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Pb-Zn-Ag-bearing Manganoan Skarns of China

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Abstract Manganoan skarns consist of special Mn (Ca, Mg, Fe, Al) silicate metasomatic minerals and are usually associated with Pb-Zn(Ag) mineralization. They occur chiefly along the lithologic contacts or faults and fractures of carbonate wall rocks distal from the intrusive contact zone, and are combined with Fe, Cu, W, Sn and Cu-bearing calcic or magnesian skarns occurring in the contact zones to constitute certain metasomatic zoning. Manganoan skarns are formed later than calcic or magnesian skarns. Their rock-forming temperatures are lower than those of calcic or magnesian skarns. The mineral assemblages of manganoan skarns occurring in different carbonate rocks (limestone or dolomite) are notably different.

Key words: manganoan skarn, calcic skarn, magnesian skarn, continental-margin orogenic belt, exocontact carbonate rocks, Pb-Zn-Ag skarn deposit

1 Introduction

Skarns are generally divided into two types according to their mineral compositions: calcic skarn and magnesian skarn (Korzhinskii, 1955; Zharikov, 1968; Einandi et al., 1981). The calcic skarn consists mainly of grossular-andradite series, diopside-hedenbergite series, wollastonite, vesuvianite, scapolite etc. Its wall rock is limestone or marble. The magnesian skarn is composed chiefly of forsterite (or its alteration product, namely serpentine), diopside, phlogopite, spinel, tremolite and the humite group, and the wall rock is dolomite rock or dolomitic marble. Based on studies of numerous skarn deposits of China, especially Pb-Zn-(Ag) skarn deposits, and in comparison with skarn deposits in other parts of the world, we proposed a manganoan skarn formation (Zhao et al., 1983, 1990, 1991). In recent years, we have studied the Bajiazi Ag-Pb-Zn-polymetallic deposit, Liaoning Province, and Jiaoli Ag-Pb-Zn-polymetallic deposit, Jiangxi Province in detail, and have got more information on manganoan skarns. The distribution and brief geological characteristics of the major Pb-Zn-(Ag)-bearing manganoan skarns in China are shown in Fig. 1 and Table 1.

2 Tectonic Setting

The tectonic environments of the Pb-Zn-(Ag)-bearing manganoan skarns may be divided into three types.

2.1 Continental-margin orogenic belt

This is the most important tectonic environment for forming manganoan skarns. Examples are the peripheries of the Shizhuyuan W-Sn-polymetallic deposit, Hunan Province, the Jiaoli Ag-Pb-Zn-W deposit, Jiangxi Province, and the Makeng Fe (Mo, Pb, Zn,) deposit and Dapai Pb-Zn deposit, Fujian Province, China (Zhao et al., 1997, 2001), as well as the Groundhog Pb-Zn-(Ag) deposit in New Mexico (Meinert, 1987), United States, the Ban Ban Zn (Cu, Pb) deposit, western Australia (Ashley, 1980), the Naica Ag-Pb-Zn deposit, Mexico (Einaudi et al., 1981), and the Aguilar Pb-Zn-Ag deposit, western Argentina (Gemmell et al., 1992).

Ore-bearing manganoan skarns and their related intrusions are mainly products of Mesozoic and Cenozoic tectono-magmatic mobile belts.

2.2 Fault depression zone on the continental block margin

The example of the ore-bearing manganoan skarns in this tectonic environment is the Bajiazi Ag-Pb-Zn-polymetallic deposit, Liaoning Province, China (Zhao et al., 2001) and the Yeonhwa Ulchin Pb-Zn(Cu,Ag) deposit, South Korea (Yun and Einaudi, 1982).

Manganoan skarns occur also in island arcs, as exemplified by the Nakatatsu, Kamioka and Chichibu Pb-Zn-(Cu-Fe, Ag) deposits, central Japan (Shimizu and Iiyama, 1982).

3 Wall-rock Conditions

The Pb-Zn(Ag)-bearing manganoan skarns are hosted by limestone, dolomitic limestone and dolomite with sandstone or siltstone of the Proterozoic, Cambrian,

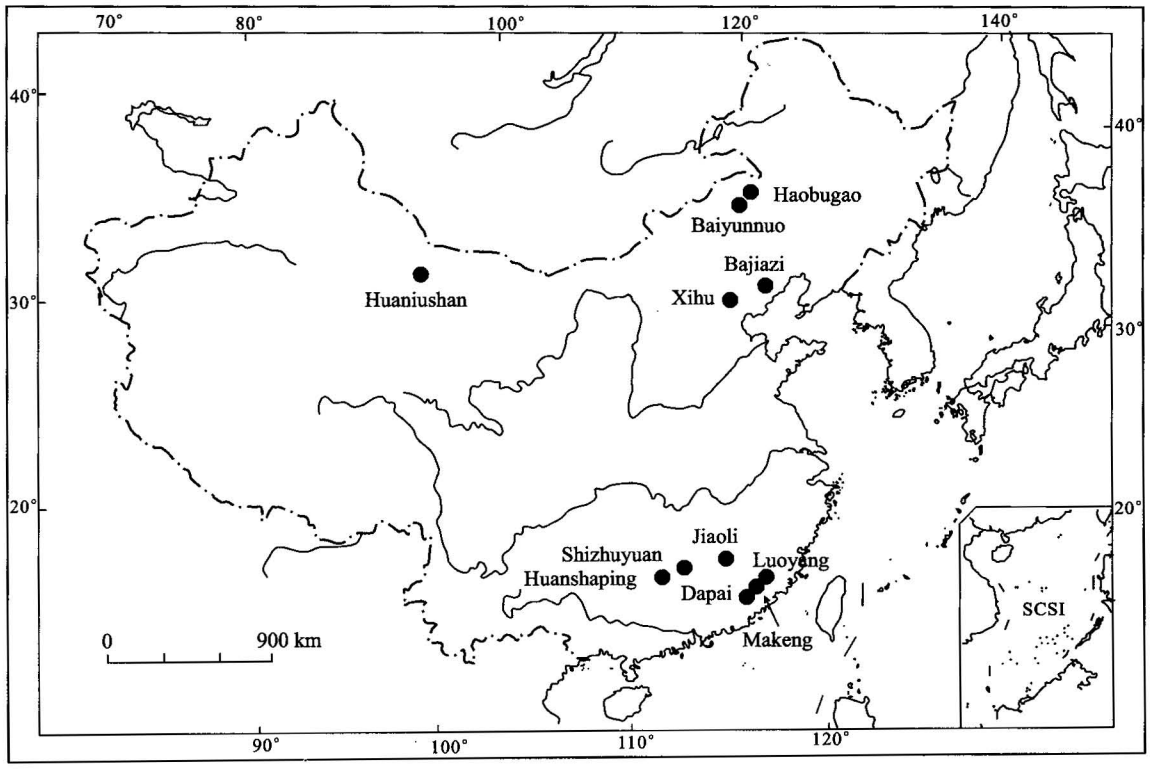

Fig. 1. Distribution of the major Pb-Zn-Ag-bearing manganoan skarns in China.

Devonian and Carboniferous-Permian formation. Studies of regional stratigraphic geochemistry suggest that most of the host-rocks have comparatively high manganese contents.

4 Related Intrusions

Intrusions related to Pb-Zn(Ag)-bearing skarns are Yanshanian in age (112–177 Ma). They include diabase-diorite, quartz diorite, quartz monzodiorite, quartz monzonite, granodiorite, granodiorite porphyry, granite, granite porphyry and quartz porphyry, and occur mainly as stocks and dykes. In the endocontact zones, K-feldspathization phenomenon is common.

The intrusions have low Fe_2O_3/FeO ratios (0.09–0.49), reflecting that they were formed under reduction conditions. The initial $^{87}Sr/^{86}Sr$ ratios of the plutonic rocks range from 0.707 to 0.746.

5 Mineral Compositions of Manganoan Skarns

Manganoan skarns are characterized by special Mn (Ca, Mg, Fe, Al) silicate mineral assemblages. Different host carbonate rocks have different manganoan skarn mineral assemblages. When the country rocks are dolomite or dolomitic marble, there may appear manganoan diopside, manganoan tremolite, magnesian pyroxmangite, magnesian rhodonite, spessartine, knebelite, mangano-anthophyllite, mangano-cummingtonite and manganpyrosmalite. The example is the Bajiazi Ag-Pb-Zn-polymetallic deposit, Liaoning Province. If the wall rocks are limestone or marble, the manganoan skarns generally are composed of manganoan hedenbergite, johannsenite, bustamite, pyroxmangite, rhodonite, spessartine, manganoan grossular, tephroite, manganoan actinolite and manganoan ilvaite, and locally, manganoan vesuvianite, manganoan grunerite and helvite may be identified.

Most of the Pb-Zn (Ag)-bearing skarns of China belong to this type.

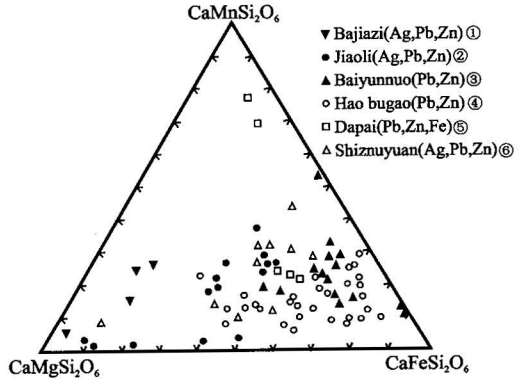

Fig. 2. Compositions of pyroxenes in the manganoan skarns (①,② and ⑤, this study; ③ and ④, after Zhao et al., 1997; ⑥, after Mao et al., 1998).

Table 1 Geological characteristics of the major Pb-Zn-(Ag)-bearing manganoan skarns in China

Locality	Ore grade	Relative size	Host rocks	Intrusive rocks	Skarn minerals	Retrograde Minerals	Ore Minerals	References
Haobugao, Inner Mongolia	Zn 4.9%, Pb 2.18%, Ag 17g/t, (Fe, Cu, Sn)	Large	Lower Permian metasiltstone, marble	Yanshanian granite (136 M a)	Ad, Gr, Di, Mn, Hd, Ves	Ep, Hast, Fe-Hrb, Fe-Ed, Qz, Cal	Mt, Py, Cp, Cas, Sph, Gn	This study
Baiyunnuo, Inner Mongolia	Zn 5.44%, Pb 2.02%, Ag 31g/t	Large	Lower Permian limestone, slate	Yanshanian granodiorite porphyry (171–160 Ma)	Ad, Di, Mn-Hd, Bust, Jo	Ep, Q, Chl, Cal	Sph, Gn, Py, Cp, Ars, Mt, Po	Zhao et al., 1997
Bajiazi, Liaoning	Ag 186g/t, Zn 2.32%, Pb 1.79%, Cu 0.30%	Large	Middle Proterozoic dolomitic marble	Yanshanian quartz monzodiorite (170–177.4 Ma)	Di, For, Ad, Sp, Pyrx, Rho, Mn-Di	Tr, Phl, Serp, Mn-Ant, Mn-Cum, Man, Mn-Tr	Mt, Py, Sph, Po, Cp, Gn, Arg, Ag, Ala, Mn-Ilm	This study
Xihu, Beijing	Ag 83g/t, (Pb, Zn, Mn)	Small	Lower Cambrian dolomitic marble	Yanshanian granite aplite	Sp, Rho, Mn-Di, Tep	Mn-Tr, Mn-Cum, Qz, Cal, Dol, Rh	Sph, Gn, Py, Cp, Po, Arg	This study
Huangshaping, Hunan	Zn 7.77%, Pb 4.52%, Ag 80g/t, WO_3 0.25%, Mo 0.04%	Large	Lower Carboniferous limestone	Yanshanian granite porphyry quartz porphyry	Ad, Di, Hd, Mn-Hd	Hast, Qz, Cal, Flu	Mt, Py, Ars, Cp, Sph, Gn, She, Cas, Mol	Zhao et al., 1990
Dapai, Fujian	Zn 3.08%, Pb 1.94%, Ag 33g/t	Small	Carboniferous limestone	Yanshanian granodiorite porphyry	Jo, Ad, Mn-Hd	Flu, Qz, Cal, Ilv	Mt, Sph, Gn, Mol, Py	Zhao et al., 1983
Makeng, Fujian	ΣFe 38.1%, Mo 0.07%, (Pb, Zn, Ag)	Large	Carboniferous limestone, sandstone	Yanshanian diabase-diorite, granite (112–164 Ma)	Di, Ad, Mn-Hd, Bust, Mn-Ilv, Ves	Ep, Flu, Cl-Hrb, Qz, Cal, Mn-Act	Mt, Py, Mol, Sph, Gn	Zhao et al., 1983
Luoyang, Fujian	ΣFe 48.6%, Zn 1.31%, Pb 4.45%	Intermediate	Carboniferous-Permian limestone	Yanshanian granite porphyry	Ad, Di, Pyrx, Mn-Hd	Ep, Qz, Cal, Chl	Mt, Sph, Gn, Py, Cp	Zhao et al., 1983
Jiaoli, Jiangxi	Ag 154g/t, Zn 1.19%, Pb 2.02% ,WO_3 0.3%	Intermediate	Cambrian metasiltstone, marble	Yanshanian granodiorite (173–193 Ma)	Di, Mn-Gr, Mn- Hd, Mn-Ves, Bust	Mn-Act, Flu, Qz, Cal, chl	Sch, Sph, Gn, Py, Po, Arg, Ag, Hes, El, Bi	This study
Shizhuyuan (periphery), Hunan	Zn 2.68%, Pb 3.56%, Ag 80g/t	Intermediate	Upper Devonian limestone	Yanshanian granite, granite porphyry (151–172 Ma)	Sp, Rho, Tep, Bust, Mn-Hd, Mn-Di	Flu, Qz, Chl, Cal	Sph, Gn, Cas, Po, Cp, Py, Ars, Sch, Arg, Ag, Mol, Bis	Mao, et al., 1998
Huaniushan, Gansu	Ag 174g/t, Zn 2.5%, Pb 5.5%	Intermediate	Sulurian-Ordovician limestone, phyllite	Hercynian granite	Ad, Di, Bust	Qz, Ser, Cal, Hrb	Sph, Gn, Py, Po, Ars, Ala, Pyr, Fre, Dy	Wanging ①, 1990

Abbreviations: Ad-andradite, Ag-native silver, Ala-alabandite, Arg-argentite, Ars-arsenopyrite, Bi-bismuth, Bis-bismuthinite, Bust-bustamite, Cal-calcite, Cas-cassiterite, Chl-chlorite, Cl-Hrb-chlorian hornblende, Cp-chalcopyrite, Di-diopside, Dy-dyscrasite, El-electrum, Ep-epidote, Fe-Ed-ferro-edenite, Fe-Hrb-ferro-hornblende, Flu-fluorite, For-forsterite, Fre-freibergite, Gn-galena, Gr-grossular, Hast-hastingsite, Hes-hessite, Hrb-hornblende, Ilv-ilvaite,Jo-johannsenite, Man-manganpyrosmalite, Mn-Act-manganoan actinolite, Mn-Ant-mangano-anthophyllite, Mn-Cum-manganocummingtonite, Mn-Di-manganoan diopside, Mn-Gr-manganoan grossularite, Mn-Hd-manganoan hedenbergite, Mn-Tr-manganoan tremolite, Mn-Ves-manganoan vesuvianite, Mol-molybdenite, Mt-magnetite, phl-phlogopite, Po-pyrrhotite, Py-pyrite, Pyr-pyrargite, Pyrx-pyroxmangite, Qz-quartz, Rh-rhodochrosite, Rho-rhodonite, Sch-scheelite, Ser-sericite, Serp-serpentine, Sph-sphalerite, Sp-spessartine, Tr-tremolite, Tep-tephroite

① Wanging et al. 1990. Silver deposits of China (unpublished report)

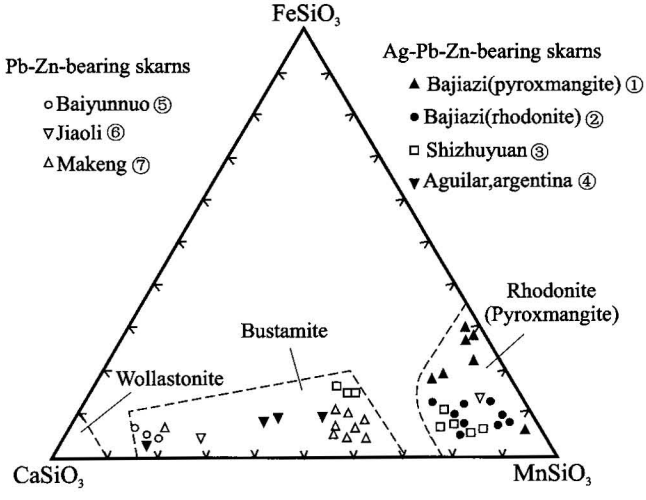

Fig. 3. Compositions of manganoan pyroxenoids in the manganoan skarns (①, ②, ⑤ and ⑥, this study; ⑦, after Zhao et al., 1983; ③, after Mao et al., 1998; ④, after Gemmell, 1992).

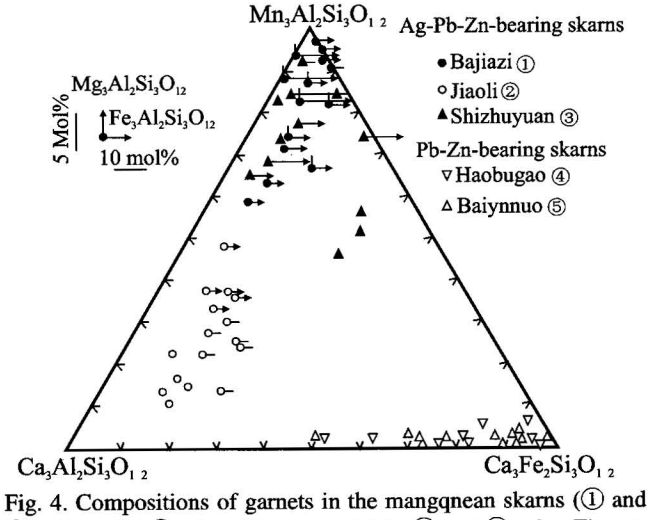

Fig. 4. Compositions of garnets in the mangqnean skarns (① and ②, this study; ③, after Mao et al., 1998; ④ and ⑤, after Zhao et al., 1997).

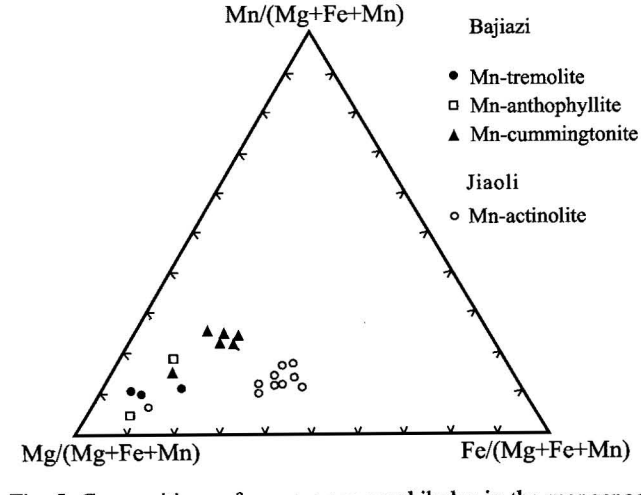

Fig. 5. Compositions of manganoan amphiboles in the manganoan skarns.

The associated ore minerals are mainly pyrite pyrrhotite, sphalerite, galena, chalcopyrite and alabandite, and various silver minerals. The late-stage superimposed hydrothermal metasomatic minerals may include quartz, fluorite, calcite, rhodochrosite, manganocalcite, kutnohorite, manganoan chlorite etc.

The compositions of manganoan pyroxenes, pyroxenoids, garnets and amphiboles are shown in Figs. 2, 3, 4, and 5 respectively.

6 Occurrence and Zonation of Ore-bearing Manganoan Skarns

Pb-Zn-(Ag)-bearing manganoan skarns occur usually in the exocontact zones along lithologic contacts, faults or fractures of carbonate wall rocks, distal from intrusives, in the form of lenses, veins, stratoid bodies or pockets. In the contact zones there occur generally Fe-, Cu-, W- and Sn-bearing calcic or magnesian skarns. Therefore, the above-mentioned different ore-bearing skarns usually display clear metasomatic zonation in space.

Here we give some typical examples of the zonal model for ore-bearing manganoan skarns.

6.1 Bajiazi Ag-Pb-Zn-polymetallic deposit

The zonation is shown as quartz monzodiorite (170–177.4 Ma)→K-feldspathized quartz monzodiorite or diopside-perthite metasomatite → Fe(Mo)-bearing magnesian skarn zone (forsterite+ diopside + tremolite + phlogopite) → Cu (S, Fe, Zn)- bearing manganoan - magnesian skarn zone (manganoan diopside + manganoan tremolite + magnesian pyroxmangite + mangano-anthophyllite) → Ag-Pb-Zn-bearing manganoan skarn zone (magnesian rhodonite + pyroxmangite + spessartine + mangano-cummingtonite) → dolomitic marble (Mesoproterozoic).

6.2 Jiaoli Ag-Pb-Zn-W deposit, Jiangxi province

The zonation is shown as granodiorite (173–193 Ma) → K-feldspathized granodiorite → W(Zn)-bearing calcic skarn zone (diopside or hedenbergite + grossular ± wollastonite) → Ag-Pb-Zn-bearing manganoan skarn zone (manganoan grossular + manganoan hedenbergite + manganoan actinolite ± bustamite ± manganoan vesuvianite) → crystalline limestone and metamorphic siltstone (Cambrian).

6.3 Haobugao Pb-Zn(Fe, Cu, Sn, Ag) deposit, Inner Mongolia

The zonation is shown as granite (136 Ma)→K-feldspathized granite→Fe-Sn-bearing calcic skarn zone (diopside or hedenbergite + andradite)→Cu(Zn)-bearing

calcic skarn zone (hedenbergite + andradite)→Pb-Zn(Ag) - bearing manganoan skarn zone (manganoan hedenberzite+andradite)→limestone (Lower Permian).

7 Formation Temperatures of Manganoan Skarns

As mentioned above, Pb-Zn(Ag)-bearing manganoan skarns occur usually in the exocontact carbonate rocks distal from the intrusive contact, and belong to infiltration metasomatic-type skarn. They formed generally later than calcic or magnesian skarns, so their formation temperatures are lower than those of calcic or magnesian skarns occurring chiefly in intrusive contact zones. Studies of fluid inclusions of the manganoan skarn minerals show that the formation temperatures for calcic or magnesian skarns range from 340 to 650°C with salinities of 27–51wt% $NaCl_{eq.}$, while for manganoan skarns, the formation temperatures are 220–420°C with salinities of 7–16wt% $NaCl_{eq.}$, corresponding with the formation temperatures of the associated sphalerite (230–380°C).

8 Conclusions

(1) In the classification of skarns, besides calcic and magnesian skarns, there is also a manganoan skarn type, which is composed of a special Mn (Ca, Mg, Fe, Al) silicate mineral assemblage and associated usually with Pb-Zn(Ag) mineralization. Different host carbonate rocks have different mineral assemblages of manganoan skarn.

(2) The most important tectonic setting of the Pb-Zn (Ag)-bearing manganoan skarns is continental-margin orogenic belts, and the less important ones are fault depression zones on continental block margins and island arcs.

(3) Manganoan skarns occur usually in the exocontact carbonate rocks distal from the intrusive contact zone, and belong to infiltration metasomatic skarn type. Their formation temperatures are lower than those of the calcic or magnesian skarns occurring in the intrusive contact zones. The former ore-bearing skarns show generally a clear metasomatic zoning.

(4) The manganoan skarn is one of the important ore-searching indicators for evaluating Pb-Zn-Ag skarn deposits.

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