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Geology and geochronology of magnetite–apatite deposits in the Ning-Wu volcanic basin, eastern China

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ABSTRACT

The Ning-Wu volcanic basin is an important part of the Middle-Lower Yangtze River Valley metallogenic belt in eastern China, where magnetite–apatite deposits are common. These magnetite–apatite deposits can be classified into two types. The first type includes the Washan, Taocun, Heshangqiao and Dongshan deposits, which are hosted in diorite porphyry and adjacent volcanic rocks. The second type includes Gushan, Baixiangshan and Hemushan deposits, developed at the contact between gabbro–diorite and sedimentary rocks. We used $^{40}Ar–^{39}Ar$ dating on phlogopite and U–Pb LA-ICP MS dating of zircon in ore-related diorite porphyry and gabbro–diorite to determine the timing of iron mineralization in the basin. The ages of the magnetite–apatite deposits such as Washan, Taocun, Heshangqiao Gushan Baixiangshan Hemushan deposits are from 130 Ma to 131 Ma. Thus the magnetite–apatite deposits in the Ning-Wu volcanic basin all formed at about 130 Ma, later than the skarn and porphyry Cu–Au deposits in the adjacent fault-uplift areas such as Edongnan, Jiu-Rui, Anqing-Guichi and Tongling clusters that are between 146 Ma and 135 Ma. Based on available petrological and geochemical data, the magnetite–apatite deposits in the Ning-Wu volcanic basin are interpreted to have formed under regional lithospheric extension and thinning, and ore-forming elements were derived from basaltic melts sourced from enriched lithospheric mantle and the crust.

1. Introduction

Magnetite (hematite) -apatite deposits are common in Proterozoic and Phanerozoic Fe–Cu–Au districts worldwide (e.g., Kiruna district, Sweden; Cloncurry district and Gawler Craton, Australia; Copiapo district, Chile; Mark and Foster, 2000; Williams et al., 2005). They are characterized by a mineral association of magnetite (hematite)–actinolite(diopside)–apatite, and are closely associated with granitic/dioritic intrusions with typical Na–Ca wall rock alteration. The magnetite (hematite)–apatite deposits are often classified into the IOCG family (Williams et al., 2005). Some magnetite (hematite)–apatite deposits have huge iron resources (Table 1) and become major iron deposits and important mineral exploration targets such as the Middle-Lower Yangtze River Valley metallogenic belt (abbreviated to "the Yangtze metallogenic belt") in eastern China, where they are one of the major sources of iron ore for the Chinese steel industry.

The Yangtze metallogenic belt is one of the most important Cu, Au, Fe and polymetallic belts in eastern China. It occurs in a fracture zone along the northern margin of the Yangtze Craton. Long-lived magmatic activity and associated Cu, Au and Fe deposits were controlled by secondary fault systems, and were localized both in fault-uplift areas and fault basins (Gu and Ruan, 1988; Chang et al., 1991; Zhai et al., 1992; Wang et al., 1996; Tang et al., 1998; Pan and Dong, 1999; Mao et al., 2006a,b; Zhou et al., 2007a,b, 2008; Dong et al., 2011; Hou and Yuan 2010; Hou et al., 2011). More than 200 ore deposits occur in seven clusters: Edongnan, Jiu-Rui (Jiujiang-Ruichang), Anqing-Guichi, Tongling, Lu-Zong (Lujiang-Zongyang), Ning-Wu (Nanjing-Wuhu) and Ning-Zhen (Fig. 1). The Edongnan, Jiu-Rui, Anqing-Guichi and Tongling clusters are located in fault-uplift areas and include skarn and porphyry Cu–Au deposits. The Lu-Zong and Ning-Wu clusters are located in fault basins and mostly are magnetite (hematite)–apatite deposits. Our work shows that these iron deposits are associated spatially with porphyry and skarn Cu–Au deposits, but are different in timing and probably in their tectonic trigger.

The Ning-Wu volcanic basin occurs in the eastern section of the metallogenic belt, and is an important district for magnetite–apatite deposits with large scale Fe mineralization associated with pyroxene diorite plutons. The Fe deposits occur either in the upper portions of plutons, at the contact between the plutons and overlying volcanic-sedimentary strata, or else they occur entirely in volcanic rocks adjacent to the plutons. They were classified as

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Table 1
Synopsis of selected magnetite–apatite and IOCG deposits in the world.

Age/region	Geological setting	Deposit/ occurrence name	Resources
Cenozoic			
Andes (Chile, Argentina, Bolivia)	Intermediate volcanic centers in closed basins	El Laco, Chile Arizaro, Argentina	(42/60Fe)
MexicanAltiplano, (Durango, Coahuila, Chihuahua)	Continentalarc felsic volcanic centers (incl. calderas)	Cerro de Mercado	(100/62Fe)
Mesozoic			
Southwestern North America (southwestern United States and western Mexico)	Arc and back arc extensional mafic or felsic volcano-plutonic complexes	Humboldt complex	(1000/30Fe; 10/1Cu)
		Yerington (Lyon)	(250/40Fe; 0.3Cu and 1/3.1Cu, 0.54Au)
Chilean coastal belt	Extensional arc mafic-intermediate volcano plutonic complexes	Candelaria	(470/16Fe, 1.07Cu, 0.22Au);
		Romeral	(200/45Fe)
Peruvian coastal belt	Extensional arc mafic-intermediate volcano-plutonic complexes	Marcona	(1400/54Fe, 0.11Cu)
		Raul-Condestable	(32/1.7Cu, 0.3Au, 6Ag),
Paleozoic			
Turgai province (Kazakhstan)	Mafic-intermediate arc volcano-plutonic complex	Kachar	(2000/45Fe)
		Sarbai	(725/45.6Fe, 4.05S)
		Sokolovsk	(967/41Fe)
Central Iran (Bafq district)	Anorogenic felsic volcanic rocks	Gole Gohar	
		Hamadan	
Late Proterozoic			
Rajasthan (India, Khetri Cu belt)	Anorogenic granites intruded into a Mid-Proterozoic volcano-sedimentary sequence	Mineville	(10/42Fe, REE)
Middle Proterozoic			
Wernecke and Ogilvie Mtns (northwestern Canada)	Thick package of continental margin sediments intruded by small volumes of mafic to intermediate igneous rocks	Olympic Dam	(3810/1.0Cu, 0.5Au, 0.04U3O8, 3.6Ag)
		Oak Dam	(560/50?Fe)
Mid Continent, United States SE Missouri)	Caldera setting in anorogenic felsic province	Kiruna	(2600/60Fe)
		Malmberget	(840/55Fe)
		Gruvberget	(70/55Fe)
Early Proterozoic			
Bergslagen, Central Sweden	Mafic-felsic volcanic sequence, possibly extensional	Langban	(1.3/40Fe)
Archean			
Carajas, Brazil	Mafic-felsicvolcano-sedimentary and granitic-dioritic plutonic rocks	Sossego	(355/1.1Cu, 0.28Au)

"porphyritic iron deposits" and magnetite–apatite deposits by Ning-Wu Research Group (1978), Ishihara et al. (1986) and Mao et al. (2006a,b), who reported that they are related to Mesozoic magmatism. The ores include magnetite (hematite)–apatite–actinolite(pyroxene), and resemble the Kiruna Fe deposit (Frietsch, 1978; Hildebrand, 1986; Chen, 2008). Mao et al. (2008) classified the Ning-Wu Fe deposits as IOCG type deposits. Since the research by the Ning-Wu Research Group (1978), little detailed and specific work was done on the geology, geochronology and tectonic setting of these deposits, and apart from minor work published in Chinese journals (Zhou et al., 2008, 2010), little work has been published in international journals, except recently by Hou et al. (2010) and Yu and Mao (2011).

Igneous rocks and associated mineralization in the Yangtze metallogenic belt have been dated using various techniques, including zircon U–Pb dating of intrusions, molybdenite Re–Os dating, and $^{40}Ar–^{39}Ar$ dating of K-bearing minerals in porphyry and skarn deposits (Wang et al., 2004; Xu et al., 2004, 2006; Zhang et al., 2006, 2008; Lou and Du, 2006; Du et al., 2007; Xie et al., 2007a,b, 2008a,b; Wang et al., 2007, 2008; Zhou et al., 2007a,b, 2008; Wu et al., 2008). These results have established the space–time relationships between the igneous events and Cu–Au mineralization. Recent similar studies in the volcano-sedimentary basins have started to establish space–time relations between magmatic-hydrothermal activities and iron deposits there (Zhang et al., 2003; Xie et al., 2007a,b; Fan et al., 2008; Zhou et al., 2008, 2010; Hou et al., 2010).

The timing of mineralization of the magnetite–apatite deposits in the basins was previously poorly constrained. The magnetite–apatite deposits in the Ning-Wu volcanic basin were dated using K–Ar and Rb–Sr techniques; $^{40}Ar–^{39}Ar$ was used on hydrothermal albite, and $^{208}Pb–^{232}Th$ ages of apatite were measured (Ning-wu Research Group, 1978; Yu and Mao, 2002; Yu et al., 2011). Because these isotopic ages were of variable reliability, the former researcher got the age from 90 Ma to 150 Ma. The origin of the magnetite–apatite mineralization has been poorly understood, as precise dating of ore-forming events is required to elucidate the metallogeny.

We have carried out detailed geological studies on different Fe deposits in the Ning-Wu volcanic basin, and sampled seven magnetite–apatite deposits to conduct $^{40}Ar–^{39}Ar$ dating on phlogopite and U–Pb LA-ICP MS dating on zircon from ore-related diorite porphyry and gabbro–diorite to determine the timing of Fe mineralization. These new investigations together with our recent studies published in Chinese journals (Fan et al., 2010, 2011; Yuan et al., 2011; Zhou et al., 2011) provide constraints on the space–time distribution, metallogenesis and tectonic settings of metallic deposits in the Ning-Wu volcanic basin as well as in other parts of the Yangtze metallogenic belt. This study will help us to understand these