The Junggar Immature Continental Crust Province and Its Mineralization

WANG Jingbin, WANG Yuwang and WANG Lijuan
Beijing Institute of Geology for Mineral Resources, Beijing 100012; E-mail: wjb@bigm.com.cn

Abstract According to the study on the peripheral orogenic belts of the Junggar basin and combined with the interpretation of geophysical data, this paper points out that there is an Early Paleozoic basement of immature continental crust in the Junggar area, which is mainly composed of Neoproterozoic–Ordovician oceanic crust and weakly metamorphosed covering sedimentary rocks. The Late Paleozoic tectonism and mineralization were developed on the basement of the Early Paleozoic immature continental crust. The Junggar metallogenic province is dominated by Cr, Cu, Ni and Au mineralization. Those large and medium-scale deposits are mainly distributed along the deep faults and particularly near the ophiolitic mélangé zones, and formed in the Late Paleozoic with the peak of mineralization occurring in the Carboniferous–Permian post-collisional stage. The intrusions related to Cu, Ni and Au mineralization generally have low $F_{O_2}$ and positive $\delta^{64}S$ values. The $\delta^{64}S$ values of the ore deposits are mostly near zero, and the lead isotopes are mostly of normal lead. All these indicate that the ore-forming material comes either directly from the mantle-derived magma (for chromite and Cu-Ni deposits) or from recirculation of the basement material of the Early Paleozoic immature crust (for most Cu and Au deposits).

Keywords: oceanic crust basement, immature crust province, orogeny and mineralization, Junggar, Xinjiang

1 Introduction

The Junggar area in Xinjiang, Northwest China, is composed of the Junggar basin and its peripheral Paleozoic orogenic belts. It is separated on the north by the Erxi fault from the Siberian plate (the Altay terrane) and on the south by the Ebinur-Kanggur fault from the Tarim plate (Zhang, 1995), and extends both eastwards and westwards, to the national boundaries, covering an area of about 450,000 km².

Geophysical data and part of petroleum geological data have confirmed that there is a unified Late Paleozoic tectonic layer beneath the Mesozoic-Cenozoic cover of the Junggar basin (Jiang, 1984). However, there have been different opinions on the nature and age of the basement beneath the Late Paleozoic tectonic layer. At first, researchers generally believed that, just like the Tarim basin, the Junggar basin has an old basement of Precambrian massif (Wu, 1987). On the basis of aeromagnetic and gravity data, geophysicists have deduced that in the depth of the Junggar depression there is an oceanic crust basement (Jiang, 1984) or Precambrian basic-ultrabasic complex (Fei et al., 1987). In recent years, based on different data, some researchers proposed or accepted the viewpoint that there is an “oceanic crust basement” in the depth of the Junggar basin (Coleman, 1989; Xiao et al., 1990; Xu et al., 1992; Chen et al., 1995).

According to the up-to-date study results in the peripheral orogenic belts, this paper will approach the type of basement in the depth of the Junggar basin and attributions of crustal structures, and then analyze the characteristics and control mechanisms of mineralization to determine the target ore deposit types and the key structural positions for ore prospecting.

2 Basic Geological Features

Because of the several kilometers thick Mesozoic-Cenozoic sedimentary covers in the Junggar basin and the explanation diversity of geophysical data, the attribution of the basement in the Junggar area must be deduced from geological and geochemical characteristics of the peripheral orogenic belts. After generalizing the previous data and verifying them by our observations and studies for many years, the orogenic belts around the Junggar basin have the following main characteristics:

(1) So far, no Precambrian rocks have been found around the Junggar basin, and the oldest strata in the orogenic belts where there is evidence of fossils are of the Ordovician-Silurian, dominated by black fine-clastic sedimentary rocks with minor carbonate rocks.

(2) Several ophiolite zones occur in the peripheral orogenic belts, which are, from north to south, the Erxi (as a boundary between the Kazakhstan-Junggar plate and the Siberian plate), Almantai, Hongguleng, Tangbale, Mayileshen, Dalabute, Karamai, North Tiansha (Bayingou) and so on (Fig. 1). Based on the data of fossils like radiolarian, isotopic age of ophiolite (Table 1) and sedimentary unconformity, it is suggested that the ophiolites in the orogenic belts around the Junggar basin...
are clearly divided into two phases: one was formed during the late Neoproterozoic–Ordovician (626–447 Ma), and closed at the end of Ordovician to Silurian. The Tangbale and Hongguleleng ophiolites are unconformably overlain by Middle-Lower Silurian siltstone-mudstone; the other started in the Early-Middle Devonian and lasted to the latest Devonian–earliest Carboniferous. The Karamaili ophiolite is overlain unconformably by the Lower Carboniferous Nanningshui Formation (Li et al., 1990). The wide distribution of Neoproterozoic–Early Paleozoic ophiolite provides direct evidence for the existence of an oceanic crust in this area.

(3) Granitoids with positive $\delta^{18}O$ values are widely distributed in the Junggar orogenic belts. Early Paleozoic granitoids are rarely found in the Junggar area, while Late Paleozoic granitoids (e.g. granite, granodiorite, diorite and...
fragments (ophiolites) and weakly metamorphosed sedimentary rocks generated by local and weak convergence and consolidation in the end of the Silurian. The complexes may be similar to the ophiolitic mélangé zones in Tangbale and Mayileshan, western Junggar. The oceanic crust basement and most of its peripheral complex zones have not been strongly modified by high-grade metamorphism, migmatization and remelting, preserving the nature of a immature continental crust province and acting as a foundation for Late Paleozoic tectonism and magmatism.

3 Types of Ore Deposits and Their Distribution

The Junggar immature continental crust province is a distinct metallogenic province dominated by Cu, Ni, Au and Cr mineralization. It is an important area for production of mineral resources in short supply in China, with its Cr, Cu, Ni and Au reserves accounting for 100%, 98%, over 60% and 34% of the corresponding reserves in Xinjiang, respectively. The main features of various ore deposits are listed in Table 2.

1) Pod-like chromite ore deposits associated with ophiolite. They occur mainly in ultramafic rocks in the lower part of the ophiolite. The important ore deposits include the Sartokay, Tangbale and Saleinuohai in western Junggar, with their proved reserves ranking second in China. The Sartokay ore deposit is a medium-sized one, with its reserves accounting for 90% of the total reserves of Xinjiang. It occurs in dunite and enstatite pyrolite at the bottom of the Early Devonian Dalabate ophiolite, appearing mainly as pod- and lens-like orebodies. These orebodies contain 20%–37% of Cr₂O₃, with the total proved reserves of 1.1 million tons; the maximum orebody is 160 m long and 25 m thick. The small-sized Saleinuohai and Tangbale deposits occur in the Early Paleozoic ophiolite and their metallogenic characteristics are similar to those of the Sartokay deposit.

2) Copper-nickel sulfide ore deposits related to mafic-ultramafic rocks. Three large Cu-Ni deposits and 3 medium-sized ones have been found in the Junggar area. These ore deposits form two metallogenic belts: the Kalatongke and the Huangshan-Xiangshan belts, and their nickel metal reserves controlled amount to 1.2 million tons, ranking second in China. In these ore deposits the copper-nickel mineralization is related to small mafic-ultramafic complexes (generally <2 km²). These ore-bearing complexes were formed in a post-collisional setting and invaded into the Early Carboniferous black fine clastic rocks. Hydrous minerals (amphibole and biotite) and pegmatitic textures are common, which suggests that the

![Fig. 2. Plot of the εNd(t) values versus ages of granitoids and ophiolites in the Junggar terrane of Xinjiang. Data of granitoids from the Caledonides, Hercynides and Himalayanides are quoted from Patchett (1992).]
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</tbody>
</table>

Notes: L – Large deposits: Cu, >500,000 t; Ni, >100,000 t; Au, >20 t; chromite (ore), >5 Mt; M – medium-size deposits: Cu, 100,000–500,000 t; Ni, 20,000–100,000 t; Au, 5–20 t; chromite (ore), 100–500 Mt.

Ore-bearing magma is rich in water. Two types of copper-nickel ores have been recognized in these deposits: the disseminated ore formed by autochthonous liquid immiscibility and the injected massive ore formed by deep liquidation.

(3) Porphyry copper ore deposits. They include porphyry copper-molybdenum and copper-gold deposits, skarn-type copper deposits and cryptexplosive breccia pipe-type copper deposits, which form a mineralization series associated with plagioclase granite-porphyry and granodiorite porphyry. Large and medium-scale porphyry copper deposits are mainly distributed in the marginal tectono-magmatic zones of the Junggar terrane, including the Tuwu porphyry copper mineralization zone associated with the Dananhu-Tousuquan Devonian island arc on the south margin and the Suorkuduk (Jiabosar) porphyry-skarn copper (molybdenum) mineralization zone on the north margin. The latter might be related to the intermediate-acid
| Table 3 Ages and Sr and Nd isotopic compositions of ore deposits in the Junggar area |
|--------------------------------------------|----------------|----------------|----------------|----------------|
| Ore deposit                               | Dating object                  | Age (Ma) (method) | \( I_{0} \) | \( \epsilon_{Nd} (t) \) | Source of references |
| Suorkuduk, Cu-Mo                          | Altered andesite                | 288±3±17.6 (Rb-Sr) | 0.7046 | +3.0          | Li et al., 1998     |
|                                           | Garnet and epidote in skarns    | 284±3±3.9 (Sm-Nd)  |         |               |                     |
| Sarbulak, Au                              | Rhyolite porphyry               | 292±1±7.3 (Rb-Sr) | 0.7033 | Li et al., 1998 |                     |
|                                           | Fluid inclusions in quartz      | 265±2±3 (Rb-Sr)   | 0.7051 |               |                     |
|                                           | Tuff                           | 320±5±9 (Rb-Sr)   | 0.7054 |               |                     |
|                                           | Syenogranite                    | 285±1±1 (Rb-Sr)   | 0.7059 |               |                     |
| Hata, Au                                  | Alkali-feldspar granite         | 296±4±1 (Rb-Sr)   | 0.7062 | Li et al., 1998|                     |
|                                           | Fluid inclusions in quartz      | 293±1±1 (Rb-Sr)   | 0.7048 |               |                     |
|                                           | Fluid inclusions in quartz      | 288±2±2 (Rb-Sr)   | 0.7050 |               |                     |
| Baogutu, Au                               | Diorite porphyrite              | 322±2±30 (Rb-Sr)  | 0.7038 |               | Shen et al., 1993   |
|                                           | Andesite                       | 347 (Rb-Sr)       | 0.7037 | +7.96         |                     |
| Burkesidai, Au                            | Alkali-feldspar granite         | 314 (Rb-Sr)       | 0.7046 | +5.65         | He et al., 1994     |
|                                           | Diabase-porphyrite              | 322 (Rb-Sr)       | 0.7037 | +6.06         |                     |
| Tasit, Au                                 | Hornblende-bearing granite      | 326±4±38.6 (Rb-Sr) | 0.70454 |               | Zhou et al., 1999   |
| Yenaquan, Au                              | Diorite porphyrite              | 263±2±21 (Rb-Sr)  | 0.7057 |               |                     |
|                                           |                               |                |       | +7.31         | Bi et al., 1993     |
| Sareshik, Sn                              | Alkali granite                  | 290±1±11 (U-Pb)  | 0.7063 | +6.43         | Hong et al., 2003   |
|                                           |                               |                |       | +3.73         | Hong et al., 2003   |
| Beilekuduk, Sn                            | Granitite                      | 313±1±18 (U-Pb)  | 0.7067 | +6.79         | Hong et al., 2003   |
| Ganliangzi, Sn                            | Alkali granite                  | 307±2±20 (Rb-Sr) | 0.70232|               | Chen et al., 1999b  |
|                                           | Fluid inclusions in quartz      | 305±2±25 (Rb-Sr) | 0.70766|               |                     |
| Kanggar, Au                               | Altered andesite                | 290±3±5 (Rb-Sr)  | 0.7099 | +2.6 to +3.2  | Li et al., 1998     |
|                                           | Altered rhyolite                | 300±3±13 (Rb-Sr) | 0.7079 | +0.2 to +0.6  | Li et al., 1998     |
|                                           | Tonalite                        | 248±1±1 (Rb-Sr)  | 0.7043 | +0.3 to +3.6  | Li et al., 1998     |
|                                           | Fluid inclusions in quartz      | 282±3±5 (Rb-Sr)  | 0.7077 |               | Li et al., 1998     |
|                                           | Magnetite and pyrite in ores    | 290±4±7.2 (Sm-Nd) | +0.51  |               | Zhang et al., 1997  |
| Xifengshan, Au                            | Adamelite                       | 284±1±3 (Rb-Sr)  | 0.70611|               | Li et al., 1998     |
|                                           | Fluid inclusions in quartz      | 275±1±3 (Rb-Sr)  | 0.7070 |               |                     |
|                                           | Andesite                        | 285±1±22 (Rb-Sr) | 0.7046 |               |                     |
|                                           | Granite porphyry                | 266±1±3 (Rb-Sr)  | 0.7054 |               |                     |
| Shiyintan, Au                             | Tonalite                        | 293±1±1 (Rb-Sr)  | 0.7039 |               | Li et al., 1998     |
|                                           | Fluid inclusions in quartz      | 288±7 (Rb-Sr)    | 0.7049 |               |                     |
|                                           |                               | 276±7 (Rb-Sr)    | 0.7051 |               |                     |
| Huangshan, Cu-Ni                         | Mafic-ultramafic rocks          | 306.9±10.7 (Sm-Nd) | +6.6   |               | Li et al., 1998     |
| Huangshandong, Cu-Ni                     | Mafic-ultramafic rocks          | 320±38 (Sm-Nd)   | +7.8   |               | Li et al., 1998     |
| Tuwu, Cu                                 | Ore-bearing andesite and trachybasalt | 416±120 (Sm-Nd) | +5.6 to +8.8 |               | Rui et al., 2002 |
|                                           | Altered mafic-feldite           | 369±69 (Rb-Sr)   | 0.7033 | +6.2 to +9.4  |                     |
granitoid porphyry emplaced in a post-collisional environment.

(4) Gold ore deposits. Gold deposits in the Junggar area are wide in distribution and varied in type (Chen, 1997; Feng et al., 2000), including the ductile shear zone type (such as Kekesayi and Kanggur), the quartz vein type (e.g. Hatu), the epithermal type (e.g. Ku'erkuwula, Shiyingtan, Surbasitao, Shuangfengshan and Jinshangou) and the felsic dike-associated gold deposits. The ductile shear zone type of gold deposits occur mostly in strong deformation zones on the margins of the Junggar terrane, forming the Ertix gold mineralization belt on the north margin and the Kanggur gold mineralization belt on the south margin. The quartz vein type of gold deposits are mainly distributed in the Karamaili-Dalabute ophiolitic mélangé zone. The epithermal type ones are controlled by volcano-faulting systems, and the orebodies mostly occur near the contacts of sub-volcanic intrusions emplaced in the volcanic center. The felsic dike associated gold deposits are a special type proposed when generalizing the metallogenic characteristics of gold in Junggar (Wang et al., 1997). This kind of mineralization is related to intermediate-acid hypabyssal dikes and their superimposed faulting breccia-alternation. The typical deposits include the Yemaquan, Burkesidai and Baogutu. The epithermal gold deposits and the felsic dike associated ones are genetically related to post-collisional volcanic-intrusive complexes, and may occur in the same ore field (as in the Ku'erkuwula-Burkesidai).

In addition, there occurs the Beilekuduk tin mineralization zone on the north side of the Karamaili ophiolitic mélangé belt in eastern Junggar, where 4 small-sized tin ore deposits were found. The tin mineralization, in the form of cassiterite-quartz vein or cassiterite-arfvedsonite-quartz vein, is genetically related to the post-collisional arfvedsonite granite (Liu et al., 1996). This type of tin deposits are not commercially important, but their mineralization related to the A-type granite has a distinctive feature.

4 Geochemical Characteristics of Ore Deposits

Intrusions related to gold, copper, nickel and tin mineralization in the Junggar metallogenic province generally have lower initial Sr isotopic values and positive εNd(t) values, in accordance with the characteristics of the Junggar's granitoids (Table 3). In the Yemaquan and Hatu gold ore deposits, gold-bearing quartz veins are similar in REE patterns to the related granitoid intrusions. The δ34S values of sulfides in the ore deposits are mostly around zero, with the maximum-minimum difference usually <5‰, and the lead isotopes in them are mostly normal lead and yield model ages close to the metallogenic ages (Shen et al., 1993; Wang et al., 1999; Hong et al., 2003). These suggest that the ore-forming material is deep-derived directly from mantle-derived magma (as for copper-nickel and chromite ore deposits) or from oceanic crust-covering sediment remelting magma (as for most of the Au, Cu and Sn deposits). Similar features are observed in other metallogenic regions of the Central Asian orogenic belts. Therefore, Hong et al. (2003) concluded that the Central Asia orogenic belts are typical mantle-derived metallogenic domains.

5 Discussion and Conclusion

Regarding such characteristics as the poor development of Early Paleozoic granites and weak deformation and metamorphism in the Junggar area, it is inferred that the Early Paleozoic Junggar oceanic basin with its overlying sediment has mainly undergone uplifting to form land, and has not suffered intensive reconstruction by deformation, metamorphism and magmatism except for some local segments. The present Caspian Sea area is probably undergoing similar evolution processes. During the Early Paleozoic, only a few small pod-like chromite ore deposits related to ophiolite were formed, while other ore deposits were poorly developed.

The Late Paleozoic is the most important mineralization epoch in the Junggar area. The tectonic mineralization of this period was developed on the basement of the Early Paleozoic immature continental crust. Different groups of ore deposits were formed in different tectonic stages. Pod-like chromite ore deposits were formed in the regenerated oceanic basin stage of the Early Devonian (e.g. the Sartokay deposit), whereas the Tuwu porphyry copper mineralization zone related to the Dananhu-Tousuquan island-arc magmatism was formed in the Late Devonian (Rui et al., 2002). After closure of the oceanic basin from the end of Late Devonian to the beginning of Early Carboniferous, there was a peak of mineralization in the Junggar area during the Late Carboniferous—Permian post-collisional stage. Most of the gold, copper (molybdenum) and copper-nickel ore deposits were formed in that stage (Table 3).

For the Kalatongke and Huangshan Cu-Ni sulfide deposits formed in the post-collisional stage, geophysical data have confirmed that there are giant paleo-magma chambers beneath those small ore-bearing mafic-ultramafic intrusions, which suggests that they are genetically related to the differentiation and invasion of the underplated mantle-derived magma. The positive εNd(t) values and low I$_{Sr}$ values for the post-collisional intrusions related to gold and copper-molybdenum mineralization, together with the
normal Pb isotope and the close-to-zero value of $\delta^{24}$S for the corresponding ore deposits, may be related to remelting of the Early Paleozoic oceanic crust and the sedimentary cover. The differentiation of the remelting magma and the leaching and extraction of subsurface fluids driven by such magma chambers should be main cause for forming copper (molybdenum) and gold deposits. It was probably the underplating of mantle-derived magma that induced such remelting (Coleman, 1989). Therefore, the underplating of mantle-derived magma and its induced recirculation of the basement material dominated by the oceanic crust should be the main cause for the large-scale post-collisional mineralization in Junggar.

All the large and medium-scale endogenetic deposits discovered in Junggar are Cr, Cu, Ni and Au deposits, while such mineralization as Pb-Zn and rare metals (Nb, Ta, Be and W) related to mature continental crust is poorly developed, and so far only small deposits and occurrences have been found, and their geochemical anomalies are poorly developed. That shows a metallogenic feature and specialization of the immature continental crust province. Hence, the Junggar immature continental crust province is a favorable mineralization area for such basic magmophile elements as Cr, Cu, Ni and Au. On the other hand, it is not optimistic to prospect for Pb-Zn and rare metallic Nb, Ta, Be and W deposits which are related to a mature continental crust. Even though small tin deposits are developed in eastern Junggar, they are genetically related to the A-type granite formed by remelting of the oceanic crust-sedimentary cover. Compared with the tin-bearing S-type granite in South China, the source of ore-forming material is poor in the region. It can thus be predicted that it would be difficult to find large and superlarge tin deposits like Dachang and Gejiu in the Junggar area.

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