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Geochemical Characteristics of Sinian Manganese Deposits in China

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Abstract Sinian is one of the main periods of the formation of manganese deposits in China. Sinian manganese deposits are mainly hosted in carbon-rich black shale and siliceous shale formed during the Sinian interglacial period. The composition of manganese ore is simple. The main ore mineral is manganiferous carbonates. The grade of manganese ore is about 16–25%, with Mn/Fe>5 and P/Mn=0.006–0.14. Based on the tectonic setting and geological and geochemical characteristics of manganese deposits, this paper discusses the process of migration and concentration of manganese and ore-forming conditions of Sinian manganese deposits in China.

Key words: manganese, deposit, Sinian, China

Sinian is one of the main Mn ore-forming periods in China. The explored Mn resources in this period is only next to those in the Devonian. Sinian Mn ore deposits are mainly distributed in two metallogenic belts, i.e., the Chengkou Mn metallogenic belt on the north side of the Yangtze plate and Songtao-Xiangtan Mn metallogenic belt on the southeast side of the Yangtze plate. Mn deposits in the two belts are similar in geological setting, host rock sequences and geochemical features.

1 Tectonic Setting

The Chengkou and Songtao-Xiangtan Mn metallogenic belts extend along the Jinningian palaeo-island arcs on the north and southeast sides of the Yangtze plate (Fig. 1). In the Jinningian stage the South China Ocean plate and Qinling ocean plate were subducted towards the Yangtze plate from the south and the north respectively, and corresponding trench-arc-basin systems developed on the north and southeast sides. The palaeo-arc on the southeast side extends from the Jiuling Mountains to the Xuefeng Mountains (Wang et al., 1986; Yang et al., 1986; Liu et al., 1993); the arc on the north side, from Ningqiang to Xixiang (Hunan Bureau of Geology and Mineral Resources, 1992; Tao et al., 1993; Zhang et al., 1993). As after the Jinning movement the oceanic plate disappeared and the Yangtze plate was amalgamated to the Cathaysian plate and the North China plate respectively (Liu et al., 1993), the Jiuling-Xuefeng island arc and Ningqiang-Xixiang island arc merged with the Yangtze plate to form the Yangtze continental-margin zones. In the Sinian, as just solidified continental crust, the crust in the palaeo-island arcs was thin and displayed the features of transitional crust. The basins located on the inner sides of the palaeo-island arcs were relatively stable tectonically and favoured precipitation and enrichment of Mn ore substances. The basins on the outer sides of the palaeo-island arcs were tectonically relatively active, where submarine volcanism and hydrothermal activities occurred frequently, thus providing a material basis for the formation of Mn deposits. Therefore, the Jinningian-aged palaeo-island arcs on the south and north sides of the Yangtze plate were the favourable tectonic environments for the formation of Sinian Mn deposits.

During the interglacial stages in the Sinian Period, the sea level rose and the Jinningian palaeo-island arcs were basically below sea level. The submerged palaeo-island arcs acted as barriers, thus forming many restricted and semi-restricted reducing sea basins in the palaeo-island arcs. Shallow basins on their continental sides and abyssal basins on their oceanic sides

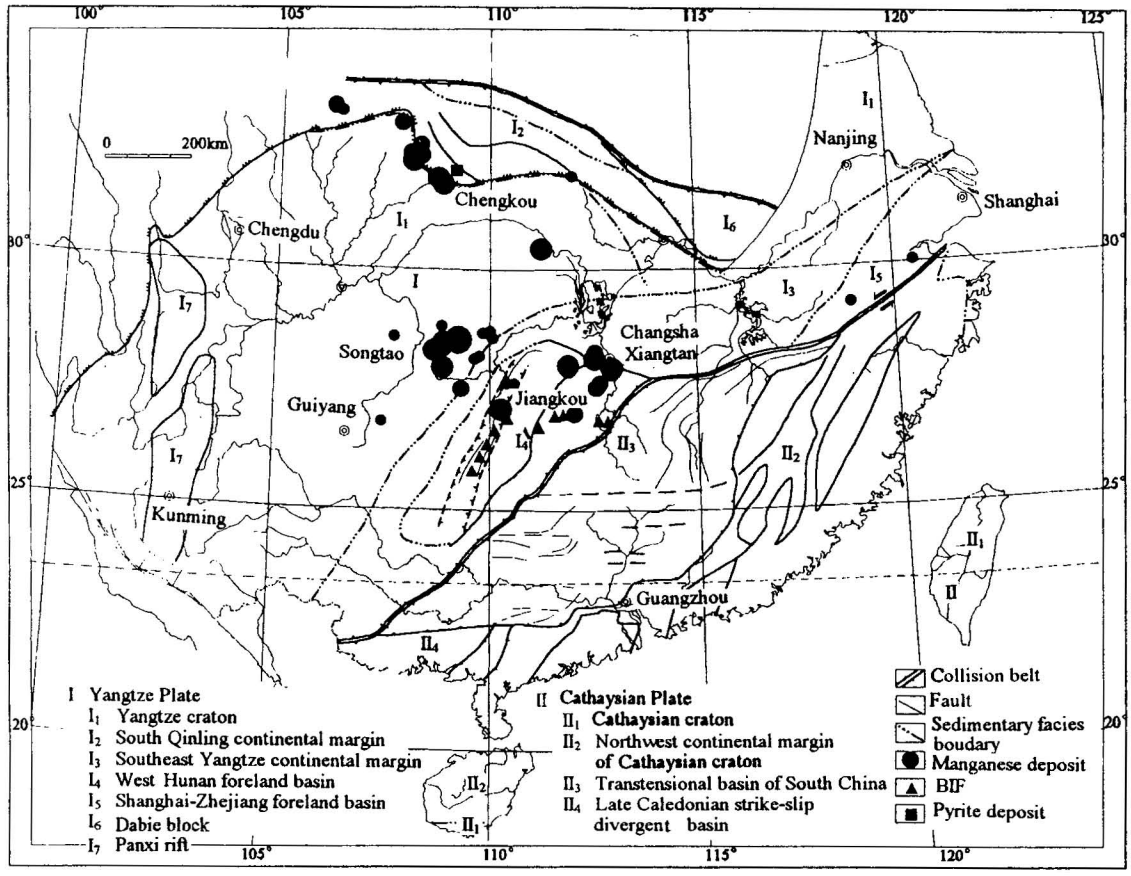

Fig. 1. Distribution of Sinian manganese deposits in China.

were oxygenated and anoxic respectively; thus abrupt change in seawater chemistry took place in the palaeo-island arcs, which was very favourable for Mn precipitation and enrichment in these chemical barrier zones.

2 Characteristics of Host Rocks of Mn Ore

Mn deposits in the Songtao-Xiantan belt mainly occur in the early Sinian Xiangmeng Group. The early Sinian consists dominantly of the Nantuo, Xiangmeng and Jiangkou formation, which were deposited during two glacial stages and one interglacial stage respectively (Hunan Bureau of Geology and Mineral Resources, 1992). Mn deposits are hosted in carbonaceous shale of the Xiangmeng Formation. In the early Sinian, sedimentary basins became deeper from the Yangtze plate to the South China Sea and the thickness, rock association and ore potential of the lower Sinian ore-bearing strata vary from place to place. Here the Songtao and Jiangkou areas are taken as examples.

The Songtao area belongs to a littoral-neritic area on the inner side of the Xuefeng palaeo-island-arc and the Jiangkou area belongs to a deep-water area of a shallow sea on the outer side of the Xuefeng palaeo-island arc. The sedimentary thickness of the lower Sinian in the Jiangkou area is much greater than that in the Songtao area (Fig. 2). The Nantuo Formation in both areas consists mainly of fluvio-glacial deposits. However, the thickness in Jiangkou is 2–3 times that in Songtao. The Xiangmeng Formation deposited in the interglacial stage hosts Mn ore in both areas. Its thicknesses are similar but its lithologies are different in the two areas. In the Songtao area carbonaceous shale is dominant, while in the Jiangkou area, in addition to carbonaceous shale, siliceous shale is developed below the Mn ore layer. The Jiangkou Formation deposits in the Jiangkou area are quite different from

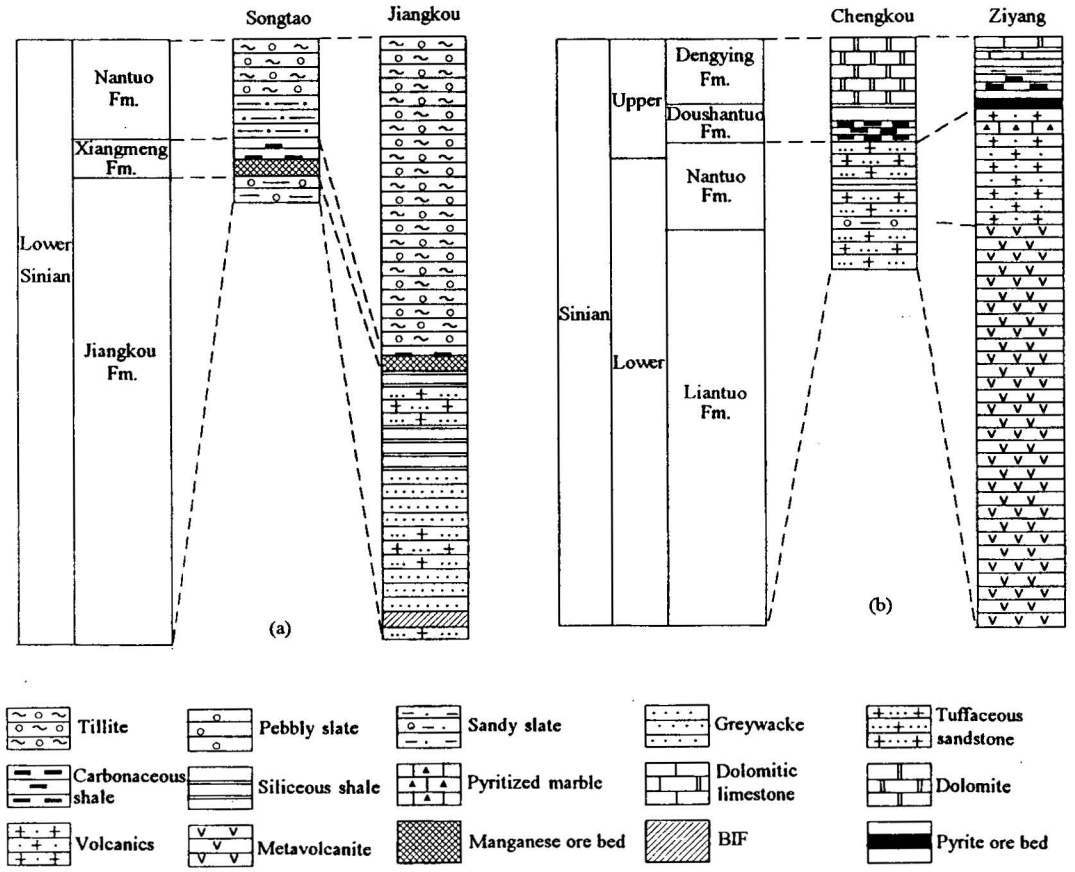

Fig. 2. Stratigraphic columnar sections of the Sinian.

(a) Songtao-Xiangtan metallogenic belt; (b) Chengkou metallogenic belt.

those in the Songtao area. In the Songtao area, the formation is composed mainly of conglomeritic slate of littoral faices, only over 10 m thick, without any Mn mineralization. In the Jiangkou area, the formation is much thicker, nearly 10 times thicker than that in the Songtao area and complicated in lithology. The strata are dominated by arenaceous rocks rich in volcanic deposits, implying that strong tectonism took place during the early Sinian there. And an iron ore layer of cherty iron-formation occurs at the bottom of the Jiangkou Formation in the Jiangkou area. This iron ore layer is widely distributed on the south side of the Songtao-Xiangmeng Mn metallogenic belt.

In the Chengkou Mn metallogenic belt, Mn ore deposits occur in the upper Sinian Doushantuo Formation. The Sinian consists of the Dengying and Doushantuo formations of the upper Sinian Series and the Nantuo and Liantuo formations of the lower Sinian Series. In some areas no subdivision can be made in the upper or lower Sinian Series, so the strata are generally designated as the upper or lower Sinian Series (Fig. 2). In the Sinian, sedimentary basin became deeper and tectonic activity became more intense from south to north in the Ningqiang-Xixiang palaeo-island arc on the north margin of the Yangtze plate. This change is recorded in the lithology and ore potentials. Here the Sinian strata in the Ziyang and Chengkou areas are taken as examples.

The Chengkou area is located on the south side of the Ningqiang-Xixiang palaeo-island arc and the Ziyang area to the north of Chengkou, far away from the continent. The early Sinian in the Chengkou area is dominated by tuffaceous sandstone intercalated with siliceous rocks and pebbly sandstone, being not divided, 800 m thick; whereas in the Ziyang area the lower Sinian is divided into the Yunxi and Yaoshan

formations, consisting of metavolcanics such as quartz schist and sericite schist and intermediate-basic and intermediate-acid volcanics, with a total thickness of 3000 m, suggesting that in the early Sinian strong tectonism and submarine volcanic erupting took place in the two areas. The eruption centre was located in the Ziyang area. In the late Sinian the two areas were under a relatively stable environment. In the Chengkou area the sea was relatively shallow. In the area, the Doushantuo Formation is dominated by carbonaceous shale and dolomite at top of the formation hosts some lenses of Mn ore, which form a Mn deposit; the Dengying Formation is composed of dolomite, and the upper Sinian in the Ziyang area is not divided, made up of siliceous rocks, carbonaceous shale and siliceous and dolomitic limestone, reflecting that they were deposited in much deeper sea water than in the Chengkou area, and pyrite and siderite mineralizations appear at the bottom.

To sum up, during the Sinian, in the two Mn metallogenic belts, the Sinian basins on the inner sides of the palaeo-island arcs were characterized by less tectonism, monotonous lithology, thin deposits with small amounts of volcanic materials, dominance of Mn mineralization and close association of Mn ore deposits with black shale; the basins on the outer sides of the palaeo-island arcs by strong tectonism, presence of abundant volcanic materials and siliceous rocks, great stratal thickness and less developed Mn mineralization, but occurrence of iron or pyrite mineralization in a horizon equivalent to or below the horizon of Mn mineralization on the inner sides of the arcs.

3 Geochemical Characteristics of Mn-Deposits

The main ore minerals in the Sinian Mn deposits of China are rhodochrosite and other Mn-carbonate minerals. The ore layers are closely associated with carbonaceous shale. Their hanging wall or footwall and even the barren rocks are all rich in carbon. The organic material content in Mn ore is also high. And abundant algal fossils are discovered in the ore, indicating that organisms participated in Mn mineralization. Generally a little pyrite is contained in the ore and the sulphur content is 1–2% of the ore.

The ore has a relatively low content of Fe (2–4%), with Mn/Fe >5. The phosphorus content is higher and the P/Mn ratio is 0.005 (Table 1). Phosphorus in ore of the Chengkou belt is higher than in ore of the Songtao-Xiangtan belt. The higher P content is inconvenient for Mn utilization. However, P is unevenly distributed in the Mn ore beds. In some Mn mines, the middle parts of ore beds have lower phosphorus and higher manganese than the lower parts and upper parts of ore beds, as exemplified by the Huayuan and Gaoyan Mn mines. In some mines Mn ore beds alternate with P ore layers. Phosphorus occurs variously in different minerals of the manganese ore. For instance, over 87% of phosphorus in the ore of the Gaoyan Mn mine is enclosed in siliceous and clay minerals, and only 12.35% in Mn carbonate minerals; 62% of phosphorus in the ore of the Gucheng Mn mine is enclosed in siliceous and clay minerals and 37% in Mn-carbonate minerals. It follows thus that phosphorus is mainly associated with quartz and clay minerals. So, Mn ore of commercial value can be obtained from

Table 1 Contents of major elements of Sinian Mn ore in China (wt%)

Metallogenic belt	Deposit	Mn	TFe	S	P	$C_{organic}$	Mn/Fe	P/Mn
Songtao-Xiangtan	Xiangtan	21.49	2.50	1.40	0.145	0.71	8.60	0.0067
	Tangganshan	20.72	3.71	2.00	0.124	3.84	5.58	0.006
	Jiangkou	16.39	3.30	0.36	0.154	0./86	0.97	0.0094
	Huayuan	19.85	2.54	1.53	0.234	1.75	7.81	0.0118
	Xiushan	16.65	3.15	0.37	0.20	1.98	5.28	0.0120
	Yanglizhang	20.00	2.96	1.10	0.208	1.84	6.75	0.0104
	Datangpo	23.17	3.57	1.29	0.209	/	6.49	0.009
Chengkou	Gucheng	18.82	2.45	2.19	0.702	3.06	7.68	0.0373
	Gaoyan	20.53	1.95	1.41	0.22	/	10.53	0.0107
	Maliuba	14.50	0.55	/	2.05	/	26.36	0.1414

high-phosphorus Mn ore belts by using appropriate mining and ore processing techniques.

4 Discussion and Conclusions

1. The Sinian manganese deposits in China are mainly distributed along the Jinningian palaeo-island arcs. In the Sinian, palaeo-island arcs along the north and south edges of the Yangtze plate are characterized by transitional crust. On the outer sides of the palaeo-island arcs, submarine volcanic activity and hydrothermal activity occurred frequently. The strata consist mainly of volcanic rocks volcanic-sedimentary rocks and siliceous rocks formed by hydrothermal activity. Iron and pyrite mineralizations are often found therein. On the inner sides of the palaeo-island arcs, tectonic environment was relatively stable, and the strata consist mainly of terrigenous clastic rocks or carbonate rocks, without or with only a small amount of volcanic deposits. Manganese deposits are mainly found in such sedimentary areas. Reverse zonation of iron and manganese mineralization shows that ore-forming materials originated from the basins. The Sinian BIF is closely associated with volcanic rocks and volcanic-sedimentary rocks. Strata hosting manganese deposits also contain a small amount of volcanic deposits. So it is inferred that ore-forming materials related to submarine volcansm and hydrothermal activity mainly originated from a deep source.

2. The high ratio of Mn/Fe in Sinian manganese deposits of China indicate that complete separation may have taken place between Fe and Mn before Mn deposition, which is also verified by the spatial zonation of manganese deposits and iron deposits in Sinian strata. The migrating ability of manganese is stronger than that of iron in nature. The separation between Mn and Fe can be achieved by the change of conditions of water media during their transportation. The Sinian manganese deposits of China have a simple element association and greatly differ in trace elements from ferromanganese nodules in present-day oceans, which indicates that the formation of Sinian manganese deposits of China progressed through a long period of transportation and separation before precipitation.

3. The Sinian manganese deposits in China were formed during the interglacial stage. The host rocks of the manganese ore beds are mainly carbon-rich black shale and siliceous rocks and the ore is also organic-rich, which reflects that the medium transporting manganese was reducing water rich in organic matter. Such an anoxic environment favoured the dissolution and concentration of manganese (Force, 1988). The Sinian manganese deposits in China have a high content of the harmful element phosphorus. Alternating manganese ore beds and phosphorus ore beds are even found in some deposits, which shows that manganese and phosphorus have the similar concentration environment and process. It is inferred that the formation of manganese deposits may be the result of the interaction between reducing water rich in manganese and oxidized water lacking in manganese.

4. Sinian manganese deposits commonly contain too much phosphorus, which is disadvantageous to industrial production, but the distribution of phosphorus in manganese ore beds is very uneven. There was a trend of separation between manganese and phosphorus during their concentration, which is mainly displayed in the following three respects: (1) Manganese ore beds and phosphorus ore beds alternate with each other in some manganese deposits. (2) The middle part of a manganese ore bed is high in manganese and low in phosphorus, while the upper and lower parts are low in manganese and high in phosphorus. (3) In high-phosphorus manganese ore, phosphorus is mainly wrapped in gangue minerals such as quartz and clays, while rhodochrosite and manganiferous calcite contain much less phosphorus. Based on this feature, suitable techniques of mining and ore dressing must be adopted in the development and use of this type of high-phosphorus manganese deposits.

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