Major types and Metallogenic model of Early Cretaceous Pb-Zn and associated metal deposits in the southern Great Xing’an Range, NE China

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Abstract. The southern Great Xing’an Range (SGXR) is one of the most important non-ferrous metal ore concentrating areas in China, and a large number of Pb-Zn and associated metal deposits have been found and mined in this area. The Early Cretaceous deposits of SGXR can be divided into three principal types according to their geological characteristics: skarn type deposits, porphyry type deposits and hydrothermal vein type deposits. In this contribution, we list some important Early Cretaceous deposits in the SGXR and summarize their geological characteristics. Research of stable isotope and fluid inclusion reveal that the sources and properties of ore-forming fluids varied between different types of mineral deposits, while the sources of ore-forming materials of different deposits are similar(characterized by deep-seated magmatic activities). We therefore conclude that the Early Cretaceous porphyry, skarn and hydrothermal vein type deposits in SGXR belong to a unified metallogenic series and developed a synthetical model for these deposits.

1. Introduction

As one of the important non-ferrous metal ore concentrating areas in northeastern China, the southern Great Xing’an Range (SGXR) has been listed as one of the 19 key belts that are often targets for mineral exploration in China [1-4]. Apart from the newly discovered deposits, the number of mineral resources from known deposits has also increased in recent years, making this belt a continuous hot area for ore deposit research in northern China.

During the past years, geologists have carried out a lot of work on zircon U-Pb, molybdenite Re-Os, cassiterite U-Pb, sphalerite Rb-Sr, and muscovite Ar-Ar dating to accurately constrain the mineralization ages of these deposits [5-10]. And the results reveal that Early Cretaceous deposits constitute the most important part of hydrothermal mineralization in SGXR. On the basis of their mineral assemblages, host rocks and major ore controlling factors, the major deposits of Early Cretaceous from SGXR can be divided into the following three types: (1) skarn type deposits, (2) porphyry type deposits, and (3) hydrothermal vein type deposits[11]. During the past years, we have successively carried out studies on geology, fluid inclusion, stable isotope, lithogeochemistry, and geochronology metallogenic prediction of the major Early Cretaceous deposit in the area [12-15]. In this paper, we reviewed the geology, fluid inclusion and isotope characteristics of the Early Cretaceous hydrothermal Pb-Zn and associated metal deposits, and the temporal, spatial and genetic relationships between different types of ore deposits.
2. Skarn type deposit

Three important skarn type deposits, mainly including Huanggang, Haobugao and Baiyin nuoe r have been found in SGXR. Results of molybdenite Re–Os dating shows that the Haobugao deposit is formed at 140.3 Ma and the Huanggang deposit is formed at 135.8 Ma, mineralization related granites of the two deposits are formed between 136.7–144.8 Ma and 136.6–136.8 Ma, respectively [7,8,10,11] (zircon LA-ICP-MS U-Pb dating). Therefore, we can conclude that the Haobugao and Huanggang deposits are genetically related to Early Cretaceous magmatism. While the formation age of Baiyin nuoe r deposit is still controversial between scholars till the present moment, and no accurate metallogenic age has been obtained yet.

The Huanggang and Haobugao deposit generally occurred along the contact between Mesozoic intrusions and Permian carbonate rocks. Magnetite, hematite, cassiterite, varlamoffite, sphalerite, scheelite, loellingite, chalcopyrite constitute the main ore minerals of the ores, which display a variety of textures. Gangue minerals of the deposit are dominated by skarn minerals such as garnet, pyroxene, amphibole, fluorite, calcite, quartz, epidote, chlorite and phlogopite. The ores of the deposit show mainly massive, banded, breccia, veinlike structures and disseminated structures. The ore-forming process of the two deposits both can be divided into the four stages based: (1) prograde skarn stage. Mineral assemblage of this stage is mainly composed of pyroxene, garnet, wollastonite; (2) retrograde alteration stage. This stage is characterized by occurrence of hydrous skarn mineral, including hornblende, actinolite, epidote, and chlorite; (3) quartz–sulfide stage; and (4) carbonate stage (Fig. 1).

3. Porphyry type deposit

Several porphyry type deposits developed in SGXR, and most of the deposits are copper-molybdenum mineralization, only a few are lead-zinc mineralization. The Dongshanwan deposit is a typical porphyry type deposit with intense mineralization of W, Mo, Pb, Zn and Ag. Molybdenite Re–Os and zircon U-Pb dating reveals that both of the mineralization and hosting granites are formed at 140–142Ma. Recently, porphyry type Cu-Mo-(Pb)-(Zn) mineralization has also been discovered in the periphery of the mining district of Haobugao deposit, which also indicates that a great potential for discovering porphyry type deposits exist in this area. Our LA-MC-ICP-MS zircon U-Pb dating of granite porphyry yielded a weighted mean $^{206}\text{Pb}/^{238}\text{U}$ age of 141.9 ± 1.2 Ma, which was interpreted as the emplacement age of the granite porphyry, while the model ages of molybdenite Re-Os dating range from 139.9 ± 2.3 Ma to 141.0 ± 1.7 Ma. The molybdenite Re-Os age is quite consistent with the LA-ICP-MS zircon U-Pb age of the host granite, suggesting a coeval and causative relation between the granite and mineralization. These deposits are characterized by veinlet–disseminated
mineralization that developed in the granitic rocks (Fig. 2), and show characteristics of alteration-mineralization zoning.

4. Hydrothermal vein type deposit
The important hydrothermal vein type deposits in SGXR include Shuangjianshan Pb-Zn-Ag deposit, Dajing Cu–Sn–Ag–Pb–Zn deposit, Bairendaba Ag-Pb-Zn deposit and Weilasituo Zn–Cu–Ag deposit. Orebodies of this type of deposits occur in Permian strata, and lack clear link with intrusive rocks in space and time. Wu et al. (2013) used the sphalerite Rb-Sr dating method to determine the mineralization age of the Shuangjianshan deposit \(^{[16]}\), and obtained the isochronous age of 132.7 + 3.9 Ma. Liao et al. (2014) carried out cassiterite LA-ICP-MS U-Pb isotope dating for the Dajing deposit and obtained the mineralization age of 144 Ma \(^{[17]}\). Muscovite Ar-Ar dating conducted by Pan et al., (2009) and Chang et al., (2010) reveals that the Weilasituo and Bairendaba deposit are formed at 133.4 Ma and 135.0Ma, respectively \(^{[18-19]}\). It can be concluded that the formation of hydrothermal vein type deposits in SGXR also mainly concentrate in the Early Cretaceous.

5. Genetic relationships and metallogenic model of different types of deposits
The research of fluid inclusion show that liquid rich, vapor-rich, daughter minerals bearing fluid inclusions have been identified in early stage of the skarn and porphyry type deposits. And CH\(_4\) and CO\(_2\) have been detected in fluid inclusions of calcites from skarn type deposits, indicating that the ore-
forming fluids of late stage are affected by materials of Permian strata. Fluid inclusion assemblages of the hydrothermal vein type deposits are quite different, which represent the complexities of metallogenic process and formation mechanism. Liquid-rich, aqueous-carbonic inclusions, vapor-rich inclusions, and CO₂-bearing three-phase inclusions have been identified in main-ore stage of vein type Weilasituo and Bairendaba deposit, indicating that the main-ore stage fluids are characterized by a complex NaCl–H₂O–CH₄–CO₂ system. Daughter minerals can also be recognized in fluid inclusions of Dajing deposit, and the fluid inclusions from Shuangjianshan deposit are characterized by simple liquid-rich two-phase inclusions. Stable isotope data from ore minerals and associated gangue minerals indicate that the initial ore fluids were dominated by magmatic waters, some of which had clearly exchanged oxygen with wall rocks during their passage through the strata. Sulfur isotope values reported from SGXR span a narrow range, generally ranging from –6 to +5‰. The narrow range for the δ³⁴S values presumably reflects the corresponding uniformity of the ore forming fluids, and these δ³⁴S values have been interpreted to reflect a magmatic source for the sulfur. The comparation of lead isotope ratios between ores and different geological units also reveals that deeply seated magma has been a significant source of lead in the ores.

![Fig. 4. Metallogenic model and genetic-spatial relationships for skarn, porphyry and hydrothermal vein type deposits in SGXR](image)

The results of zircon U-Pb geochronology and major-, trace-and rare earth-element geochemistry reveal that the Early Cretaceous granitoids of SGXR show characteristics of A-type granites. And it is broadly accepted that this kind of granites are formed in an extensional within plate tectonic environment [10,12]. Therefore, the formation process of the Early Cretaceous deposits from SGXR can be summarized as follows: during the Early Cretaceous, the A-type granites originated from the partial melting of the upper crust with some input of mantle material. It appears plausible that the lithospheric thinning not only resulted in emplacement of magmatic rocks and related Pb–Zn polymetallic mineralization, but also caused outward migration of mineralizing fluids in a regional thermal gradient. These magmas emplaced at a shallow level and finally formed porphyry–skarn–hydrothermal vein Pb–Zn and associated metal deposits. The spatial distribution of the deposits usually shows an obvious regularity, that is, from the internal to outer zone of the intrusion, porphyry→skarn→vein deposits distribute in order.

6. Conclusions

(1) Mineralization of skarn type deposits occur in the contact zone between Early Cretaceous granites and Permian formations. The main characteristics of these deposits are a wide variety of calc-silicate and associate minerals, which is dominated by garnet, pyroxene, tremolite and actinolite.
(2) Porphyry type mineralization occurs as veinlets and disseminations in the phyllic and K-silicate alteration zones developed in Early Cretaceous granitic intrusions.

(3) The hydrothermal vein type deposits are mainly hosted in various terranes or different lithologies, and orebodies of this type of deposits are strictly controlled by faults. Alteration assemblages of this type of deposit are dominated by silicification, sericitization, chlorination and carbonation.

(4) A close genetic relationship exist between porphyry, skarn and hydrothermal vein type deposits, and these deposits belong to a unified metallogenic series.

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Reference
[1] Wu, G., Chen, Y.J., Sun, F.Y., Li, J.C., Li, Z.T., Wang, X.J. (2008). Geochemistry of the late Jurassic granitoids in the northern end area of Da Hinggan Mountains and their geological and prospecting implications. Acta Petrologica Sinica 24, 899–910 (in Chinese with English abstract)
[2] Liu, J. M. (2004). The regional metallogeny of DaHinggan Ling, China. Earth Sci. Front., 11, 269-277.
[3] Zeng, Q., Liu, J., Yu, C., Liu, J. Y. H. (2011). Metal Deposits In The Da Hinggan Mountains, NE China: Styles, Characteristics, And Exploration Potential. International Geology Review, 53(7), 846-878.
[4] Mei, W., Lü , X., Cao, X., Liu, Z., Zhao, Y., & Ai, Z., et al. (2015). Ore genesis and hydrothermal evolution of the Huanggang skarn iron–tin polymetallic deposit, Southern Great Xing’an range: evidence from fluid inclusions and isotope analyses. Ore Geology Reviews, 64(1), 239-252.
[5] Zhou, Z. H., Linsu, L., & Feng, J. R. (2010a). Molybdenite re-os ages of Huanggang skarn sn-fe deposit and their geological significance,Inner Mongolia. Acta Petrologica Sinica, 26(3), 667-679.
[6] Zhou, Z. H., Mao, J. W., & Lyckberg, P. (2012). Geochronology and isotopic geochemistry of the A-type granites from the Huanggang Sn–Fe deposit, southern Great Hinggan Range, NE China: implication for their origin and tectonic setting. Journal of Asian Earth Sciences, 49, 272-286.
[7] Zhou, Z., Lü , L., Yang, Y., & Li, T. (2010b). Petrogenesis of the Early Cretaceous a-type granite in the Huanggang Sn-Fe deposit,Inner Mongolia: constraints from zircon u-fb dating and geochemistry. Acta Petrologica Sinica, 26(12), 3521-3537.
[8] Wan, D., Li, J., Wang, Y., Wang, K., Wang, Z., & Wei, L. (2014). Re-os radiometric dating of molybdenite in hongling lead-zinc polymetallic deposit,inner mongolia,and its significance. Earth Science, 39(6), 687-695.
[9] Liu, Y., Jiang, S., & Bagas, L. (2016). The genesis of metal zonation in the Weilasituo and Bairendaba Ag–Zn–Pb–Cu–(Sn–W) deposits in the shallow part of a porphyry Sn–W–Rb system, Inner Mongolia, China. Ore Geology Reviews, 75, 150-173.
[10] Li, J.F., Wang, K.Y., Quan, H.Y., Sun, F.Y., Zhao, L.S., & Zhang, X.B.(2016).Discussion on the magmatic evolution sequence and metallogenic geodynamical setting background of Hongling Pb-Zn deposit in the southern DaXing’an Mountains. Acta Petrologica Sinica,32(5):1529-154( in Chinese with English abstract)
[11] Wang, C.Y., (2015). Lead-zinc polymetallic metallogenic series and prospecting direction in Huanggangliang-Ganzhulmiao metallogenic belt, Inner Mongolia (Doctoral dissertation, Jilin University).
[12] Wang C.Y., Wang K.Y., Liu G.H., Fu L.J., Quan H.Y. (2018a). Characteristics of fluid inclusions and stable isotopes from hydrothermal vein-type deposits in southern Great Xing’an Range, China: implications to genesis of the deposits. Geological Journal of China Universities, 24(4), 491-503. (in Chinese with English abstract)

[13] Wang, C., Li, J., & Wang, K. (2019). Fluid Inclusions, Stable Isotopes, and Geochronology of the Haobugao Lead-Zinc Deposit, Inner Mongolia, China. Resource Geology, 69(1), 65-84.

[14] Wang, C., Li, J., Wang, K., Yu, Q., & Liu, G. (2018b). Geology, fluid inclusion, and stable isotope study of the skarn-related Pb–Zn (Cu–Fe–Sn) polymetallic deposits in the southern Great Xing’an Range, China: implications for deposit type and metallogenesis. Arabian Journal of Geosciences, 11(5), 88.

[15] Zhang, X.B., Wang, K.Y., Wang, C.Y., Li, W., Yu, Q., Wang, Y.C., & Huang, G.H. (2017). Age, genesis, and tectonic setting of the Mo-W mineralized Dongshanwan granite porphyry from the Xilamulun metallogenic belt, NE China. Journal of Earth Science, 28(3), 433-446.

[16] Wu, G. B., Liu, J. M., Zeng, Q. D., Sun, H. S., & Liu, M. T. (2013). Metallogenic age of the Shuangjianzishan Pb–Zn–Ag deposit in the Great Xing’an Range, Inner Mongolia. Acta Minal. Sinica, 2(Supp), 619-620.

[17] Liao, Z., Wang, Y.W., Wang, J.B., Li, H.M., & Long L.L. (2014). Cassiterite La-mc-icp-ms U-Pb dating of Dajing tin polymetallic deposit in Inner Mongolia and its significance. Mineral Deposits, 421-422. (in Chinese)

[18] Pan, X. F., Guo, L. J., Wang, S., Xue, H. M., Hou, Z. Q., Tong, Y., & Li, Z. M. (2009). Laser microprobe Ar–Ar dating of biotite from the Weilasituo Cu–Zn polymetallic deposit in Inner Mongolia. Acta Petrologica et Mineralogica, 28(5), 473-479.

[19] Chang, Y., & Lai, Y. (2010). Study on characteristics of ore-forming fluid and chronology in the Yindu Ag–Pb–Zn polymetallic ore deposit, Inner Mongolia. Acta Scientiarum Naturalium Universitatis Pekinensis, 46(4), 581-593.