New classification of magmatic sulphide deposits in China and metallogenesis related to small intrusions

Tang Zhongli, Yan Haiqing, Jiao Jiangang
College of Earth Science and Land Resource, Chang'an University, No.126, Yanta Route, Xi'an, China

Li Xiaohu
Lanzhou University, Lanzhou 730000, China

Abstract. Many important metals, such as Ni (Cu, Co) and PGE, are taken from magmatic sulfide deposits. The magmatic sulphide deposits in China can be divided into four types according to their tectonic setting, size of intrusion, ore deposit mode, deposit scale, rock types and metallogenic elements. The four types are: (1) Deposits hosted in intra-continental small intrusions; (2) Deposits associated with continental flood basalts; (3) Deposits associated with small intrusions in orogenic belts; and (4) Deposits related to ophiolites. Among them the first type is the most important in China. According to the experience of prospecting, we propose that there are big potentialities for prospecting ore deposits in small intrusions. Mineralization not only occurs in small mafic-ultramafic intrusions, but also in small intermediate-felsic intrusions with important economic value.

Keywords. Magmatic sulfide deposits, new classification, small rock-bodies, metallogenesis

1 Classification of magmatic sulphide deposits

Previous classifications of magmatic sulphide deposits are mainly focused on the controlling factors of geological settings and rock types (Tang, 1996; Liu, 1998). These classifications were helpful for prospecting and research. However, as the development of geological studies advances, small intrusions have been recognized as being important in mineralization. It thus is necessary to put forward a new classification as detailed in Table 1.

2 Characteristics of different types of magmatic sulphide deposits

2.1 Deposits hosted in intra-continental small intrusions

This type of deposits usually occurs in rifts at the margins of Palaeo-continents. In China, these deposits are of Proterozoic age. Mafic and ultramafic magmas originated from mantle emplaced in deep-seated magma chambers. Due to melt-separation and crystallization differentiation, four melt layers formed and include sulfide melt, sulfide-rich silicate magma, sulfide-bearing magma and silicate magma from the base upward.s The four-layer magmas penetrated into different spaces once or several times, and formed several to tens rock groups (or zones). Intrusions are, however, not usually mineralized. We propose classification criteria for small intrusions (i.e. less than an area of 10 square kilometres). Mineralization related to small intrusion is the main metallogenic pattern in China, such as the deposits in Jinchuan, Chibaisong, Tongdongzi and Xiaonanshan.

2.2 Deposits associated with continental flood basalts

This type of deposits formed in igneous intrusions related to the extrusion of large-scale continental flood basalts in the geological history. One characteristic of this type of ore deposits is that the hosting intrusions show a close spatial relationship with the flood basalts. According to the main metallogenic element association, the deposits can be divided into two subtypes: Ni-Cu-Co-Pt and Pt-Pd-Ni-Cu ones. The former is mainly composed of Ni and Cu, such as the Baimazhai and Dapoling deposits; and the latter is mainly composed of Pt and Pd, such as the Jingbaoshan and Yangliuping deposits.

2.3 Deposits associated with small intrusions in orogenic belts

This type of deposit formed during post-orogenic extension mainly in Carboniferous-Permian in China. The metallogenic mechanism is similar to ore deposits in intra-continental small intrusions.

2.4 Deposits related to ophiolites

From the base to top, ophiolites generally consist of four parts: ultra-mafic complex, gabbro cumulative complex, mafic sheet dyke complex and mafic volcanic complex, each of which has different mineralization (Zhang, 2000). The mineralization usually occurs during the stage of growth and movement of oceanic crust. However, the oceanic crust is a dismembered slice in orogenic belts due to tectonic emplacement. Different parts of the opliolites show diverse mineralization. Some ore deposits belong to this type in China, such as those of Jianchaling in Proterozoic Era, and Shijuli, and De'erni.

Table 1: Types of magmatic sulfide deposits in China

Tectonic setting	Intruding way	Ores-hosted main rocks	Deposit mode	Deposit scale	Main metallogenic elements
Palaeo-continent	Small intrusion	Lherzolite	Jinchuan	Supper large	Ni, Cu, Co, Pt
		Diabase,Gabbro	Chibaisong	Middle	
		Gabbro-Diabase	Tongdongzi	Small	
		Gabbro	Xiaonanshan	Small	
	Intrusion associated with the continental flood basalt	Diorite-Gabbro-Diabase- Pyroxenite	Dapoling	Small	Ni, Cu, Co, Pt
		Diorite-Gabbro-Peridotite	Limahe	Middle	
		Gabbro-Pyroxenite-Peridotite	Baimazhai	Middle	
		Diabase-Gabbro-Peridotite	Jinbaoshan	Large	Pt, Pd, Ni, Cu
		Gabbro-Peridotite	Yangliuping		
Orogenic belt	Small Intrusion	Enstatatite	Hongqiling	Large	Ni, Cu, Co, Pt
		Gabbro-Peridotite-Lherzolite	Huangshan	Large	
		Norite-Olivine Norite	Kalatongke	Large	
	Ophiolites	Basalt-Clastic rock-Jade	Shijuli	Middle	Cu, Zn
		Talc- Magnesite Orthopyroxene-Pyroxenite Olivine	Jianchaling	Large	Ni
		Pyroxenite-Peridotite-Orthopyroxene-Pyroxenite Olivine	De'erni	Large	Cu, Zn, Co, S

3 Metallogenesis of small rock-bodies

3.1 The main type of magmatic sulfide deposits in China

The first three types of magmatic deposits are spatially and temporally associated with small intrusions (Table 1). Super large deposits (such as Jinchuan) and large scale ones such as Hongqiling, Kalatongke, Huangshan, Jinbaoshan are also hosted in small intrusions. Ni-Co-PGE metal resources in China mainly come from this type of ore deposits. Although some magmatic sulfide deposits, such as De'erni and Jianchaling, are related to ophiolites. They are less important in terms of their economic values.

3.2 Concept on magmatic deposits in small intrusions

Tang (2002) suggested a model for magmatic deposits in small intrusions. This can be summarized as following: Large-scale, rich ore bodies form in small magmatic intrusions or nearby; the size of small intrusions is typically less than 10 square kilometers, and some are less than one square kilometer; the mineralized proportion (the volume of orebody /the volume of intrusion x 100%) of small intrusions is high. The mineralized proportion is more than 43% in Jinchuan, Kalatongke ore deposit is more than 50%, and No. 7 ore body of the Hongqiling ore deposit is more than 90%.

3.3 Small intrusions in three geological settings

Some small intrusions occur in rifts at the margin of the Palaeo-continent, and their metallogenic epochs are mainly at Palaeo-Proterozoic and meso-Proterozoic (such as the Chibaisong and Jinchuan deposits), and Paleozoic (such as the Xiaonanshan deposits). Some small intrusions are at the margin of the Palaeo-continents, and associated with the continental flood basalts. Their metallogenic epochs are mainly late-Proterozoic (such as the Dapoling deposits), and Paleozoic (such as the Limahe, Baimazhai, Jinbaoshan and Yangliuping deposits). Some small intrusions in orogenic belts are related to post-orogenic extension. Their metallogenic epochs are mainly Paleozoic (such as the Kalatongke, Hongqiling, and Huangshan deposits).

3.4 Key factors for formation of magmatic deposits in small intrusions

The magmatic ore deposits in small intrusions occur along deep faults. For instance, the suture between the North China block and Qilian mountains on the southern side of the Jinchuan ore deposit; the Kangguertage – Huangshan deep fault on the southern side of the Huangshan ore deposit; the Huifahe deep fault on the southern side of the Hongqiling ore deposit and the Eerqisi north-west deep fault on the northern side of the Kalatongke ore deposits all provided channels for mantle magmas to ascend and mineralize. Olivine-rich magmas and orthopyroxene-rich magmas are helpful for metallogenesis. Olivine-rich magma is characterized by high temperature and high nickel content, and is easy for contaminating SiO_2-rich country rock. The ore deposits of Jinchuan, Huangshan, Baimazhai, Noril'sk, Voisey's Bay are associated with olivine-rich magmas. Orthopyroxene-rich magmas may have the same significance as olivine-rich magmas. No.7 ore body of the Hongqiling ore deposit and Kalatongke ore deposit formed from orthopyroxene-rich magmas. There are wo types of sulfur source. Firstly, there is a small change in the values of $\delta^{34}S$, which are close to zero and distributed with normal distribution, indicative of characteristics of magmatic sulfur The Jinchuan, Hongqiling, Kalatongke, Huangshan, Chibaisong and Sudbury are the examples of this. Secondly, there are large scale variations in $\delta^{34}S$, which appear to be related to contamination with crustal sulfur. The Limahe, Noril'sk and Voisey's Bay are samples for this type. From the above discussion, we can state that mantle sulphur is the main characteristic of magmatic deposits in small intrusions in China. As the host intrusion is small in size, the ore bodies are relatively big and cannot derive solely from the small intrusion itself. Thus, during or prior to the emplacement of the intrusion, partial crystallization and liquation of magma must have occurred in the deep seated magma chambers, where the magma formed several parts: ore magma, sulfide-rich magma, sulfide-bearing magma and ore-free silicate magma from the base upwards. Then the differentiated magma penetrated into different spaces within the crust once or several times. In general, after the crystallization and differentiation and liquation of magma, the volume of ore-free silicate magma is much larger than the total volume of ore magma, sulfide-rich magma and sulfide-bearing magma. During the magma ascending, ore-free silicate magma penetrated into different spaces to form intrusive complex or erupt to the surface to form lavas. The remeining magma comprising ore magma, sulfide-rich magma and sulfide-bearing magma can penetrate into the same space, such as occurred in the Jinchuan, Kalatongke, Baimazhai and Limahe deposits, or penetrate into different spaces, such as the No.1 and No.7 ore bodies of the Hongqiling deposits. By comparison with local liquation, the ore/rock proportion of the small intrusions is much higher than average. This mechanism can explain why a small intrusion is accompanied by a large or supper large deposits.

4 Further study on magmatic deposits in small intrusions

Prospecting for this type of magmatic sulfide deposits started in 1980s in China. The Noril'sk-Talnanhk deposits are the other examples, with major reserves of copper and nickel within an area of 3 square kilometers. The Voisey's Bay deposits cover an area of less than 1 square kilometers. Some researchers have put forward "why are there no major Ni-Cu sulfide deposits in large layered mafic-ultramafic intrusions?" (e.g. Maier 2001).

From the present study on magmatic sulfide deposits, the deposits in small intrusions are Cu-Ni-PGE deposits with higher tenor of Cu and Ni than PGE, but the deposits in large layered intrusions are Pt-Pd deposits with low tenor of Cu and Ni. As there are no large layered intrusions in China, we should pay more attention to prospecting for Cu-Ni-PGE deposits in small intrusions.

On the other hand, metallogenesis in intrusions is not only important to mafic-ultramafic rocks, but also have important economic value and academic significance in intermediate-acidic rocks.

References

Naldrett AJ (1999) World-class Ni-Cu-PGE deposits: key factors in their genesis. Mineralium Deposita 34: 227-240

Liu YX, Tang HS, Wu HZ (1998) Types and ore–control factors of Cu-Ni sulfide deposits in China. Mineral Resources and Geology 12: 86-90. (in Chinese)

Tang ZL (196) Main types of magmatic sulfide deposit in China. Acta Geology Gansu 5: 45-64. (in Chinese)

Tang ZL (2002) Magmatic ore deposits in small intrusions in China. Engeering Science 4 : 9-12.(in Chinese)

Maier WD, Chusi L, De Waal S (2001) Why are there no major Ni-Cu sulfide deposits in large layered mafic-ultramafic intrusions? Canadian Mineralogist 39: 547-556

Zhang Q, Qian Q, Wang Y (2000) Rock Assemblages of Ophiolites and Magmatism beneath Oceanic Ridges. Acta Petrologica et Mineralogica 19: 1-7 (in Chinese)