		Li Huaqin et al. (1998)
		albite porphyry	331±8 (Rb-Sr)	0.7059±9		Li Huaqin et al. (1998)
		andesite porphyrite	289±15 (Rb-Sr)	0.7076±1		Li Huaqin et al. (1998)
		fluid inclusion of quartz vein	340±8 (Rb-Sr)	0.7062±2		Li Huaqin et al. (1998)
			311.5±14 (Rb-Sr)	0.7069±4		Li Huaqin et al. (1998)
	Nileke-Cu	basalt	298±7 (Rb-Sr)	0.7050±1	+3.5-+5.8	Li Huaqin et al. (1998)
		quartz albite porphyry	247.8±5 (Rb-Sr)	0.7054±1	+0.8-+0.9	Li Huaqin et al. (1998)
	Kekenaier Cu-bearing pyrite	quartz keratophyre	425.3±5 (Rb-Sr)	0.70577±1		Li Huaqin et al. (1998)
East Tianshan mountain	Kangguertage -Au	altered andesite	290±5 (Rb-Sr)	0.7099±2	+2.6-+3.2	Li Huaqin et al. (1998)
		altered rhyolite	300±13 (Rb-Sr)	0.7079±3	+0.2-+0.6	Li Huaqin et al. (1998)
		tonalite	248±1 (Rb-Sr)	0.7043±1	+0.3-+3.6	Li Huaqin et al. (1998)
		fluid inclusion of quartz vein	282.3±5 (Rb-Sr)	0.7077±2		Li Huaqin et al. (1998)
			258±21 (Rb-Sr)	0.7106±3		Li Huaqin et al. (1998)
	Xifengshan -Au	monzogranite	284±13 (Rb-Sr)	0.7061±1		Li Huaqin et al. (1998)
		fluid inclusion of quartz vein	272±3 (Rb-Sr)	0.7070±1		Li Huaqin et al. (1998)
	Yuxi-Ag	mylonitic granite	266.7±4 (Rb-Sr)	0.7071±3		Li Huaqin et al. (1998)
	Shiyingtan -Au	andesite	285±12 (Rb-Sr)	0.7046±1		Li Huaqin et al. (1998)
		granite porphyry	266±3 (Rb-Sr)	0.7054±1		Li Huaqin et al. (1998)
		rhyolitic ignimbrite	256.8±13.6 (Rb-Sr)	0.7074±4		Li Huaqin et al. (1998)
		tonalite	293±1 (Rb-Sr)	0.7039±1		Li Huaqin et al. (1998)
		fluid inclusion of quartz vein	288±7 (Rb-Sr)	0.7049±1		Li Huaqin et al. (1998)
			276±7 (Rb-Sr)	0.7051±1		
			244±9 (Rb-Sr)	0.7059±1		

Table 2. *Contd.*

Mine	Ore-bearing rocks	Age (Ma, determining method)	I_{Sr}	εNd	Reference
Huangshan -Cu-Ni	basic -ultrabasic rocks	308.9±10.7 (Sm-Nd)		+6.6	Li Huaqin et al. (1998)
East Huangshan -Cu-Ni	basic-ultrabasic rocks	320±38 (Sm-Nd)		+7.8	Li Huaqin et al. (1998)
Tuwu-Cu	rhyolite	416±120 (Sm-Nd)		+5.6	Rui Zongyao et al. (2002)
	dacite	416		+8.8	Rui Zongyao et al. (2002)
	ore-bearing andesite	416		+8.8	Rui Zongyao et al. (2002)
	ore-bearing basalt-	416		+8.0	Rui Zongyao et al. (2002)
	trachyte			+8.3	Rui Zongyao et al. (2002)
	ore-bearing trachyte-	416		+8.2	Rui Zongyao et al. (2002)
	andesite-basalt			+8.6	
	altered	369±69 (Rb-Sr)	0.70328±32	-1.4	Rui Zongyao et al. (2002)
	plagiogranite	369±69 (Rb-Sr)		+7.4	Rui Zongyao et al. (2002)
	porphyry	369±69 (Rb-Sr)		+9.4	Rui Zongyao et al. (2002)
		369±69 (Rb-Sr)		+7.2	Rui Zongyao et al. (2002)
		369±69 (Rb-Sr)		+7.0	Rui Zongyao et al. (2002)
		369±69 (Rb-Sr)		+8.3	Rui Zongyao et al. (2002)
		369±69 (Rb-Sr)		+6.2	Rui Zongyao et al. (2002)
Heilongjiang, China					
Duobaoshan-Cu-Mo	granodiorite	292 (K-Ar)	0.7037-0.7054	+2.66	Du qi (1988)
				+6.70	Wu Fuyuan et al. (1999)
				+3.58	Wu Fuyuan et al. (1999)
Tongshan-Cu-Mo	granodiorite	310 (Rb-Sr)	0.7040±1	+7.11	Zhao Yuanli et al. (1997)
				+3.56	Wu Fuyuan et al. (1999)
				+3.90	Wu Fuyuan et al. (1999)
Inner Mongolia, China					
Wulugetushan-Cu-Mo	biotite monzogranite	211±21 (Rb-Sr)	0.70617±53		Qin Kezhang et al. (1998)
Jiawula-Ag-Pb-Zn	granodiorite	225.4±7.9 (Rb-Sr)	0.70533±14		Qin Kezhang et al. (1998)
Xiaobaliang-Cu-Au	gabbro, spilite, tuff	243±15 (Rb-Sr)	0.7049±2		Chen Deqian et al. (1995)
Mengsentaolegai-Ag -Pb-Zn	monzogranite	246.79 (Rb-Sr)	0.7039		Sheng Jifu et al. (1999)
Haregentai-ilmenite	monzogranite	278 (Rb-Sr)	0.7051		Zhao Yiming et al. (1997)
Baiyinnuo-Pb-Zn	granodiorite porphyry	171 (Rb-Sr)	0.7056		Zhao Yiming et al. (1997)
	acidic tuff	160(Rb-Sr)	0.7077		Zhao Yiming et al. (1997)
Huanggang-Sn-Fe	syenogranite-alkali feldpar granite	142.05(Rb-Sr)	0.7028		Zhao Yiming et al. (1997)
Maodeng-Cu -Sn	granite porphyry	149 (Rb-Sr)	0.70501		Zhao Yiming et al. (1997)
Aonaodaba-Ag-Sn-Cu	granite porphyry	148.30 (Rb-Sr)	0.708		Zhao Yiming et al. (1997)
Anle-Sn-Cu	granite porphyry	134.2±20.7 (Rb-Sr)	0.7018±40		Wang Guozheng (1997)
Haobugao-Pb-Zn-Cu	syenogranie	131.2 (Rb-Sr)	0.7077		Zhang Dequan (1993)
Dongshanwan-Sn	granite porphyry	134.7 (Rb-Sr)	0.7096		Zhang Dequan (1993)

Table 2. *Contd.*

	Mine	Ore-bearing rocks	Age (Ma, determining method)	I_{Sr}	εNd	Reference
	Budunhua-Cu	plagiogranite porphyry	166±2 (Rb-Sr)	0.7055		Sheng Jifu et al. (1993)
	Berzhe-Nb-Y-Be	peralkaline granite	127.2 (Rb-Sr)	0.7071	+2.44	Zhang Dequan (1993)
			127.2 (Rb-Sr)		+2.36	Wang Yixian et al. (1997)
			127.2 (Rb-Sr)		+2.14	Wang Yixian et al. (1997)
			127.2 (Rb-Sr)		+2.50	Wang Yixian et al. (1997)
			127.2 (Rb-Sr)		+2.20	Wang Yixian et al. (1997)
			127.2 (Rb-Sr)		+1.93	Wang Yixian et al. (1997)
	Biliutai-Au	syenodiorite	200±10 (Rb-Sr)	0.70442±140	+4.62	Zhu et al. (2001)
			200±10 (Rb-Sr)		+4.79	Zhu et al. (2001)
			200±10 (Rb-Sr)		+4.50	Zhu et al. (2001)
			200±10 (Rb-Sr)		+4.80	Zhu et al. (2001)
			200±10 (Rb-Sr)		+4.17	Zhu et al. (2001)
			200±10 (Rb-Sr)		+3.32	Zhu et al. (2001)
			200±10 (Rb-Sr)		+3.21	Zhu et al. (2001)
	Bainaimiao-Cu	amphibole granite	459±2.9 (U-Pb)		-3.76	this paper
			459±2.9 (U-Pb)		-4.21	this paper
			459±2.9 (U-Pb)		-2.63	this paper
			459±2.9 (U-Pb)		-3.38	this paper
		quartz diorite	454±14 (U-Pb)		-2.67	this paper
			454±14 (U-Pb)		-1.36	this paper
			454±14 (U-Pb)		-3.78	this paper
Mongolia						
North Mongolia	Erdenet-Cu-Mo	early stage granite porphyry	253±18 (Rb-Sr)	0.70416±8		Sotnikov et al. (1995)
		late stage granite porphyry	221±14 (Rb-Sr)	0.70412±8		Sotnikov et al. (1995)
Central Mongolia	Dzanchivlan rare metal	leucogranite	195.3±0.6	0.7063±22	+0.5-+1.2	Kovalenko et al. (1999)
	Ongon Haierhan rare metal	ongonite	128.3±0.8	0.7060±22		Kovalenko et al. (1999)
	Baga-Gazrin rare metal	biotite granite	202	0.7112±11	+1.9	Kovalenko et al. (1999)
East Mongolia	Borun-tsogtin rare metal	amazonite granite	125	0.709-0.713	+1.8	Kovalenko et al. (1997)
	South Zirsk -W-Mo	leucogranite	282 (U-Pb)	0.7148	+1.60	Kovalenko et al. (1999)
		amazonite-albite granite	282 (U-Pb)	0.7280	+1.36	Kovalenko et al. (1999)
		granite porphyry	157	0.7117	+0.82	Kovalenko et al. (1999)
		biotite granite	200	0.7083	+0.57	Kovalenko et al. (1999)
		biotite granite	157	0.7056	+0.44	Kovalenko et al. (1999)
		biotite granite	162	0.7083		Kovalenko et al. (1999)
West Mongolia	Kyzyl-Tauy, Altai-Mo-W	biotite granite	189±20 (Rb-Sr)	0.7056±28		Kozlov et al. (1995)
		leucogranite	180±15(Rb-Sr)	0.7286±135		Kozlov et al. (1995)
	Khaldzan-Buregtey, Kobdo -Nb-Zr-REE	peralkaline granite	376±11(Rb-Sr)	0.7044±1	+6.48	Kovalenko et al. (1992)
			376±11(Rb-Sr)		+5.80	Kovalenko et al. (1992)
			376±11(Rb-Sr)		+7.00	Kovalenko et al. (1992)
			376±11(Rb-Sr)		+7.67	Kovalenko et al. (1992)
		nordmarkite	376±11(Rb-Sr)		+2.76	Kovalenko et al. (1992)
		rare metal	374±36 (Rb-Sr)	0.7043	+5.01	Kovalenko et al. (1992)

Table 2. *Contd.*

	Mine	Ore-bearing rocks	Age (Ma, determining method)	I_{Sr}	εNd	Reference
		peralkaline granite	374±36 (Rb-Sr)		+4.33	Kovalenko et al. (1992)
			374±36 (Rb-Sr)		+4.79	Kovalenko et al. (1992)
			374±36 (Rb-Sr)		+5.43	Kovalenko et al. (1992)
			374±36 (Rb-Sr)		+5.70	Kovalenko et al. (1992)
			374±36 (Rb-Sr)		+5.70	Kovalenko et al. (1992)
		pantellerite	374±36 (Rb-Sr)		+4.87	Kovalenko et al. (1992)
			374±36 (Rb-Sr)		+5.49	Kovalenko et al. (1992)
			374±36 (Rb-Sr)		+5.02	Kovalenko et al. (1992)
			374±36 (Rb-Sr)		+5.62	Kovalenko et al. (1992)
		Granite	374±36 (Rb-Sr)		+2.68	Kovalenko et al. (1992)
		Leucite basalt	374±36 (Rb-Sr)		+4.33	Kovalenko et al. (1992)
		dolerite	374±36 (Rb-Sr)		+2.76	Kovalenko et al. (1992)
Russia						
Traanbaikalia	Betsimian rare metal	amazonite granite	265 (Rb-Sr)	0.700	-6.9	Kovalenko et al. (1999)
	Haragul rare metal	amazonite granite	317± 7 (Rb-Sr)	0.711±16	-1.2--2.7	Kovalenko et al. (1999)
	Ermakov Be	granite	283±30 (Rb-Sr)	0.7059±4		Lykhin et al. (2001)
		Syenite-alkaline granite	224±5 (Rb-Sr)	0.7056±5		Lykhin et al. (2001)
		leucogranite	224±1.3 (Rb-Sr)	0.70658±10		Lykhin et al. (2001)
Chita	Orlov rare metal	amazonite granite	142.9±1.8 (Rb-Sr)	0.706±5	+0.1	Kovalenko et al. (1999)
	Hangilai rare metal	amazonite granite	142		-1.3	Kovalenko et al. (1999)
	Soktui rare metal	biotite granite	142		-0.1	Kovalenko et al. (1999)
	Atinkin rare metal	amazonite granite	142		+1.4	Kovalenko et al. (1999)
	Ari-Bulak rare metal	ongonite	142		-0.9	Kovalenko et al. (1999)
Southern Gorny Altai	Chindagatui -W-Mo	leucogranite	199±0.8 (Rb-Sr)	0.7122±2	-4.08--4.35	Vladimirov et al. (1998)
		spodumene-bearing granite			-3.29--4.99	Vladimirov et al. (1998)
	Kungurdzharin -W	leucogranite			-2.33--2.53	Vladimirov et al. (1998)
	Kalgutin -W-Mo	biotite granite	204±1.5 (Rb-Sr)	0.7069±2		Vladimirov et al. (1998)
Northern Altai	Savvushkino -Sn-W	leucogranite	241±4.5 (Rb-Sr)	0.7051±4		Vladimirov et al. (1997)
	Belokurikha -Sn-W	granite	245±8 (Rb-Sr)	0.7071±6		Vladimirov et al. (1997)
	Arisky-Sn-W	leucogranite	244.3±5.3 (Rb-Sr)	0.7058±4		Vladimirov et al. (1997)
	Karakol-Sn-W	leucogranite	241 (Rb-Sr)	0.7061		Vladimirov et al. (1997)
Kazakhstan						
	Aksu-Au	quartz monzodiorite	450	0.70505	3.49	Heinhorst et al. (2000)
				0.70754	3.53	Heinhorst et al. (2000)
		porphyritic granodiorite	450	0.70546	3.13	Heinhorst et al. (2000)
				0.70545	3.12	Heinhorst et al. (2000)
		hornblende gabbro	450	0.70475	2.83	Heinhorst et al. (2000)
		granite	450	0.70635	2.82	Heinhorst et al. (2000)

Table 2. *Contd.*

Mine	Ore-bearing rocks	Age (Ma, determining method)	I_{Sr}	εNd	Reference
Stepnyak -Au	hornblende gabbro	450	0.70809	0.04	Heinhorst et al. (2000)
	quartz monzodiorite	450	0.71277	-0.76	Heinhorst et al. (2000)
Dollinye -Au	gabbro	300	0.70435	5.54	Heinhorst et al. (2000)
	porphyritic granodiorite	300	0.70541	4.52	Heinhorst et al. (2000)
	porphyritic monzodiorite	300	0.70472	5.54	Heinhorst et al. (2000)
	quartz diorite	300	0.70502	4.95	Heinhorst et al. (2000)
	quartz diorite	300	0.70551	5.32	Heinhorst et al. (2000)
Aqtogay -Cu	porphyritic granodiorite	300	0.70964	5.58	Heinhorst et al. (2000)
	granodiorite	300	0.70798	4.45	Heinhorst et al. (2000)
	granite	300	0.71380	5.41	Heinhorst et al. (2000)
	porphyry stock	300	0.70622	2.86	Heinhorst et al. (2000)
	granophyre	300	0.70710	5.94	Heinhorst et al. (2000)
Kounrad -Cu	hornblende granodiorite	325		0.72	Heinhorst et al. (2000)
Nurataldy rare metal	leucogranite	330		2.03-0.88	Heinhorst et al. (2000)
Batystau rare metal	leucogranite	310		-0.59- -0.43	Heinhorst et al. (2000)
Bektauata rare metal	leucogranite	290		0.89	Heinhorst et al. (2000)
Kounrad East rare metal	aplite	295		1.62	Heinhorst et al. (2000)
Aqshatau rare metal	leucogranite	285		0.75- -3.03	Heinhorst et al. (2000)
Verkhnee Espe REE	riebeckite granite	250		7.86-5.28	Heinhorst et al. (2000)

Table 3. S isotope of sulfide in metallic mineral deposits from northern Xinjiang and Hinggan Mountains.

	Mine	Sample number	$\delta^{34}S$‰ Range	Maximium difference	Average	Reference
North Xinjiang	QiqiuI-Au	14	-0.3–+0.7	2	0.9	Li Huaqin et al. (1998)
	Qiqiu II-Au	20	-1.5–+3.0	4.5	0.99	Li Huaqin et al. (1998)
	Kuogeshaye-Au	22	-0.8–+3.6	4.4	2.15	Li Huaqin et al. (1998)
	SaertuohaiI-Au	11	+2.3–+4.3	2	3.3	Li Huaqin et al. (1998)
	Jinwuozi-Au	30	-1.4–+8.4	9.8	5.4	Li Huaqin et al. (1998)
	Nanjinshan-Au	3	-0.4–+5.9	6.3	3.1	Li Huaqin et al. (1998)
	Xiaomazhuangshan-Au	3	-3.2–+5.6	8.8	1.7	Li Huaqin et al. (1998)
	Duonalasayi-Au	12	-7.02–-2.46	4.56	-3.86	Li Huaqin et al. (1998)
	Saerbulake-Au	11	-6.1–+1.2	7.30	-1.32	Li Huaqin et al. (1998)
	Kangguertage-Au	9	-0.9–+3.3	4.2	0.06	Li Huaqin et al. (1998)
	Axi-Au		+0.9–+4.3	5.2		Li Huaqin et al. (1998)
	Jinshangou-Au		-0.7–+3.5	4.2	1.9	Li Huaqin et al. (1998)
	Kalatongke-Cu-Ni	29	-1.1–+0.8	1.9	-0.3	Li Huaqin et al. (1998)
	Huangshan-Cu-Ni	5	-0.2–+0.9	1.1	0.3	Li Huaqin et al. (1998)
	East Huangshan-Cu-Ni	24	-0.8–+2.8	3.6	0.8	Li Huaqin et al. (1998)
	Jingbulake-Cu-Ni	3	0.3–1.2	1.5	0.6	Li Huaqin et al. (1998)
	Lamasu-Cu-Ni	2	3.1–5.5	2.4	4.3	Li Huaqin et al. (1998)
	Caihuagou-Cu	10	-1.5–3.5	5.0	2.6	Li Huaqin et al. (1998)
	Ashele-Cu-Zn	88	2.2–7.63	5.43	4.06	Li Huaqin et al. (1998)
	Suoerkuduke-Cu-Mo		-1.77– -10.17	8.4	-3.87	Li Huaqin et al. (1998)

Table 3. *Contd.*

	Mine	Sample number	Range	$\delta^{34}S$‰ Maximium difference	Average	Reference
	Maanqiao-Pb-Zn	8	-11.8 – -0.2	11.6	-5.4	Li Huaqin et al. (1998)
	Tonghuashan-Pb-Zn	5	-23.4 – -27.8	4.4	-25.4	Li Huaqin et al. (1998)
	Tiemuerte-Pb-Zn	6	+3.4 – -23.2	26.8	-7.75	Li Huaqin et al. (1998)
	Keketale-Pb-Zn	48	-4.1– -15.3	11.2	-10.4	Li Huaqin et al. (1998)
	Sawayeerdun-Au-Sb	14	-3.0–+1.3	4.3	-0.42	Ye Qingtong et al. (1999)
Heilogjiang	Duobaoshan-Cu-Mo	234	-5.2–+3.3	8.5	-0.77	Zhao Yiming et al. (1997)
	Tongshan-Cu-Mo	41	-3.3–+1.6	4.9	-0.39	Zhao Yiming et al. (1997)
	Sankuanggou-Cu-Au	11	-1.0–+1.5	2.5	0.45	Zhao Yiming et al. (1997)
	21th zhan-Cu-Au	3	+1.2–+2.0	0.8	1.60	Zhao Yiming et al. (1997)
Central Inner Mongolia	Xieertala–Fe-Zn	110	-0.3–+15.9	16.2	7.33	Zhao Yiming et al. (1997)
	Wulugetushan-Cu-Mo	53	-0.2–+4.2	4.4	2.38	Zhao Yiming et al. (1997)
	Badaguan -Cu-Mo	15	0.5–+4.8	4.3	2.64	Zhao Yiming et al. (1997)
	Jiawula-Ag-Pb-Zn-Cu	71	-2.9–+4.0	6.9	2.60	Zhao Yiming et al. (1997)
	Chaganbulagen-Ag-Pb-Zn	25	-4.0–+5.1	9.1	2.57	Zhao Yiming et al. (1997)
	Erentaolegai-Ag	15	-4.0–+4.1	8.1	2.37	Zhao Yiming et al. (1997)
	Lianhuashan-Cu-Ag	32	-1.4 –+3.3	4.7	1.45	Zhao Yiming et al. (1997)
	Naoniushan-Cu	9	-0.3–+2.5	2.8	1.46	Zhao Yiming et al. (1997)
	Budunha-Cu	36	-2.6–+1.5	4.1	-0.89	Zhao Yiming et al. (1997)
	Changchunling-Pb-Zn-Ag	12	+0.7–+3.6	4.3	2.32	Zhao Yiming et al. (1997)
	Mengsentaolegai-Ag-Pb-Zn	24	+0.7–+4.9	4.2	2.22	Zhao Yiming et al. (1997)
	Baiyinnuo-Pb-Zn	53	-6.6–+2.6	9.2	-3.38	Zhao Yiming et al. (1997)
	Haobugao-Pb-Zn-Cu	9	-4.7–+0.9	5.6	-2.46	Zhao Yiming et al. (1997)
	Aonaodaba-Ag-Sn-Cu	7	-6.2–+3.0	7.4	0.34	Zhao Yiming et al. (1997)
	Dajing-Ag-Cu-Sn	47	-3.9–+3.5	7.4	0.39	Zhao Yiming et al. (1997)
	Huanggang-Sn-Fe	21	-4.0–+3.4	7.4	0.33	Zhao Yiming et al. (1997)
	Xiaobaliang-Cu-Au	3	+2.0–+3.9	1.9	2.90	Zhao Yiming et al. (1997)

and maximum difference lower than 5‰, similar to CHUR. Hence the ore sulfur could have been derived from the deeper crust, upper mantle, subducted oceanic crust or lower crust (Zhao Yiming and Zhang Dequan, 1997; Li Huaqin et al., 1998; Wang Denghong et al., 2002). Addition of sulfur from crustal sources, even on a minor scale, can reset the mantle $\delta^{34}S$ values. Because of convective circulation of the ore-forming fluids in the crust, sulfur isotope composition could be mixed and homogenized sufficiently, resulting in a narrow-range of $\delta^{34}S$.

Most of the ore deposits in northern Xinjiang and Xinggan mountains are characterized by a quite narrow range of ore lead and rock lead isotopes, with low μ values and Th/U ratio (Table 4). All the lead isotopes data cluster near the curves for mantle and orogeny, and lie within range of arc lead and oceanic volcanics lead. The data are linearly arrayed in the $^{207}Pb/^{204}Pb$ vs. $^{206}Pb/^{204}Pb$ diagram (Fig. 4), which indicate that the source of lead for most of the mineral deposits in the CAOB could be mantle or paleo-oceanic crust with a mixture of crust lead.

As mentioned above, Sr, Nd isotope of ore-bearing rocks and S, Pb isotope of metallic ore deposits in the CAOB, regardless of their types, mineralization epoch and tectonic settings, attribute source materials ultimately derived from the mantle. The data are consistent with those for the regional granitoids.

Conclusion

An area characterized by a particular assemblage of mineral deposits, or by one or more characteristic types of mineralization can be called as a metallogenic province. A metallogenic province may contain more than one episode of mineralization, or metallogenic epoch (Bates and Jackson, 1987). As described above, the metallogenic epoch and sources of the polymetallic ore deposits in the CAOB are consistent with those of regionai granitoids, at least from the Paleozoic to the Mesozoic. Most of them show isotopic characteristics consistent with mantle-derived source materials. Even W, Sn and rare metallic deposits in the CAOB, were influenced obviously by mantle-derived materials although they possess heterogeneous signature of both mantle- and crust- derived materials. In comparison with South China metallogenic province

Table 4. Pb isotope of metallic mineral deposits in northern Xinjiang and Hinggan Mountains.

	Mine	Sample number	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$	μ	Th/u	Reference
North Xinjiang	Ashele-Cu-Zn	129	17.831-18.924	15.359-15.649	37.506-38.969	9.102-9.511	3.502-4.002	Li Huaqin et al. (1998)
	Ketetale-Pb-Zn	23	18.075 18.192	15.55-15.629	38.065-38.177	9.17-9.376	3.749	Wang Denhong et al. (2002)
	Tiemuerte-C-W	21	16.742-18.039	15.495-15.541	37.763-37.843	9.06-9.374	3.818	Wang Denhong et al. (2002)
	Kalatongke-Cu-Ni		17.691 18.656	15.232-15.658	37.232-38.522			Wang Denhong et al. (2002)
	Saerbulake-Au	9	17.962 18.038	15.423 15.499	37.505 37.708	9.167-9.306	3.557-3.611	Wang Denhong et al. (2002)
	Saidu-Au	1	18.110	15.431	37.568			Wang Denhong et al. (2002)
	Kekesayi-Au	1	18.478	15.778	38.721			Wang Denhong et al. (2002)
	Jinshangou-Au	3	17.784-17.858	15.405-15.488	37.308-38.127			Wang Denhong et al. (2002)
	Beilekuduke-Sn	2	18.339-18.850	15.628-15.773	38.399-38.559			Wang Denhong et al. (2002)
	Sareshike-Sm	2	18.150-18.503	15.486-15.545	37.774-38.211			Wang Denhong et al. (2002)
	Buerkesida-Au	2	17.952-18.105	15.443-15.534	37.599-37.981			Wang Denhong et al. (2002) Wang Denhong et al. (2002)
	Kangguertage-Au	3	18.156-18.166	15.534-15.546	37.930-37.963	9.111-9.146	3.776-3.790	Ji Jinsheng et al. (1994)
	Sawayaerdun-Au-Sb	9	18.012-18.203	15.470-15.639	38.062-38.464	8.89-9.58	3.82 3.94	Ye Qingtong et al. (1999)
Heilongjiang	Duobaoshan-Cu-Mo	3	17.869-17.996	15.512-15.568	37.684-37.769	9.35-9.44	3.63-3.71	Zhao Yiming et al. (1997)
	Tongshan-Cu-Mo	3	17.560-17.630	15.434-15.485	37.300-37.415	9.23-9.33	3.65-3.68	Zhao Yiming et al. (1997)
Central Inner Mongolia	Wulugetushan-Cu-Mo	7	18.352-18.433	15.510-15.633	38.068-38.421	9.29-9.52	3.59-3.72	Zhao Yiming et al. (1997)
	Jiawula-Ag-Pb-Zn	19	18.263-18.647	15.457-15.736	37.841-38.710	9.19-9.71	3.53-3.82	Zhao Yiming et al. (1997)
	Chaganbulagen-Ag-Pb-Zn	7	18.266-18.364	15.455-15.591	37.601-38.264	9.19-9.45	3.43-3.68	Zhao Yiming et al. (1997)
	Erentaolegai-Ag	4	18.079-18.765	15.539-15.885	38.060-38.759	9.37-9.98	3.74-3.78	Zhao Yiming et al. (1997)
	Budunhua-Cu	3	18.248-18.290	15.476-15.537	37.911-38.113	9.23-9.35	3.57-3.65	Zhao Yiming et al. (1997)
	Chuangchunling-Pb-Zn-Ag	3	18.104-18.237	15.427-15.530	37.815-38.158	9.15-9.34	3.60-3.69	Zhao Yiming et al. (1997)
	Mengsitaolegai-Ag-Pb-Zn	7	17.942-18.304	15.540-15.756	38.460-39.109	9.34-9.78	3.94-4.13	Zhao Yiming et al. (1997)
	Baiyinnuo-Pb-Zn	17	18.228-18.683	15.480-15.850	37.925-38.871	9.24-9.92	3.58-3.85	Zhao Yiming et al. (1997)
	Haobugao-Pb-Zn-Cu	12	18.248-18.479	15.478-15.634	37.927-38.436	9.24-9.52	3.58-3.77	Zhao Yiming et al. (1997)
	Aonaodaba-Ag-Sn-Cu	3	18.231-18.321	15.491-15.591	37.935-38.271	9.26-9.45	3.60-3.71	Zhao Yiming et al. (1997)
	Dajing-Ag-Cu-Sn	12	18.258-18.498	15.478-15.787	37.969-38.925	9.25-9.82	3.59-3.92	Zhao Yiming et al. (1997)
	Huanggang-Sn-Fe	4	18.183-18.414	15.448-15.690	37.897-38.632	9.18-9.63	3.60-3.83	Zhao Yiming et al. (1997)
	Xiaobalian-Cu-Au	3	17.531-17.743	15.397-15.601	37.094-37.403	9.16-9.55	3.57-3.63	Zhao Yiming et al. (1997)
	Lianhuashan-Cu-Ag	3	18.104-18.492	15.427-15.739	37.815-38.570	9.15-9.72	3.73-3.91	Sheng Jifu et al. (1999)

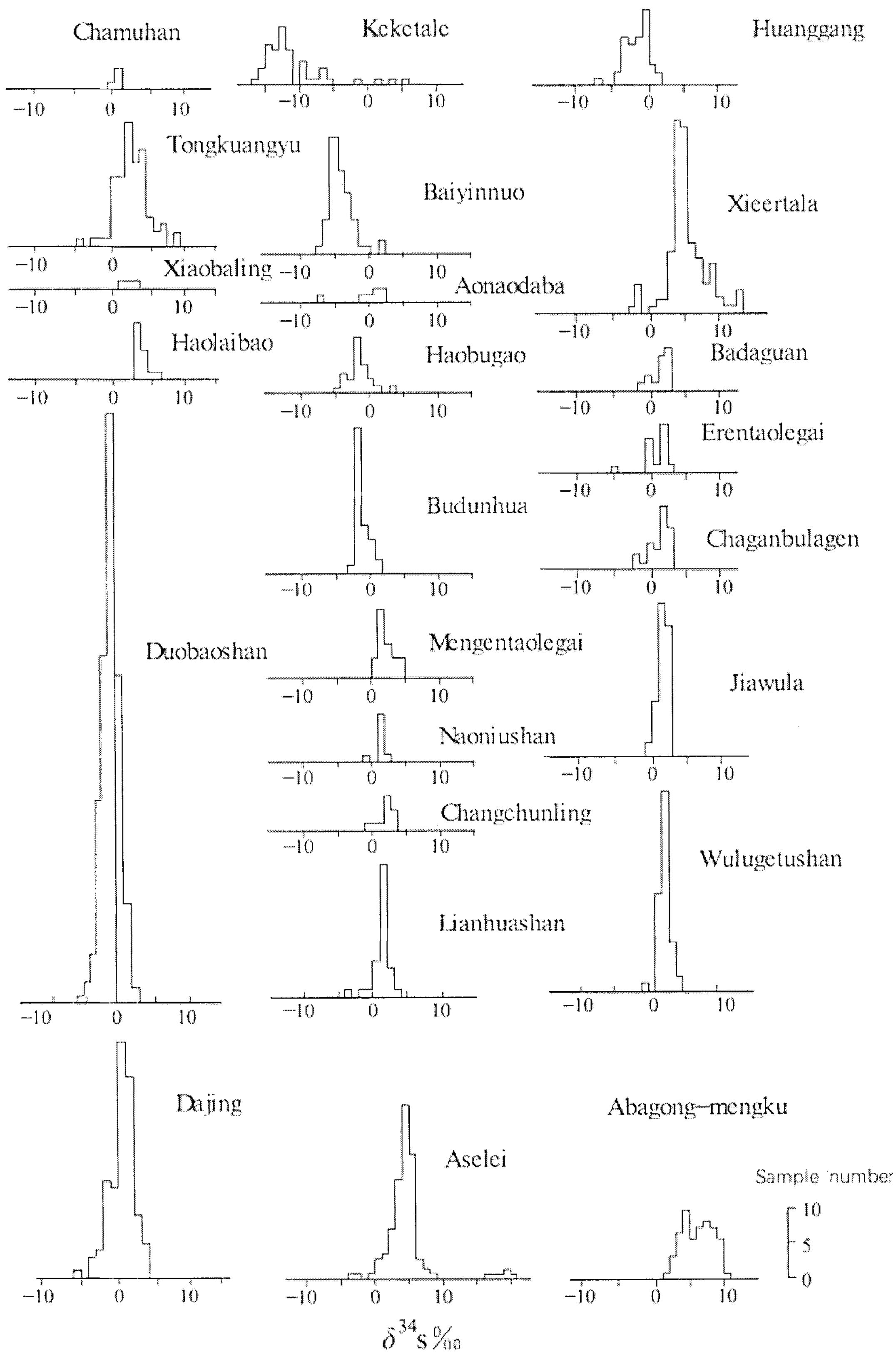

Fig. 3. Histograms of sulfur isotope compositions for mineral deposits. Aselei, Abagong-mengku and Keketale after Wang Denghong et al. (2002); Dajing after Chu Xielei et al. (2001); others after Zhao Yiming and Zhang Dequan (1997).

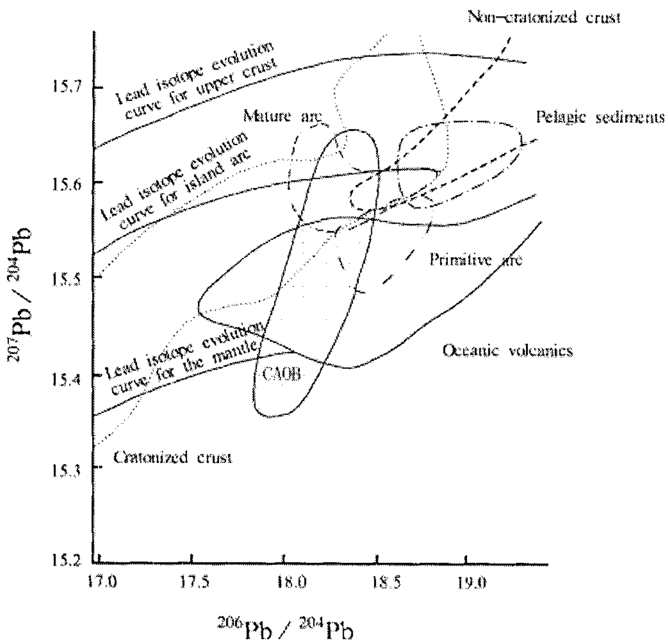

Fig. 4. Variation of $^{207}Pb/^{204}Pb$ versus $^{206}Pb/^{204}Pb$ diagrams for mineral deposits. Lead-isotope evolution curves after Zartman and Doe. (1981); tectonic environment discrimination after Doe and Zartman (1979).

derived from the crust and characterized by W, Sn, Nb, Ta deposits (Hong et al., 1998), the CAOB could be viewed as a typical metallogenic province with mantle signature. Whether the source materials were differentiated directly from the mantle, derived from the lower crust through underplating of basaltic magma, or resulted from the juvenile crust derived from the subducted oceanic crust remain to be evaluated in future studies.

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