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Geology of carbonate-hosted lead-zinc deposits at Qixiashan, Jiangsu Province, southeast China

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Abstract: The Qixiashan stratabound lead-zinc deposits in Southeast China occur in the Carboniferous carbonate rocks of the Yangtze Platform sedimentary cover. The host rocks of the ore deposits have undergone an intense Indosinian deformation during Late Triassic. The Qixiashan deposits are distributed along a main axial fault, originally thrust, cutting through the southern limb of an anticline generated at the northern margin of the platform.

The ore deposits are characterized by the development of brecciated, massive and bedded ores. The brecciated ore contains breccias of the host limestone which are mostly a sort of solution collapse breccias and, in some cases, fault breccias. The ore shows features of filling by ore minerals of interstitial open space of these breccias. The bedded ore is composed of an alternation of sulfide bed and mudstone, and is intervening in the brecciated and massive ores. The sulfide bed exhibits many of features of turbidites such as lamination, graded bedding, penecontemporaneous erosion, intraformational fragments and slumped beds. The massive ore is subdivided into two kinds; brecciated ore with few breccias and thick bedded turbidite sulfide. One of the most important facts is that the bedded ore was deposited in the overturned host rocks.

The Qixiashan lead-zinc deposits share much characters with the Mississippi Valley type lead-zinc deposits in North America: (1) shallow marine carbonate host rocks, (2) no relation to igneous activity, (3) development of the solution collapse breccia, (4) open space filling by ore minerals, (5) simple ore mineral assemblage, mainly composed of sphalerite, galena, pyrite and marcasite, (6) inclusion of bituminous materials, (7) dolomitization and silicification and (8) relation to unconformity. Nevertheless, the Qixiashan deposits also exhibit some different features: (1) strongly deformed host rocks, (2) predominance of manganese dolomite in the dolomitization and (3) delay of the mineralization from the host rock sedimentation. The Qixiashan deposits may be one of the variations of the Mississippi Valley type deposits.

The Qixiashan mineralization and associated solution collapse breccias are closely related to the main axial fault which controls their distribution. The ore deposits were emplaced during Late Triassic Indosinian movement after the host rocks became to be overturned. The deposited metals and sulfur are assumed to have originated in the platform sedimentary cover, and migrated to the site of deposition through the main axial fault. The bituminous materials in the ore, together with the bituminous Qixiashan Limestone, have possibly played an active role in reduction of sulfate in the ore solution.

Introduction

Since newly launched geological journals of China became available in a past few years, we have an increasing amount of information on the carbonate-hosted lead-zinc deposits from this country (TU and YIN, 1980; LI *et al.*, 1980; CAO *et al.*, 1983; WAN, 1983; WAN *et al.*, 1983). In Southeast China, this type of ore deposits is known from Jiangsu and Jiangxi Provinces, and exists, in a fairly large number, in Hunan Province (WAN, 1983).

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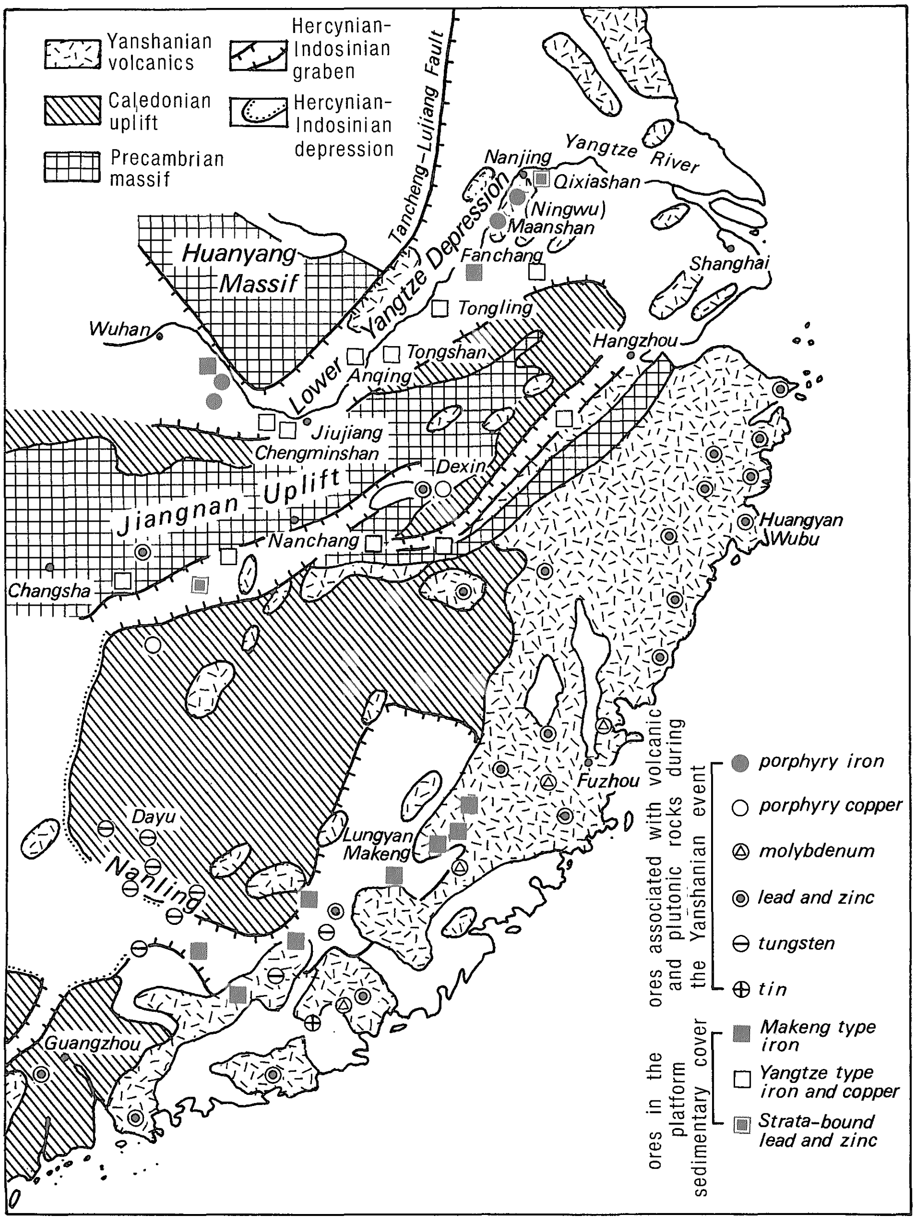


Fig. 1 Map of Southeast China showing the major structural features and ore deposits.

However, very little literature contains satisfactory descriptions on the occurrence of the ore and its surrounding geology.

The Qixiashan lead-zinc deposits, located at 20 km east of Nanjing city in Jiangsu Province, represent one of the most typical stratabound type deposits in China. The deposits occur in the Carboniferous limestones in the Yangtze platform, which developed between Precambrian Jiangnan and Huanyang massifs (Fig. 1). The northern half of the platform is a northeast-southwest-trending depression zone, called the Lower Yangtze Depression, which was active during a Mesozoic time.

The Lower Yangtze Depression is well

mineralized. Many ore deposits are known to occur along the Yangtze River, such as Ningwu, Tongshan, Anqing and Jiujiang mineralized areas (Fig. 1). They contain various metals, but mainly iron and copper; a composite occurrence of iron and copper ore bodies in a single mineralized area as stratabound, skarn and porphyry types is referred in China to the Yangtze type ore deposits. The Qixiashan deposits are located in the northeastern part of the mineralized zone and are unique in the igneous history and ore mineral assemblage. The Yangtze type deposits are always associated with the Mesozoic intrusive rocks, whereas the Qixiashan deposits accompany no intrusives in the vicinity. The mineralogy of the Qixiashan deposits is rather simple, mainly composed of galena, sphalerite, pyrite and marcasite. Dolomitization prevails related to the mineralization.

The Qixiashan deposits were discovered by XIE Jiabao and his geological team in 1950's. Mining began at the end of 1970's (CAO *et al.*, 1983). Detailed information on the tonnage and the production is not available but size of the deposits may correspond to one of the Kuroko ore deposits in the Hokuroku district of Japan, among which the biggest one reaches a few tens of million metric tons. The Qixiashan ores contain generally 2 to 3 percent lead, 5 to 6 percent zinc, 0.1 percent copper, 20 percent sulfur and 6 to 8 percent

Table 1 Stratigraphic column in the Qixiashan mine

Jurassic	Upper	Huangshiba Fm. Hunghuaqiao Fm. 151m	tuff, welded tuff, red bed, fine sandstone
	L.-M.	Hsiangshan Gr. 1000m	terrestrial sandstone, siltstone, pebbly sandstone, mudstone
Permian	Upper	Lungtan Fm. 114m	carbonaceous shale, siltstone, arkosic sandstone, coal
	Lower	Kuhfeng Fm. 35m	siliceous shale, chert
		Qixiashan Fm. 185m	black bituminous limestone, siliceous limestone
Carboniferous	Upper	Chuanshan Fm. 40m	limestone, dolomite
		Huanglung Fm. 61-87m	limestone, dolomite, chert
	Lower	Hochow Fm. 4.4m	shale, marl, dolomite, siltstone
		Kaolishan Fm. 13-25m	siltstone, mudstone, fine sandstone
		Kinling Fm. 0-10m	limestone, siltstone
Devonian	Upper	Wutung Quartzite 180m	Quartzite, fine sandstone, siltstone
Sil.	Mid.	Fentou Fm.	fine sandstone, siltstone

manganese on the average. Ag, Au, Cd, Ga and Se are reported as associated minor elements.

This paper describes geology and mineralogy of the ore deposits which were studied under the ITIT Project No. 8113 (GSJ ed., 1985) and discusses their genesis in comparison with the Mississippi Valley type deposits in U.S.A.

Stratigraphy

The Yangtze platform cover is composed of mainly Paleozoic but includes the Sinian (Late Precambrian) and Triassic strata, which are mostly shallow marine deposits. Sedimentary rocks of the Qixiashan area are divided into two major units: 1) Silurian to Triassic platform sedimentary cover, and 2) Jurassic shallow marine and terrestrial clastic deposits with pyroclastic rocks (Table 1). The former consists mainly of mudstone, siltstone, arkosic sandstone, quartzite, limestone and dolomite with some 1,000 m of total thickness. The carbonate rocks of the platform cover are preponderant in the middle part of the sequence. The Qixiashan lead-zinc deposits occur in the Huanglung and Chuan-

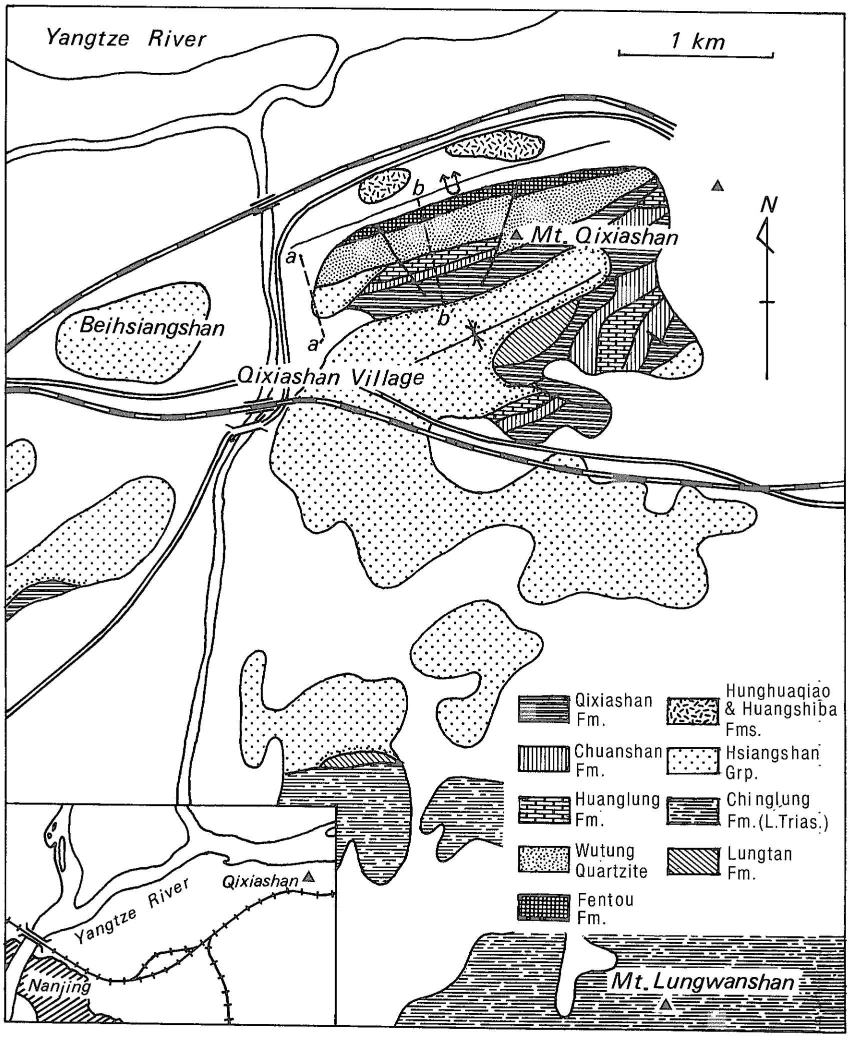


Fig. 2 Geologic map of the Qixiashan area (after JIANGSU METAL. GEOL. PROS. CO. 810 GR., 1983).

shan Formations of the Upper Carboniferous age.

A parallel unconformity is present between the Middle Silurian and Upper Devonian strata which spread over the Yangtze platform. The Upper Silurian to Lower Devonian strata are generally missing. Consequently, the Middle Silurian Fentou Formation is directly overlain by the Upper Devonian Wutung Quartzite, which exhibits many of characteristic features of shallow water facies such as cross-bedding, occasional conglomerate beds and land-plant fossils. Most of significant stratabound ore deposits in the Lower Yangtze Depression are known to occur just above the Wutung Quartzite. The Lower Carboniferous strata are absent between the Wutung Quartzite and the Huanglung Formation in many places, but exist in the Qixiashan area as three formations, being composed of siltstone, mudstone, shale, fine sandstone, limestone and dolomite. The Upper Carboniferous Huanglung and Chuanshan Formations are widespread and have a uniform lithofacies with lead-zinc ore bodies. They consist of light grey to grey colored thick bedded limestones with dolomite and dolomitic limestone. These ore-bearing carbonates are conformably overlain by a characteristic lithofacies of the Lower Permian age, i.e., the bituminous limestone of the Qixiashan Formation, which smells of petroleum when it is crushed by a hammer. The Qixiashan limestone is dark grey to black in color, partly interbedded with oolitic limestone, chert and shale. The platform sedimentary cover continues upwards to the Triassic strata, which are distributed to the south of the Qixiashan area (Fig. 2). As a whole, the Triassic beds exhibit a regressional facies which starts from shallow marine sediments built of limestone, dolomite and mudstone in the Lower Triassic age, then a transitional facies formed by lagoonal dolomite and evaporitic gypsum beds of the Middle Triassic age, and ends up with the Upper Triassic terrestrial beds containing fine-grained clastics interbedded with red beds and coal seams.

The platform cover in the Qixiashan area is unconformably overlain by the Jurassic beds of the Lower to Middle Jurassic Hsiangshan Group, then conformably by the Upper Jurassic Hunghuaqiao and Huangshiba Formations. The Hsiangshan Group, occurring to the south of the Qixiashan mine area (Fig. 2), reaches a thickness of about 1,000 m. It is chiefly clastic sediments composed of terrestrial sandstone, siltstone and mudstone which are widespread in the Lower Yangtze Valley. It is considered as an intermountain-basin sediments (WENG and WANG, 1981). This clastic facies is a symptom of another big tectonic event, i.e., the Upper Jurassic to Lower Cretaceous Yanshanian movement. Sedimentation during the Yanshanian movement is seen as the Upper Jurassic Hunghuaqiao and Huangshiba Formations in the Qixiashan area. They are mainly built of tuff, welded tuff, red bed and fine sandstone.

The Lower Yangtze Valley is assumed to be an inland volcano-tectonic zone during this period. The Qixiashan area is considered to constitute a part of the Lujiang-Ningwu volcanic subzone of the Lower Yangtze volcano-tectonic zone, where the volcanic rocks are mainly andesites of calc-alkaline suite. However, volcanic rocks of this area can be observed only in the Upper Jurassic strata which are confined to narrow areas north of the Qixiashan mountain (Fig. 2).

Geologic Structure

The Lower Yangtze Depression, located in the northeastern part of the platform is a north-northeast trending tectonic depression zone between the Jiangnan massif to the southeast and the Huanyan massif to the northwest (Fig. 1). The depression initiated during Late Triassic to Early Jurassic when the Tancheng-Lujiang fault on the northwestern margin became active. The entire part of the platform cover exhibits a moderate folded structure, but it is highly compressed and folded with some thrusting in some parts of the depression zone. The folding strikes north-northeast or northeast along the Yangtze valley between Nanjing and Jiujiang, but to the further northeast, the strike changes nearly east-west around Nanjing, following the big bend of the Yangtze River. To the east from there, two principal anticlinoria, i.e., the Yangzhon and Ningzhen anticlinoria, are recognized, which are also parallel to the easterly-flowing Yangtze River.

The Qixiashan mine is located in the western part of the Ningzhen anticlinorium which is composed of three individual anticlines. The ore deposits are present in the northernmost one. The anticlinal axis lies on the northern foothill of Mt. Qixiashan where the oldest strata of this area, the Middle Silurian Fentou Formation, is distributed (Fig. 2). The east-west trending main ridge of the mountain is made up of the ridged Wutung Quartzite which forms the southern limb of the anticline. The Carboniferous to Permian strata crop out on the southern foothill, where the Qixiashan lead-zinc deposits are embedded (Fig. 3). Further to the south, this whole succession repeatedly folded to form a syncline, the axis of which passes through the Qixiashan village. The axial part of the syncline is broadly occupied by the Lower to Middle Jurassic Hsiangshan Group, which overlies the platform sedimentary cover with clino-unconformity. The structural difference between two units above and below the unconformity is conspicuous in the Qixiashan area, where the platform sedimentary cover shows tight folding with steep or reversed dipping in contrast with the Hsiangshan Group which is subhorizontal or inclined up to 30 degrees (Fig. 4).

The folding of the platform cover and the formation of the unconformity are due to the Indosinian event which took place at the end of Triassic period. On the other hand, the tilting and the deformation of the upper unit of Jurassic strata can be attributed to the Yanshanian event. The Lower to Middle Hsiangshan strata of the Qixiashan mine abut on the unconformity from southwest to northeast, so that they are mainly distributed in the southwestern area.

The main fault of the Qixiashan mine is a reverse axial fault of N75°E strike and steep dip, passing through the ridge of the Qixiashan mountain. It traverses the Hsiangshan strata as well as the platform cover. Due to it, the northern block of the fault is uplifted. The fault plane is subparallel to the bedding plane of the platform strata, and the main part of the ore deposits is distributed along this fault (Fig. 4). Some cross-faults with trend of north-northeast and north-northwest can be found in the mine area. The location of fault breccia ores is controlled by this subsidiary faulting (Fig. 5).

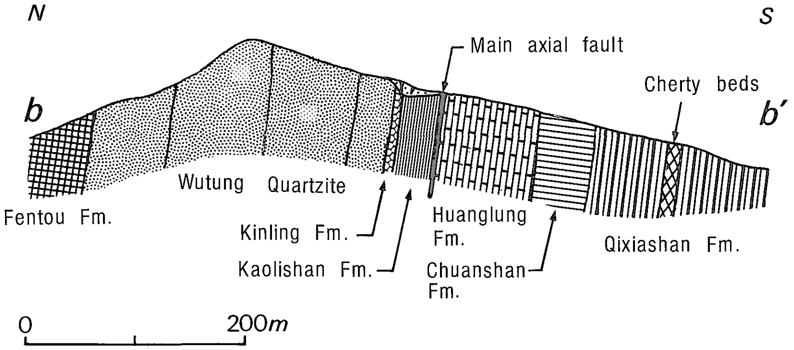


Fig. 3 Cross section of the Mt. Qixiashan (after JIANGSU METAL. GEOL. PROS. CO. 810 GR., 1983).

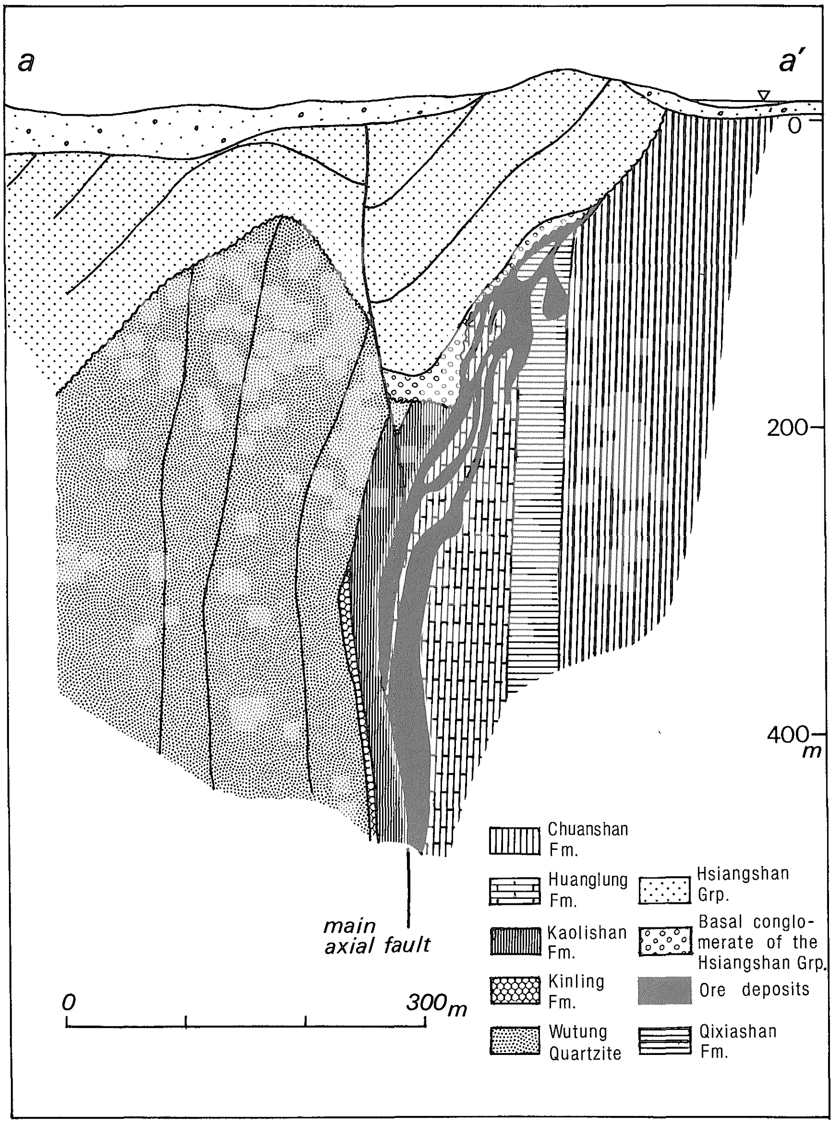


Fig. 4 Cross section of the Qixiashan ore deposits (after JIANGSU METAL. GEOL. PROS. CO. 810 GR., 1983).

Ore deposits

General Features

The Qixiashan ore deposits are composed of various types of orebodies, but as a whole they range from 5 to 50 m in thickness, 410 m in length and more than 600 m in depth. The ore deposits have been confirmed down to −575 m level by the lowest tunnel and are known to extend further down by drilling. The ore deposits are subparallel to the wall rock bedding plane, i.e., vertical to steeply dipping toward north (Fig. 4). The ore deposits are constituted by several orebodies; each irregularly branches out into the wall rocks or joins together. They often jut out in the form of pocket, sink or cave. Consequently, the lateral variation in the thickness of ore body is remarkable. Many of blocks and rapidly pinching-out beds of the wall rocks are included everywhere in the orebodies.

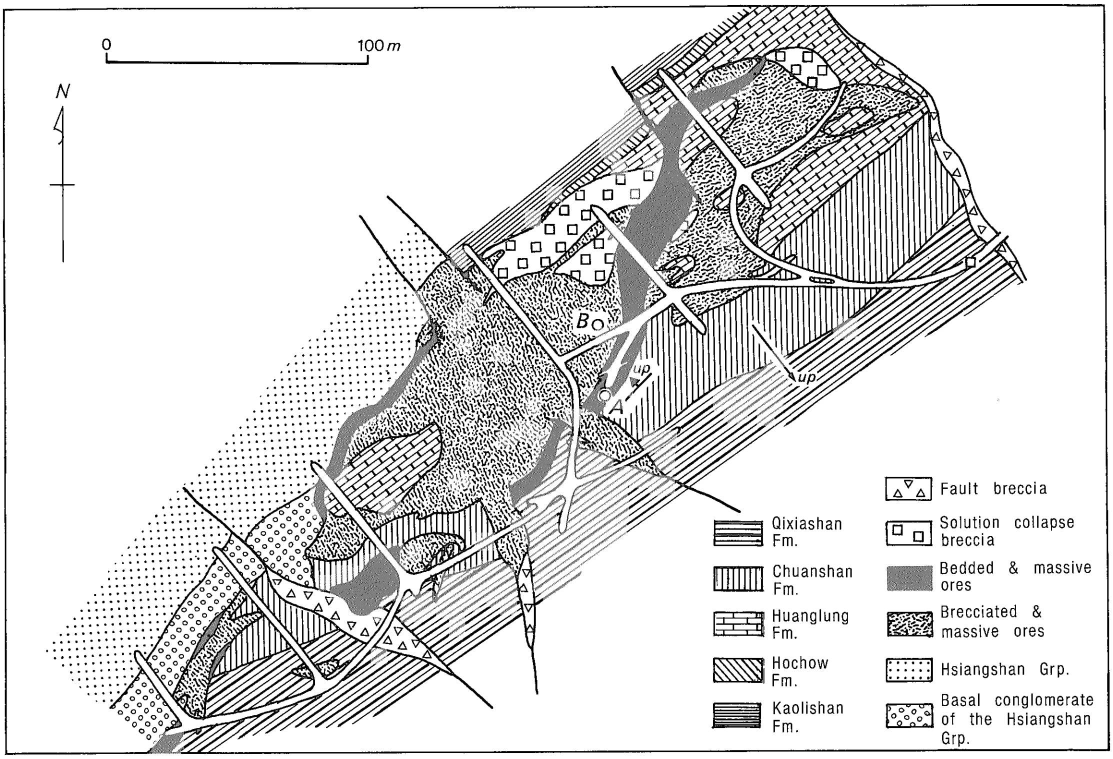


Fig. 5 Map of the Qixiashan ore body. Modified from Jiangsu Metal. Geol. Pros. Co. 810 Gr. (1983). The eastern extension of bedded ore becomes to be the massive pyrite ore. The graded bedding of the bedded ore indicates upside direction toward northwest (location A). Breccias of the bedded ore occur in the brecciated ore (location B).

A typical horizontal section of the ore deposits is shown in Figure 5. The dimensions are about 410 m by 50 m. Many cross faults cut the ore body to cause offshoots or veins of brecciated ore. The main part of the ore deposits occurs in the lower portion of the Huanglung Formation, but extends to the top of the Chuanshan limestone (Fig. 5). Minor offshoots and veins are present in the Qixiashan limestone.

Both ore deposits and wall rocks are unconformably overlain by the Lower to Middle Jurassic Hsiangshan Group (Fig. 4). A few fragmental sulfide ores are seen in the basal conglomerate just above the unconformity, indicating that a part of the ore deposits was exposed to the surface before the Jurassic time. Except this, no sign of mineralization is known in the Lower to Middle Jurassic rocks.

The Qixiashan ore deposits exhibit three varieties in the mode of occurrence of brecciated, massive and bedded orebodies. Besides, veins, veinlets and disseminated ores occur locally in nearby wall rocks.

Brecciated ore

This type of ore exhibits two different modes of occurrence. One is brecciated ore in which ore minerals fill up free space of the collapse limestone breccias (Fig. 6). It occupies a large part of the main ore deposit. The limestone breccias may have formed by the dissolution of the wall rocks. The other brecciated ore is distributed along the cross faults transecting the main orebody, thus is considered as fault breccia cemented by the ore minerals. The former brecciated ore occurs also along the major axial fault. This suggests

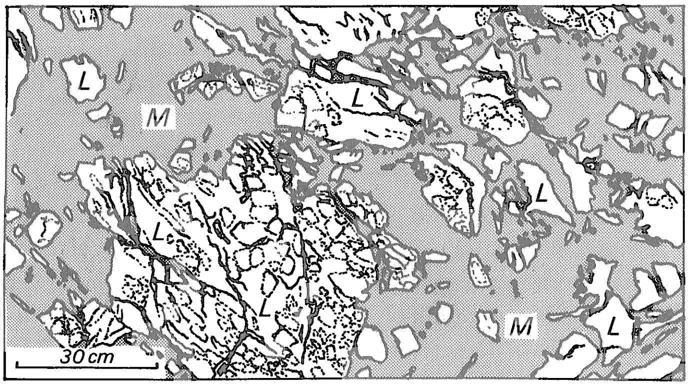


Fig. 6 Brecciated ore containing limestone fragments (L) which are cemented by sphalerite, galena, pyrite, quartz, calcite and manganese dolomite (M). The fragments are manganese-dolomitized along their margin.

that the dissolution of the wall rocks may have been triggered by brecciation along the axial fault. Both types of brecciated ores consist of angular limestone breccias up to 2 meters in size, mainly from the Huanglung and Chuanshan limestones. In a few cases, chert breccia also occurs. Small limestone fragments in the orebodies are usually altered to manganese dolomite, rhodochrosite and quartz, but the central part of big blocks over a few meters are not suffered from the alteration. The cementing ore minerals are mainly pyrite, sphalerite, galena and marcasite, decreasing in volume in this order.

Massive ore

This ore is also subdivided into two different types according to depositional processes. One type of massive pyrite ore which forms thick beds is composed of pyrite grains with a clastic nature loosely packed in the matrix of clay materials and fine-grained pyrite. A massive pyrite bed observed in the middle of the main ore body in Figure 5 belongs to this type. It is directly connected with the bedded ore which will be mentioned later. Both the massive and bedded ores contain solid organic materials. On the other hand, the other type massive ore occurs being related to the brecciated ore in the main ore deposits. It gradually changes into the brecciated ore and contains a few limestone breccias in it (Fig. 7). It irregularly changes in mineral assemblage. In some parts, the ore

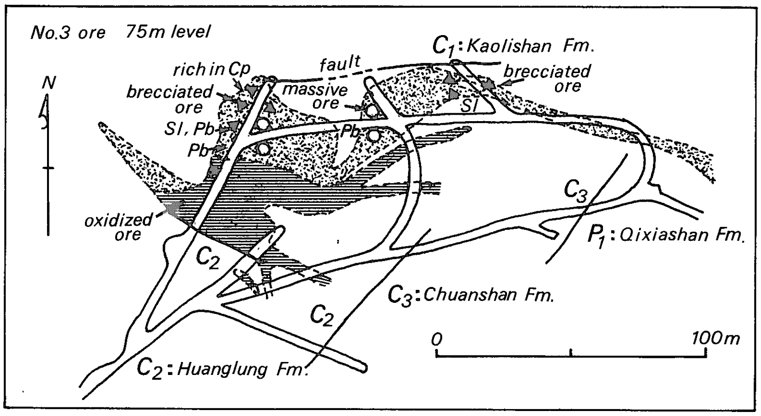


Fig. 7 Relation between brecciated and massive ores which gradually change into one another. The composition of the ore minerals is not homogeneous; in one part, rich in chalcopyrite, but in other parts, rich in sphalerite or galena. At this level of the mine, large portion of the ore is oxidized.

consists mainly of galena, but in other parts, sphalerite, pyrite or chalcopyrite is predominated. Consequently, the ore shows extremely high grade in some parts.

Bedded ore

The bedded ore is an alternation of sulfide bed and mudstone (Figs. 8 and 9). The sulfide bed contains clastic pyrite, quartz and solid organic material with small amounts of sphalerite and galena (Fig. 11). The grain size ranges from very coarse sand to silt. Cementing materials are mainly solid organic substance and clay minerals with fine pyrite. The thickness of the individual sulfide bed and the mudstone is a few millimeters to some ten centimeters. The sulfide bed exhibits lamination, graded bedding, intraformational mudstone fragments, penecontemporaneous erosion and other sedimentary structures characteristic of turbidites (Fig. 9). The mudstone is silt to clay in grain size, and always black in color because of intimate association with fine pyrite. In the −125 meters level section of the ore body, a northeast trending bedded ore intervenes near the central portion (Fig. 5). By this ore, the main orebody is divided into two parts. The bedded ore changes eastwards into a massive pyrite ore which has no mudstone intercalations. The sedimentary features of the sulfide bed typical of turbidites indicate that the bedded ore have been deposited in a sink of a big open space formed in the limestone host rock. The original materials of the clastic grains might have been produced as insoluble residues resulted from dissolution of the pre-existing ores and the host limestones. The clastic materials could have been transported to the site of deposition by turbidity currents

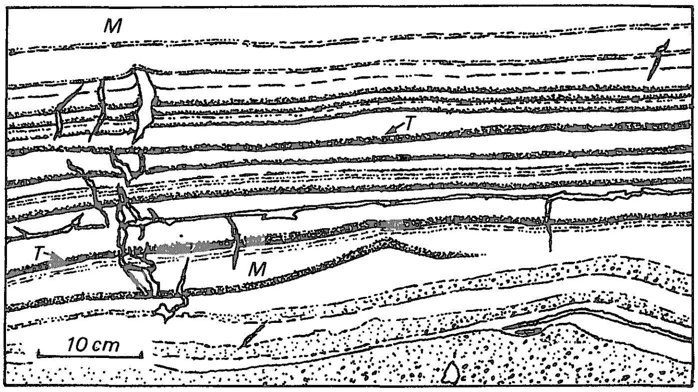


Fig. 8 Bedded ore composed of an alternation of sulfide turbidite (T) and mudstone (M). The bottom part shows slightly slumped beds.

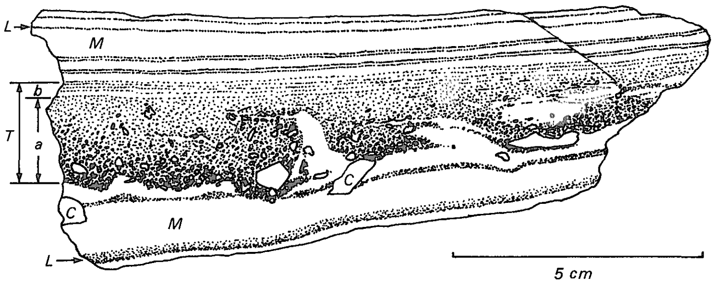


Fig. 9 Sulfide turbidite bed (T) and lamina (L) containing pyrite, solid organic matter and clay materials (C) with small amounts of shalerite and galena. Note that the bed exhibits a variety of sedimentary structures characteristic of turbidites such as graded division (a), division of lower parallel lamination (b) and penecontemporaneous erosion (underlying mudstone M eroded at the base of the sulfide bed).

generated by slumping of the depositional cone of the residues.

Based on the graded bedding of the sulfide layers, the upside direction of the bedded ore can be decided. Surprisingly, the direction is opposite to that shown by the superposition of the host rock beds (Fig. 4). This means that the bedded ore has been deposited after the host rocks were nearly turned over, probably after a big tectonic event. The time of the ore formation would be much later than that of the host rock accumulation.

The main ore deposits separated by the intercalated bedded ore and its equivalent are mainly composed of the brecciated and massive ores. Each separated portions have a similar ore mineral assemblage. However, the western part is slightly rich in sphalerite and galena. The solid organic material seems to be selectively included in the western orebody, where the massive ore rather predominates. In the section of the −125 meters level, the western orebody is truncated by the unconformity and directly overlain by the Jurassic strata. It should be noted that a various size of breccias of the bedded ore are contained in the brecciated ore of the western part (Fig. 10). This is consistent with that the western orebody overlies the bedded ore, being judged from the reversed upside direction of the ore deposits to the host rock.

Mineralogy and paragenesis

As the Qixiashan lead-zinc deposits are fairly oxidized down to about 100 meters below the surface, the fresh ores appear under such depth. More than twenty ore minerals were reported from the deposits, but the minerals of the primary ore are few in number. The major constituents are sphalerite, galena, pyrite and marcasite. As minor sulfide minerals, chalcopyrite, tetrahedrite and tennantite are relatively common, and others known by the geologists of the mine are pyrrhotite, argentite, pyragyrite and arsenopyrite. In the oxidized zone, limonite and hematite are commonly encountered with small amounts of manganese oxides. The gangue minerals include quartz, sericite, kaolinite, calcite, dolomite, siderite, rhodochrosite and kutnahorite, and minor barite, fluorite, gypsum, talc and chlorite. The ore forming material that must be mentioned here is a solid organic matter.

Galena and sphalerite of the significant volume usually occur in the brecciated and massive ores, and a small amount in the bedded ore, veins and veinlets, and vugs in the wall rocks. On the other hand, pyrite and marcasite are common in any type of ore except that the latter is rare in the bedded ore. Especially, pyrite is rich in the bedded ore and is disseminated throughout the wall

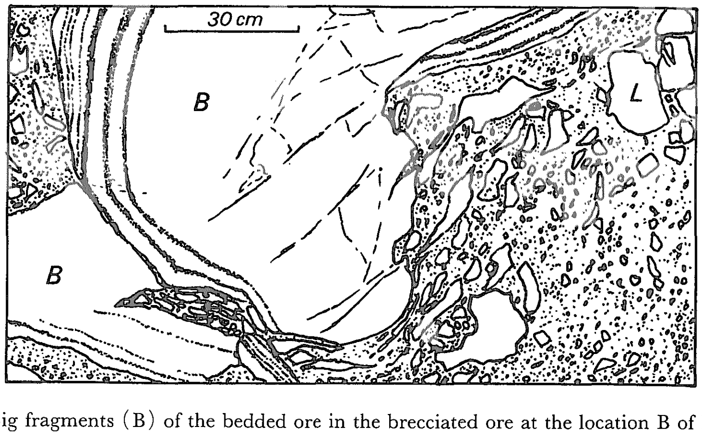


Fig. 10 Big fragments (B) of the bedded ore in the brecciated ore at the location B of Figure 4; (L) limestone fragment.

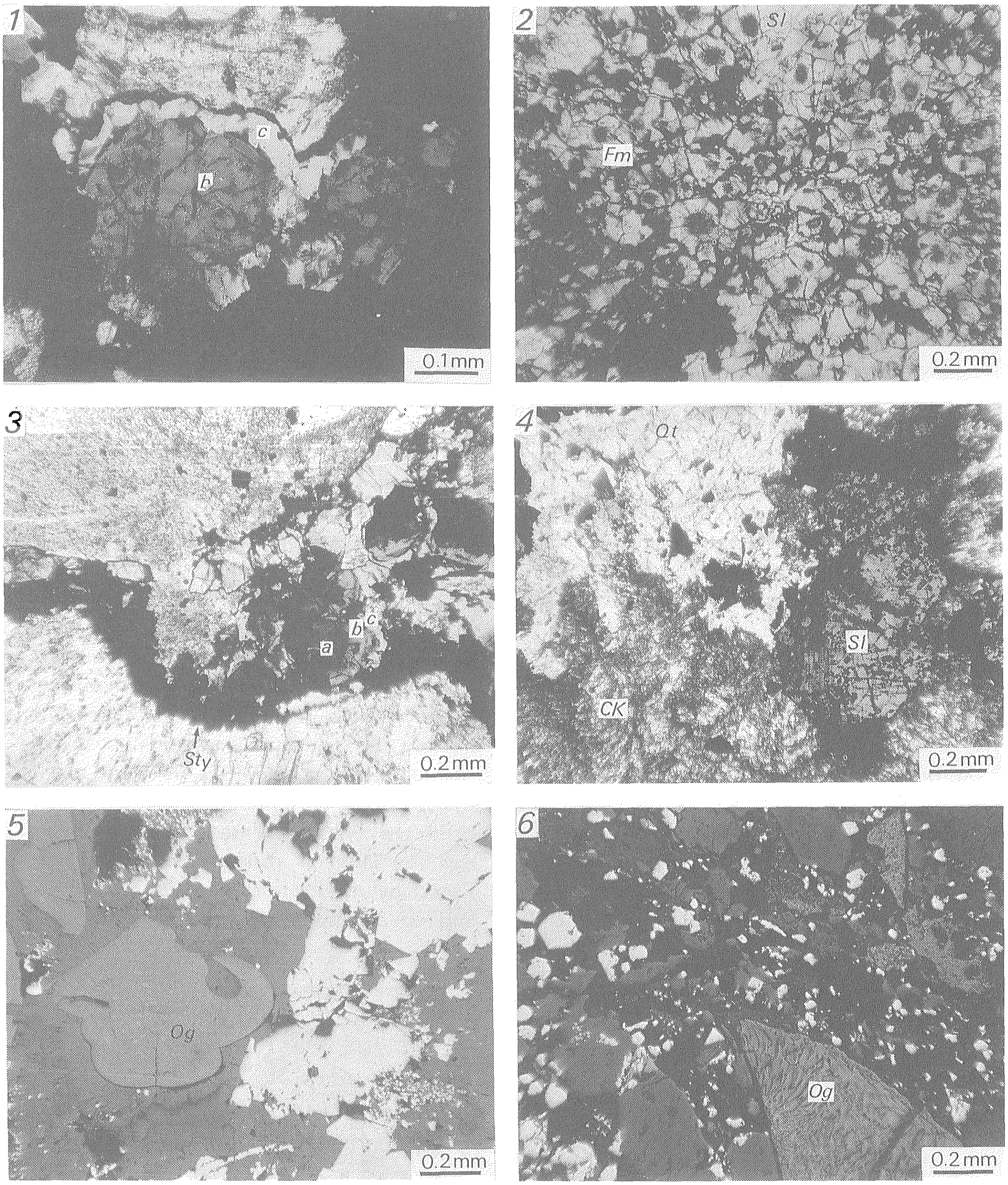


Fig. 11 Textural relationships of ore minerals from the Qixiashan mine. 1. Yellow brown sphalerite (b) crystallizing on early pyrite (bottom, black), overgrown by late colorless sphalerite (c), and cemented by kutnahorite (top, light grey). 2. Pale sphalerite crystals (Sl) with a inclusion of framboidal pyrite (Fm) in the center. 3. Growth banding sphalerite (core a: reddish brown, middle b: yellow and outer rim c: colorless bands) on the wall of the stylolite mainly lined with pyrite (central black band) in the host limestone. 4. Quartz cement (Qt) altered by late calcite-kutnahorite aggregate (CK). 5. Rounded solid organic material (Og) in the massive ore; light grey=pyrite. 6. Angular solid organic material (Og) in the sulfide turbidite of the bedded ore; light grey=pyrite, dark grey=quartz.

rocks. The minerals of the massive ore are well crystallized. Crystals of sphalerite and galena are relatively large in size, ranging from a few millimeters to 5 centimeters in diameter. They are generally intergrown with one another.

Sphalerite is transparent with pale yellow, yellow, brownish yellow and reddish brown in color, and frequently colorless, viewed in transmitted light through doubly polished thin section. Together with growth banding sphalerite, homogeneous one without any internal texture is observed, especially in the massive ore. The growth banding of sphalerite exhibits an alternation of pale yellow and brownish yellow bands. In the case of a complete zoning, the central part of the sphalerite crystal shows the reddish brown core, then yellowish bands crystallize on it, and finally colorless ones encrust them (Fig. 11). This indicates that the chemistry of the ore solution may have been changeable.

In some cases, sphalerite contains small inclusions such as chalcopyrite, pyrite, tennantite and solid organic matter. If sphalerite is present near chalcopyrite crystals, it tends to include many of fine chalcopyrite inclusions, sometimes being aligned along the growth banding; that is chalcopyrite disease (BARTON Jr., 1978). The primary inclusions in sphalerite crystal, which may be products of early mineralization, are found in the massive ore. These inclusions are usually pyrite framboids which are settled in the center of individual sphalerite crystals (Fig. 11). The diameter of each framboids ranges from 30 to 100 micrometers, whereas the encrusting sphalerite crystal is up to 300 micrometers in size. Another peculiar inclusion, fine-grained solid organic material, is found in the sphalerite of the massive ore. Compared with solid inclusions, fluid inclusions within sphalerite have been rarely observed in this study.

As stated above, sphalerite is generally intergrown with galena. Sphalerite was deposited on early pyrite, followed by subsequent cementing by quartz and calcite. In some cases, corrosion and crushing of sphalerite crystals took place before this cementation. The framboid-centered sphalerite also has been partially corroded, and then has been cemented by quartz. These interstitial minerals, quartz and calcite, were replaced by manganese dolomite at a later stage.

In the Qixiashan ore deposits, galena is contemporaneous with sphalerite. There is also a few evidences that galena crystallized on the wall of crucks in other sulfide minerals. Like sphalerite, the corrosion of galena sometimes occurs along its margin. Observed solid inclusions in galena are chalcopyrite and tetrahedrite, usually found in bigger crystals.

Pyrite is one of the pre-ore minerals which occurs in the host rocks, and a major constituent of the ore deposits as well. The pre-ore pyrite consists of mostly framboidal pyrite, especially rich in the Qixiashan limestone. Pyrite of the ore deposits usually exhibits a euhedral crystal or its aggregates. Colloform, spheroidal, botryoidal and framboidal pyrites are also found in the ore deposits, but they are not common. In the brecciated and massive ores, most of pyrite are intimately intergrown with sphalerite and galena. In some places, however, it is encrusted by growth banding sphalerite or occurs as framboidal pyrite in the sphalerite crystal (Fig. 11). The later stage pyrite is also found throughout the ore deposits. It crystallized on other sulfide minerals as well as on quartz, calcite and even later manganese dolomite.

Marcasite which is less in amount than pyrite, occurs as twinned crystals, colloform and radial aggregates, partly as a skeletal crystals on calcite veinlets, in the brecciated and massive ores. Pyrite has crystallized over a relatively long period of the mineralization, whereas marcasite is restricted to rather later stages. Detrital pyrite is a major constituent of the bedded ore, but marcasite is not found in it. Marcasite might be difficult to remain as a detrital mineral in such condition that hematite was formed as a result of oxidation of pyrite.

Among less common sulfides, chalcopyrite is rather abundant. Usually, it occurs as small crystals intergrown with sphalerite and galena. Chalcopyrite inclusions are also observed in the latter sulfides. Some massive ores rich in chalcopyrite occur in the western part of the main ore deposits. The ores consist of chalcopyrite grains of a few millimeters in size. Each chalcopyrite grains are covered by tennantite which includes small patches of stromeyerite. On the chalcopyrite grains, two kinds of later formed pyrite crystallize; single euhedral pyrite and aggregate of fine pyrite.

Hematite and limonite are often encountered in the secondary oxidized zone. They are also found in the bedded ore in a small amount. Generally, they are replacement products of pyrite. Partly replaced pyrite along its margin and euhedral pyrite completely replaced by hematite and limonite are observed. These oxidized minerals occur in the wall rocks as well.

Rhodochrosite occurs as an endmember of a sequence of minerals formed by manganese dolomitization. It is found in the limestone fragments of the brecciated ore as well as in the altered wall rocks together with calcite and manganese dolomite. The matrix of this brecciated ore is composed of euhedral and spheroidal pyrite with less sphalerite and galena. The euhedral pyrite has been often replaced by hematite. Amorphous manganese oxides are frequently observed in the dark colored calcite veins cutting the wall rocks, and sometimes in the oxidized brecciated ore.

Siderite is not common in the Qixiashan ore deposits. The mining geologist pointed out that it exists in the limestone of the Lower Carbonifeous contiguous to the ore deposits. A specimen from the drill hole intersecting ore horizon shows siderite to crystallize on sphalerite and galena as elongated crystals. Most of the siderite crystals have been replaced by manganese dolomite along their inside crucks and outer margin.

The occurrence of solid organic material might be one of the most interesting features to suggest the origin of the Qixiashan deposits. It is lustered black in color. Its surface is generally rounded and smooth, but sometimes, it is fragmental with sharp edges like crushed pitch (Fig. 11). Many of vesicles infilled by sulfide minerals can be observed in it. It is not yet well crystallized on the X-ray powder pattern; it is not in graphite grade. The solid organic substance of up to 1 centimeter in diameter exists in the brecciated and massive ores as well as in the bedded ore. In the bedded ore, it occurs as fragmental grains and in the matrix as finer irregular-shaped particles. It is difficult to deduce the origin of the solid organic matter. However, it is thought to be a kind of bituminous material originated from petroleum, judging from its shape and the presence of nearby bituminous Qixiashan limestone. Frangmental nature indicates that it was deposited as a clastic grain. On the other hand, rounded or irregular shaped one suggests that it has migrated into the ore as liquid.

Aside from the host rocks, the most common gangue minerals are quartz, calcite and manganese dolomite. Quartz and calcite are interstitial to the sulfides, and they are intergrown together. Quartz fills vugs and fractures in the wall rock as well as in the ore. Well-developed, purplish colored quartz crystals up to a few centimeters long are found in some vugs of the massive ore. However, many of interstitial quartz is dusty and shows undulatory extinction. Manganese dolomitization prevails not only over the ore but also in the neighboring host limestone. Based on the X-ray powder patterns, the resulting mineral is generally calcite-kutnahorite aggregate. This aggregate does not show any lamellar twinning typical of calcite. In many cases, it is fine grained and dusty. It also occurs in veinlets as well as in the matrix. It replaces quartz and calcite in the matrix of the ore, and, in turn, is covered by disseminated pyrite. It is assumed that the ore forming solutions were silica-carbonate bearing and manganese bicarbonate bearing as well.

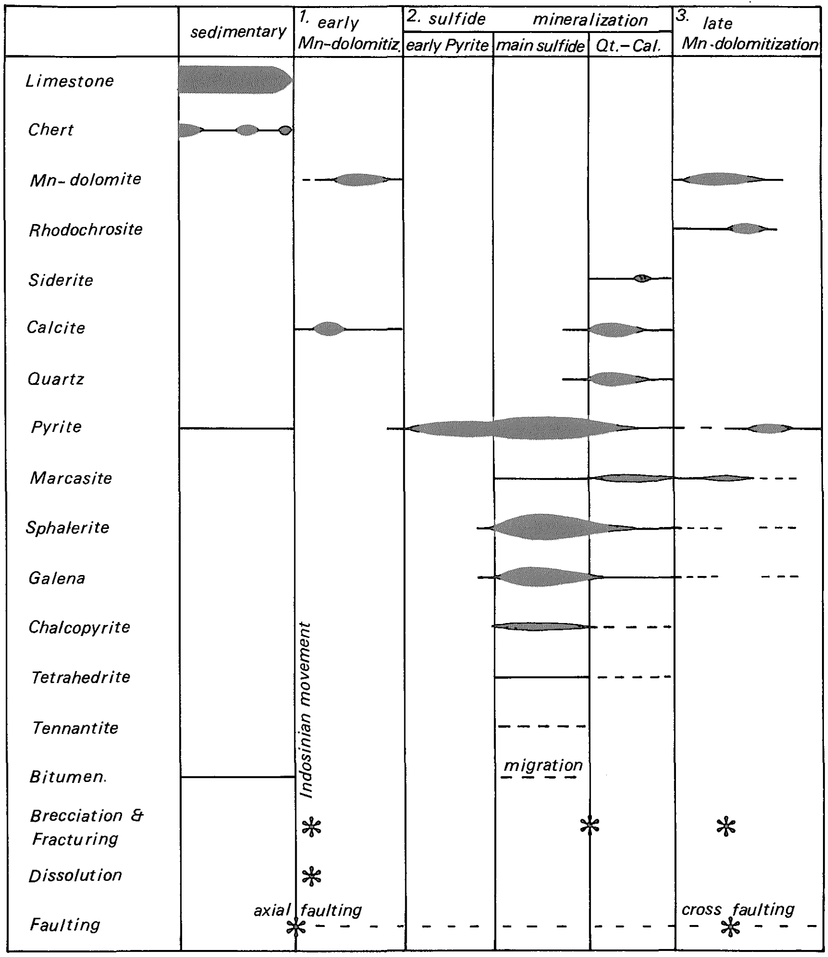


Fig. 12 Paragenetic diagram for the Qixiashan ore deposits.

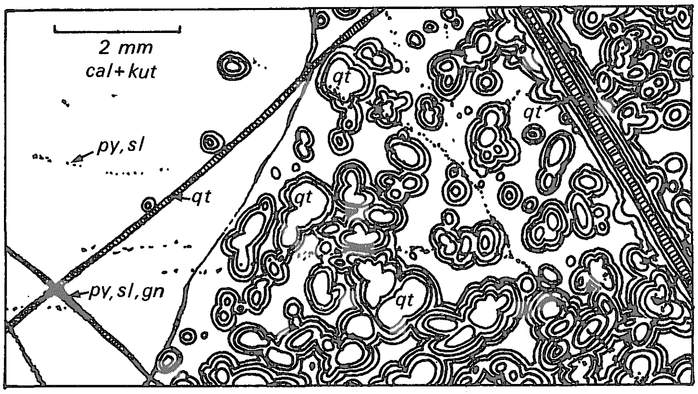


Fig. 13 Colloform and vein quartz (qt) developed on manganese dolomitized limestone (cal+kut); py=pyrite, sl=sphalerite, gn=galena, cal=calcite and kut=kutnahorite.

The paragenetic sequence of the primary minerals in the Qixiashan ore deposits is summerized in Figure 12. It also shows the relationship between the mineralization and the associated major tectonic events of the area. The synsedimentary process formed the limestone and chert beds of the host rock. Framboidal pyrite was deposited at the same time or during early diagenesis in the mudstone and the limestone. Petroleum component in the Qixiashan limestone might have originated at this stage over the whole area of the Yangtze platform.

The Qixiashan mineralization is divided into three stages based on the paragenetic relationship, the wall rock alteration and the tectonic events in the area. For the main ore deposits has been emplaced along the main axial fault, which was probably originated in a thrust fault, the ore formation might greatly depend on the faulting. Manganese dolomitization has occurred at two stages, before

Fig. 14 X-ray diffractograms illustrating the various grades of progressive manganese dolomitization. Note the gradual increase in 2θ of calcite from 1 (unaltered) to 2 (slightly altered). Kutnahorite (k) appears in 3, 4 and 5 (altered). Specimen in grade 3 includes a silicified part. Grades 3 and 4 consist of calcite-kutnahorite aggregate. Grade 5 shows intense manganese dolomitization.

and after the sulfide mineralization. Earlier manganese dolomitization has been associated with the dissolution and the recrystalization of calcite of the wall rocks. Early dolomitization is usually not easy to recognize because of strong later manganese dolomitization.

The main sulfide mineralization was initiated by the early pyrite deposition, followed by quartz-calcite cementation. Locally, carbonate veinlets with small amounts of pyrite, marcasite, sphalerite and galena, are found in the orebody and the wall rocks. These veinlets cut the manganese dolomitized wall rocks to suggest their later stage origin. The main ore deposit at Qixiashan is separated into two parts by the intervening bedded ore as already mentioned. This indicates that the mineralization took place recurrently before and after the deposition of the bedded ore. Therefore, the mineralization from sulfide stage to manganese dolomitization shown in Figure 12 would have been repeated twice. The later carbonate veinlets are possibly a result of the repeated mineralization.

Wall rock alteration

The limestone, the principal constituent of the wall rocks, is mostly biomicrite and biosparite containing lots of well-preserved fossils of crinoids, corals and foraminifera. The matrix is usually made up of micrite less than 2 micrometers in diameter, whereas shell cavities are infilled by sparry calcite which ranges from 10 to 100 micrometers in size. Recrystallized calcite also occurs as thin veinlets in the limestone. However, most of the limestone distal to the ore body has not been subjected to any alteration related to the mineralization.

On the other hand, the limestone contiguous to the orebody is considerably altered; manganese dolomitization and silicification. The width of the altered zone is narrow, usually less than 1 meter. The host limestone has recrystallized in many places along the ore boundary. The calcite crystal has grown up to make the host limestone crystalline. Subsequently, the early manganese dolomitization has occurred to give rise to calcite-kutnahorite aggregate on the recrystalline calcite. Many of vugs are observed in the altered host limestone. They were caused partly by the dissolution of the host rock, and partly by the manganese dolomitization which yielded decreasing in volume due to replacement of calcium ion by manganese and magnesium ions with smaller ionic radii. It is assumed that the dissolution and fracturing of the host rock have taken place mainly during this stage.

Quartz with colloform texture was developed on the manganese dolomitized host limestone (Fig. 13). It also crystallized on the wall of vugs in the limestone, being accompanied by calcite crystal. These silicifications are intimately associated with sulfide mineralization. Together with quartz and calcite, pyrite, sphalerite and galena occur in vugs, veinlets and small open spaces between the recrystallized calcites, even in the stylolite, of the host limestone (Fig. 11). This paragenetic relationship is essentially the same as that in the ore deposits.

Later manganese dolomitization occurred widely in the wall rocks as well as in the orebody. Quartz and calcite formed at the stage of the sulfide mineralization have been replaced by calcite-kutnahorite aggregate. A network of manganese dolomite veins cuts pre-existing sulfides and associated minerals. This later manganese dolomitization has overlaped on the earlier one.

A progressive alteration of the host limestone is observed from the contact of the ore and the wall rock toward outside (Fig. 14). The unaltered limestone consists only of pure calcite crystal, whereas the contents of quartz and manganese dolomites increase toward the contact. First, the peaks of calcite crystal shown by X-ray powder patterns shift to the higher angle side in the weakly altered zone. Approaching to the contact, kutnahorite appears, being accompanied by altered calcite. The peak shift to the higher angle side means the narrowing of the lattice interval of calcite crystal. Thus, the weakly altered calcite is supposed to be resulted from exchange of calcium ion with manganese and magnesium ions. Progressing supply of manganese and magnesium ions would produce a new mineral of kutnahorite. Close to the contact, only kutnahorite has formed as a result of strong manganese dolomitization. An example of extreme alteration may be represented by rhodochrosite.

Discussion–Comparison with the Mississippi Valley type deposits

The Qixiashan lead-zinc deposits exhibit many of characteristic features of the Mississippi Valley type deposits in U.S.A. However, the Qixiashan deposits also display some principal difference from the latter. In order to understand somewhat complex character of the Qixiashan deposits, the comparison with the Mississippi Valley type deposits will be summarized here.

The Mississippi Valley type deposits are known to occur in Appalachian, Tri-State, Southeast Missouri, and upper Mississippi Valley districts in the U.S.A., the Mackenzie Valley (Pine Point) in Canada, and in the Alpine, Silesian, Central Irish Plain, and Pennines district of Europe and Great Britain (SANGSTER, 1976). In the most mining districts, the deposits are intimately related with a thick carbonate sequence without any igneous activity in the surroundings, but are somewhat different between North America and Europe. SANGSTER (1970, 1976) noted that the typical Mississippi Valley type deposits in North America are strata-bound, emplaced after lithification of the host rocks, and the result of open-space filling, whereas the deposits in Europe, which are the Alpine type, named after deposits of the Alpine Mesozoic geosyncline of central Europe, is stratiform and synsedimentary deposits. The Qixiashan lead-zinc deposits are concluded to be not syngenetic deposits related to their host rocks, judging from the structural, sedimentological and mineralogical studies, so that if we follow the SANGSTER's criteria, the Alpine type lead-zinc deposits will be excluded from this discussion.

Table 2 compares characteristic features of the North American deposits and the Qixiashan deposits. Among many features to designate the Mississippi Valley type deposits, such as sedimentary environment of the host rock, facies change, unconformities, dolomitization, dissolution of carbonate rocks, open space fillings, and presence of hydrocarbons, the first priority is given to the open-space filling mineralization in pre-existing rocks (SANGSTER, 1976). In the Qixiashan deposits the major ore minerals of the brecciated and massive ores have been deposited in the open space formed in the host rocks and their breccias.

The importance of unconformities in relation to the location of a number of Mississippi Valley type ore districts has been stressed as well (CALLAHAN, 1964). The presence of unconformity implies development of karst in the paleo-surface and associated brecciation through which groundwater can penetrate easily. These structural controls to precipitate lead and zinc sulfides suggests an epigenetic origin for the ore solution. Here, at Qixiashan, the ore deposits occur in the Upper Carboniferous limestones, but the main mineralization took place during Late Triassic to Early Jurassic, being closely related to the unconformity formed at this period. In most of the Mississippi Valley type deposits, delay of the mineralization from the host rock formation appears to be small. On the contrary, the time gap between the host rock deposition and the mineralization is rather large in the Qixiashan deposits.

The brecciated ore of the Qixiashan deposits includes a sort of solution collapse breccia which also typifies the Mississippi Valley type deposits. The development of typical

Table 2 Comparison of the characteristics of the Qixiashan deposits with Mississippi Valley type deposits. The principal characteristics of the Mississippi Valley type deposits are taken from HAGNI (1976).

Mississippi Valley type deposits	Qixiashan deposits
(Host rock character and alteration)	
A. Shallow-water carbonates	Shallow-water Upper Carboniferous platform carbonates
B. Certain stratigraphic horizons are the principal producers, but mineralization extends over a large stratigraphic interval	Main producer is the Upper Carboniferous Huanglung Formation, but it extends into the Uppermost Carbonifeous Chuanshan Formation.
C. Unconformities beneath and within the mineralized stratigraphic interval influence sedimentary facies patterns	Unconformity between the Upper Devonian Wutung Quartzite and the Lower Carboniferous may influence the Lower Carbonifeous sedimentary facies, but the effect to the Upper Carbonifeous is not clear.
D. Dolomitization; most ore deposits are confined to dolomitized areas	Ore deposits occur in manganese-dolomitized rocks.
E. Recrystallization; limestone contiguous to ore deposits shows recrystallization of fossils and oolites to sparry calcite	Intense recrystallization to form large calcite.
F. Silicification; developed to variable degrees	Rather strong silicification; quartz occurs in vugs or replaces the host rocks.
(Regional structure and ground preparation)	
A. Districts occur on the flanks or above major positive features, especially domal structures	Qixiashan mine is located on the Ningzhen anticlinorium at the northern margin of the Lower Yangtze Depression.
B. Major faults and fault breccias are important to the localization of subdistricts or fields, but most individual deposits are controlled by local structures of sedimentary, tectonic, and dissolution origin	The mine roughly lies near the changing point in the trend of the Lower Yangtze fold system. Locally, the position of the ore body is controlled by the major axial fault.
C. Permeable horizons allow extensive lateral movement of the ore solutions	The Upper Devonian Wutung Quartzite and the Lower Caboniferous Kaolishan fine sandstone prepare permeable horizons, but its mechanism needs further study
D. Ground prepared by minor faults and fractures	Ground prepared by main axial fault and associated minor faults
E. Ground further prepared by solution and collapse through the action of ground waters related to unconformities both above and within the minerallized stratigraphic intervals	Ground mainly prepared by dissolution and collapse along the main axial fault by ground waters related to unconformity formed during Late Triassic to Eary Jurassic
(Local structural controls)	
A. Sedimentary structures	Sedimentary structures
(1) Ridges or bars	(1) Both have not been observed
(2) Reefs and reef-like structures	(2) Both have not been observed
(3) Submarine slide breccias	(3) Submarine slide breccias have not been observed
(4) Pinchouts	(4) Pinchouts related to the ore deposits have not been observed
(5) Lateral facies changes	(5) Systematic lateral facies changes have not been observed
B. Tectonic structures	Tectonic structures
(1) Folds	(1) Important minor folds in formation of ore deposits have not been observed. The ore body lies on the southern limb of the anticline
(2) Minor faulting and fracturing	(2) Role of minor faulting and fracturing in the

Table 2 (Continued)

Mississippi Valley type deposits	Qixiashan deposits
	localization of individual deposits is not obvious
(3) Fault breccias	(3) Fault breccias play an important role in the localization of the shoots and veins from main ore body
C. Solutional structures	Solutional structures
(1) Solutional collapse breccias are very important; many were initiated along fractures by ground water related to erosion surfaces, and the process was continued by ore fluids; solutional thinning of the underlying beds is a dominant factor in the development of many collapse structures; collapse structures may occur near and parallel to major faults; a great variety of shapes is exhibited by the resultant breccia bodies	(1) Solutional collapse breccias have greatly influenced the development of ore deposits. Originally, they have been formed along major axial fault. Ground water related to the Upper Triassic to Lower Jurassic unconformity, initiated the formation of the solutional structures. Faulting and fracturing, subsequent ground water circulation, and the development of solutional structures are all controlled by the main axial fault formed along the contact between carbonate and non-carbonate.
(Ore character)	
A. Open space filling of vugs, fractures, and breccias is the principal manner of ore occurrence	The brecciated and massive ores are made up of crystals deposited in various size of open space formed in the host rock and its breccias
B. Disseminated replacements are associated with cavity-filling ores	Disseminated ore is associated with cavity-filling
C. Veins are locally associated with predominantly stratiform deposits	Calcite and manganese dolomite veins with disseminated sulfide minerals are associated with altered wall rocks
D. Size of ore deposits is controlled by the size of the local controlling structure	Size of ore deposits is controlled by the size of brecciated zone along the main axial fault
E. Most deposits are relatively low grade	Brecciated ore is not high grade, but massive ore is generally high grade
(Mineralogy)	
A. Principal minerals are restricted to a small number	Principal minerals are sphalerite, galena, pyrite, marcasite, quartz, calcite and manganese dolomite
B. Principal minerals have simple chemical compositions	Principal minerals have simple chemical compositions except for manganese dolomite
C. Few additional minor minerals	Chalcopyrite, tetrahedrite, tennantite, hematite, limonite, siderite, rhodochrosite, sericite and kaolinite are locally present in minor quantities
(Mineral paragenesis)	
A. Substantial portions of the mineralization were deposited as open space fillings in which crystals of one mineral coat those of another; these well crystallized minerals are particularly well suited for a study of their sequence of deposition	Minerals deposited in the open space of the brecciated ore and in the cavity of the host rock are well suited for a study of mineral paragenesis. Minerals in massive ore commonly well crystallized.
B. Minerals were deposited in a general sequence in which most of ore mineral tends to be deposited before most of another mineral	Principal minerals deposited in the following general sequence; calcite-manganese dolomite, pyrite, sphalerite-galena-chalcopyrite-pyrite, marcasite-quartz-calcite, manganese dolomite-pyrite
C. Two minerals, whose periods of deposition are closely spaced in time, may exhibit partially overlapping relationships	Overlapping deposition is found in part

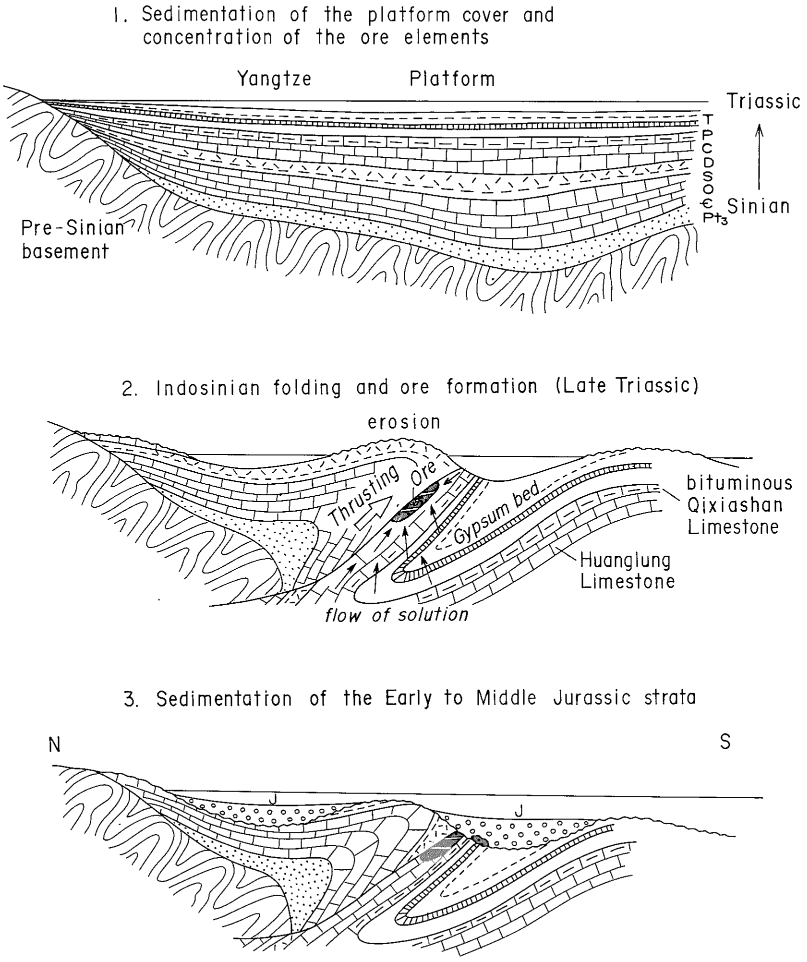
Table 2 (Continued)

Mississippi Valley type deposits	Qixiashan deposits
D. Repetitive deposition of the principal minerals in many intervals is characteristic. Although many of the intervals beyond those of their main depositional periods are of minor importance, other repetitions are quantitatively significant and may represent separate pulses of the ore solutions	Deposition of the principal minerals and manganese dolomitization occur repeatedly. Pyrite was deposited during a long interval. Principal sulfide minerals were deposited during later manganese dolomitization in a small amount. Except for the bedded ore, mineral deposition took place during two intervals
(Chemical constituents in the ore)	
A. Major elements include: Zn, Pb, Cu, Fe, Si, Ca, Mg, Ba, F, S, C, and O	Major elements are: Zn, Pb, Cu, Fe, Mn, Si, Ca, Mg, S, C, and O
B. Minor elements present in the principal minerals: Fe, Ag, Cd, Ge, Ga, In, Co, and Hg, in sphalerite; Ag, Sb, Bi, and As in galena; Co, Ni, Ag, and Cu in pyrite and marcasite; Sr, Y, Ba, and Mn in calcite. Additional minor elements reported for these minerals, and perhaps part of the above elements are present partly to wholly as microscopic inclusions of separate phases	Traces of Au, Ag, Ga, Cd, Se and As are reported, but data on minor elements in the principal minerals are not available
C. Isotopic composition	Isotopic composition
(1) Lead; Wide range of values, J-type radiogenic character (for deposits of Mississippi Valley proper)	(1) Lead; Rather limited range of values based on a few data, according to personal information from the mining geologist of the Qixiashan
(2) Sulfur; Wide range of values, characteristic of biogenic sulfur	(2) Sulfur; Wide range of values is reported; $\delta^{34}S=-18.4\sim+14.1‰$. The values for pyrite show a broad range, but those for sphalerite and galena have narrow ranges around zero per mil.
(Fluid inclusion character)	
A. Mainly a very concentrated saline brine, dominated by Na, Ca, and Cl; becomes more dilute in some younger minerals	Data not available
B. Filling temperatures range from about 40-150°C; showing a general decrease with time	Filling temperatures for sphalerite range from 150-300°C according to personal information from the Qixiashan mine
C. Density greater than normal water	Data not available

karst features such as karst caves and sinks with fillings composed of solution collapse breccias and sandstone beds has been reported around the ore deposits (XIAO and GUO, 1984). The formation of the solution collapse breccia and open space might be related to the main axial fault-unconformity system in the Qixiashan area.

Sedimentary environments of the host rock, i.e., reef facies and a marginal facies of miogeosyncline, are common characteristic of the Mississippi Valley type deposits, yet non-reef, platform carbonate rocks like in the Qixiashan area also constitute the host rocks for other Mississippi Valley type deposits. As is well known, the Mississippi Valley type deposits are closely associated with oil fields. In some ore fields of this type, black viscous percolated bitumen and finely disseminated solid organic material can be found. In the case of Qixiashan deposits, the ore contains fair amounts of solid bituminous materials. Besides, nearby Lower Permian limestone shows high bitumen content.

In general, dolomitization prevails in the wall rocks of the Mississippi Valley type deposits. Necessary porosity in carbonates for the mineralization can be provided through this process. The Qixiashan deposits are associated with manganese dolomitization.



1. Sedimentation of the platform cover and concentration of the ore elements

2. Indosinian folding and ore formation (Late Triassic)

3. Sedimentation of the Early to Middle Jurassic strata

Fig. 15 Schematic representation of genetic model for the Qixiashan lead-zinc deposits.

The manganese was possibly supplied from the host limestone for which the mining geologists in the Qixiashan pointed out somewhat higher manganese content.

Many of the Mississippi Valley type deposits are associated with silicification. The Tri-state deposits in U.S.A., for example, are characterized by intense silicification to form jasperoid (HAGNI and GRAWE, 1964; MCKNIGHT and FISHER, 1970). The silicification is closely related to the sulfide mineralization in space and time. The Qixiashan deposits exhibit the same characteristics. The sulfide mineralization has been accompanied by relatively intense silicification throughout the ore deposits and the wall rock contiguous to the mineralization.

Major faults and thrusts are important to the localization of ore fields of the Mississippi Valley type deposits. Sometimes, these faults are thought to have provided a conduit for the ore solution. In the Qixiashan ore deposits, dolomitization and associated solution collapse breccias have been greatly controlled by the main axial faulting. The localization of the ore deposits are intimately related to the presence of the main axial fault.

Many of these affinities in essential features of both deposits of China and North America lead us to conclude the Qixiashan deposits to be of the Mississippi Valley type. However, we cannot exclude some differences between these two deposits. The Mississippi Valley type ore districts usually have not undergone significant tectonic disturbance since the deposition of the host rocks, whereas the Qixiashan host rocks were subjected to the intense Indosinian deformation during Late Triassic. The delay of the mineralization from the host rock deposition is also a big difference. Consequently, the Qixiashan deposits may not be typical Mississippi Valley type but one of its variations.

The Qixiashan mineralization apparently does not show any relationship to nearby igneous activity as not the Mississippi Valley type. The elements of the ore minerals are assumed to have been derived from the host rocks or the surrounding sedimentary rocks of the Yangtze platform. The presence of the organic substances in the Qixiashan deposits is suggestive of a generally accepted view that the metallic elements have been carried by brines-connate or formation waters together with oil (DOZY, 1970). These organic substances are also postulated possibly to have served reduction of dissolved sulphate to form sulfide (BARTON, Jr., 1967). The organic material itself can contribute to the ore formation as a sulfur source (SKINNER, 1967). In the case of the Qixiashan deposits, the Middle Triassic gypsum beds might be another candidate of the sulfur source. Reconstruction of the Qixiashan geology indicates that the host rocks were almost overturned prior to the Upper Triassic to Early Jurassic unconformity (Fig. 15). This indicates that the Qixiashan ore deposits had a possibility to have been underlain by Triassic gypsum beds together with the bituminous Qixiashan limestone. Thus, the upward rising brines-connate or formation waters could have dissolved calcium sulfates of the gypsum beds, and then the dissolved sulfate could have been reduced into sulfide during their percolation through the Qixiashan limestone.

The metals of ore-forming minerals of the Qixiashan deposits may have been derived from the sedimentary rocks when the solutions passed through, as is the case of the Mississippi Valley type deposits. The platform sedimentary cover is reported to contain an average of 200 to 290 ppm lead and zinc in the Upper Carboniferous Huanglung Formation, and an average of 220 ppm zinc in the Lower Carbonifeous Kaolishan Formation (WAN and XING, 1983). These values are large enough to be extracted by the brains.

The site and space of the deposition of the Qixiashan ores were prepared by the development of the karst topography in the carbonate host rocks, main axial fault and associated solution collapse breccias. The compaction of the platform sediments and the subsequent release of the solution and ore elements might have been caused by the compressional stress due to the Late Triassic tectonic movement (Fig. 15).

Conclusions

The mode of occurrence and characteristic features of the Qixiashan stratabound lead-zinc deposits are summarized as follows.

1) The ore deposits occur in the Upper Carboniferous carbonate rocks of the Yangtze platform sedimentary cover.

2) The ore deposits are typified by the development of brecciated, massive and bedded ores. The massive ore has an economic importance, whereas the brecciated and bedded ores provide useful information to understand the ore genesis.

3) The brecciated ore includes solution collapse breccias composed of the host limestones and in some cases, the bedded ore. It shows features of open space filling by ore minerals of the breccias and fault fracture zone.

4) The bedded ore consists of sulfide bed and mudstone. The sulfide bed contains clastic grains of sulfide minerals, and displays many of characteristics of turbidites, such as lamination, graded bedding, penecontemporaneous erosion, intraformational fragments and slumped structures.

5) The Qixiashan ore deposits are, as a

whole, emplaced not only parallel to the bedding plane of the wall rocks but also along the main axial fault, originally thrust, in the southern flank of the overturned anticline.

6) The ore deposits and their wall rocks are truncated by the Upper Triassic to Early Jurassic unconformity.

7) The upside direction indicated by graded bedding of the bedded ore is opposite to that of the wall rocks. This means that the bedded ore has formed in a depositional space or basin inside of the wall rocks after the deformation of the wall rocks.

8) The ore mineral assemblage is simple, being mainly composed of sphalerite, galena, pyrite and marcasite.

9) Solid bituminous substance is included in some parts of the ore deposits, especially in the bedded ore in considerable amounts.

10) The mineralization is accompanied by intense manganese dolomitization and silicification.

11) The wall rocks contiguous to the ore body have also undergone the same type of dolomitization and silicification.

12) Principal minerals were deposited in the following sequence; calcite-manganese dolomite, pyrite, sphalerite-galena-chalcopyrite-pyrite, marcasite-quartz-calcite and manganese dolomite-pyrite.

The wall rocks of the Qixiashan ore deposits have suffered a strong deformation during the Late Triassic Indosinian movement. The mineralization and associated solution collapse breccias are closely related to this important tectonic activity. The breccias in the ore were presumably derived by solution collapse of the host limestone, and partly by fault fracturing. The circulation of the solution might have been enhanced by the main axial fault. The clastic grains of the turbidite sulfides in the bedded ore are considered to have originated from dissolution of the preexisting ores and the host limestones. The deposited metals and sulfur are assumed to have been transported to the site during the Late Triassic tectonic movement by brines which have originated in the platform sedimentary cover. The bituminous material in the ores possibly have played an active role in reduction of sulfate carried by the ore solution, together with the nearby bituminous Lower Permian limestone.

In summary, the Qixiashan ore deposits share many features characteristic to the Mississippi Valley type deposits in North America, such as shallow water carbonate host rock, development of solution collapse breccia, dolomitization, silicification, open space filling and associated unconformity, etc. These features indicate the Qixiashan mineralization to be of the Mississippi Valley type. However, they also have some differences from the typical Mississippi Valley type deposits, i.e., a large time gap between the host rock deposition and mineralization, manganese dolomitization and strong deformation of the host rocks. If an emphasis is placed on these points, we may call the Qixiashan deposits "Yangtse Valley type carbonate-hosted lead-zinc deposits" as a variation of the Mississippi Valley type deposits.

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中国江蘇省，栖霞山鉛・亜鉛鉱床の地質

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要　旨

中国南東部の栖霞山鉛・亜鉛鉱床は，揚子プラットフォーム被覆層中の石炭系炭酸塩岩に胚胎する層準規制型鉱床である．鉱床の母岩は三畳紀後期のインドシナ造山によって強い変形を被っており，鉱床は揚子プラットフォーム北縁に生じた背斜の南翼を通る主断層(衝上断層)に沿って分布する．

鉱床は主に礫状鉱，塊状鉱及び層状鉱からなる．礫状鉱は石灰岩角礫を含み，その角礫の大半は一種の溶解性崩壊角礫であるが，一部には断層角礫もある．礫状鉱の鉱石鉱物は，これらの角礫間の空隙の充塡として産する．層状鉱は硫化物層と泥岩の互層からなり，全体としては礫状鉱や塊状鉱の中に挟まれている．硫化物層は，葉理，級化層理，同時侵食，偽礫及びスランプ層などのタービダイトの特徴を示す．塊状鉱には2種類みられ，1)礫状鉱のほとんど角礫を含まないものと2)タービダイト硫化物の厚いものがある．注目すべきことは，級化層理からみて層状鉱は母岩が逆転した時点でその中に堆積したということである．

栖霞山鉛・亜鉛鉱床は，北米のミシシッピーバレー型鉛・亜鉛鉱床とは次のような多くの共通点をもつ．(1)母岩は浅海性炭酸塩岩からなる．(2)火成岩を伴わない．(3)溶解性崩壊角礫の発達．(4)鉱石鉱物による空隙の充塡．(5)単純な鉱石鉱物組成．主に閃亜鉛鉱，方鉛鉱，黄鉄鉱及び白鉄鉱からなる．(6)瀝青質物質を含む．(7)ドロマイト化及び珪化．(8)不整合との関連性．しかし，栖霞山鉱床は次のような相異点も示す．(1)母岩の強い変形．(2)マンガンドロマイトを伴うドロマイト化作用．(3)鉱化作用の母岩堆積時からの遅れ．

栖霞山鉱化作用とそれに伴う溶解性崩壊角礫は，それらの分布を規制する主断層に密接に関係している．鉱床の形成時期は，母岩が変形・逆転した三畳紀後期のインドシナ造山の時期である．鉱石鉱物中の金属元素や硫黄はプラットフォーム被覆層中に起源があり，それらは主断層を通路として鉱床形成の場へと移動したと考えられる．鉱床中の瀝青質物質は，瀝青質栖霞山石灰岩と共に，鉱液中の硫酸塩の還元に主要な役割をはたしたとみなされる．

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