THE ROLE OF VOLCANIC AND VOLCANO-SEDIMENTARY PROCESSES IN THE FORMATION OF CERTAIN MINERAL DEPOSITS OF CHINA

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I. Introduction

The significance of the volcanic and the volcano-sedimentary processes in the formation of mineral deposits has, as a rule, not yet been sufficiently recognized by geologists. Intensive studies carried out recently by the Soviet geologists in the Altai[1] and Ural regions[2] have furnished more and more informations regarding the genetic relations between volcano-sedimentary processes and the formation of ores. The development of the pyritic copper deposits in the spilite-keratophyre series and the formation of the silicate replacement type of certain lead and zinc deposits are but some of the leading examples. Studies on the type and origin of "Secondary Quartzite",[3] a name introduced by the Soviet geologists, have proved that volcanism is also important in the formation of non-metallic deposits such as alunite, andalusite, corundum, kaolinite and pyrophyllite. The recent article by Schatskee[4] "On the Manganiferous Formation and the Origin of Manganese" explains in a more detailed way manganese mineralization in relation to volcanism and volcano-sedimentary processes.

After a causal study of the mineral deposits of China, the same conclusion is reached, indicating that volcanism and volcano-sedimentary processes play an important role in the formation of certain metallic and non-metallic deposits.

II. Distribution and Mineralization of the Volcanic and Volcano-sedimentary Rocks in China.

According to geologic age, the volcanic and volcano-sedimentary series in China may be divided into five systems as follows:

(1) *Pre Cambrian volcanic series*:

This may again be divided into two groups with the Sinian formation as the dividing line. The Pre Sinian volcanics are as a rule intensely metamorphosed and deformed, so their exact age and nature can not be determined.

In the Lowest Sinian there occurs in the provinces of Honan, Hopei and Shansi of North China a thick layer of andesite[5] amounting to several hundred to thousand metres thick. This andesite contains at many places in the Chungtiaoshan region of S. Shansi numerous copper-bearing quartz veins, which were

worked in ancient times, though at present they are not important economically. Some authors believe that the ultimate source of the iron which formed the well known iron ore beds in the Sinian formation, was derived from the weathering and decomposition of this andesite eruptive.

(2) *Devonian and Carboniferous volcanic series*:

Metamorphosed volcanic series has been discovered at many places in W. Szechuan by Y. C. Cheng and C. Y. Jen.[6] The rocks are usually slightly metamorphosed, but at some places intensely altered stressed representatives such as gneiss and schist were also seen. In a section from Kangting to Moukung near Chintang, rhyolite, quartz porphyry, agglomerate and tuff were seen to lie under the Hosin limestone which carries middle Devonian fossils. The volcanic series shows a thickness of about 1180m. The underlying limestone and shale contain only a few poorly preserved fossils and their age is not determined. In a section near Lungpapu, S. E. of Kanting, volcanic tuff of greatly reduced thickness lies above a black shale formation of clearly Lower Silurian age. The time of the volcanic eruption can then be accurately determined to be Pre-Middle Devonian to Post Lower Silurian. The rocks are characterized by acid to intermediate composition and are probably of submarine eruptive origin. They are most probably related to the Caledonian Movement.

The thick volcanic series in the Mingchia Series of N. W. Yunnan which was held by Gregorys as post Silurian and probably upper Devonian, may be correlated with the section of W. Szechuan.

Thick volcanic series consisting of andesite, trachyte and rhyolite with interbedded tuff and agglomerate, has been discovered at many places in the Nanshan geosynclinal belt from Tsiuchuan to Lanchow in Kansu Province. Although definite fossil evidences were lacking, a rough stratigraphic and lithologic correlation with other sections in the Chiehliensban range may undoubtedly assign the volcanic series to Devonian or Siluro-Devonian age. In other words, it is the product of the early Variscian Movement.

The well known Chiehliensban pyritic copper deposit and the recently discovered iron deposit of Northwestern kansu are all found in this volcanic series though they seem to occur at different horizons. The ore bearing rocks at the Chiehliensban belong to the Spilite-Keratophyre series which has been intensely altered to sericite, chlorite and kaolinite.

At many places in the Nanshan range, a volcanic rock of a younger age occurs in the Laochungshan conglomerate formation of Lower Carboniferous age.

Up to now, no evident mineralization is seen in the latter series.

(3) *Permian basalt*:

The Omeishan besalt of Permian age show wide distribution in the bordering region of the three provinces Yunnan, Szechuan and Kweichow. Limestone patches or intercalations are often found in the basalt, so the latter is held by many authors to be at least partly sub-marine eruption. The numerous gabbro intrusions seen at Tungchuan, Yunnan, and some diabase dikes occasionally found in the region of Weining and Suicheng, Kweichow Province, may possibly represent the intrusive phase of the Omeishan basalt.

A zeolite copper mineralization is frequently observed in this basalt, though none of them is rich enough to be worthy of attention. At Toke in the Yungfeng district of Yunnan Province, some galena and sphalerite were seen in the basalt. From the fact that the wide belt of lead and zinc deposits of E. Yunnan and W. Kweichow lies actually within and in many places closely associated with this Permian basalt and moreover, almost all these lead-zinc deposits occur in Pre-Permian rocks, it may be inferred that the lead-zinc mineralization may be genetically related to the Permian basalt, especially its intrusive phase.

A Pre-Jurassic and probably Permian volcanic series composed chiefly of diabase, trachyte, agglomerate etc. occurs in the Western Hills of Peking, south part of Inner Mongolia and W. Honan. Traces of native copper are often found in the diabase.

(4) *Mesozoic volcanic and volcano-sedimentary series*:

This is the most widely distributed volcanic series of E. China, being found from the Great and the Small Khingan in the north to as far as the southeast coast of Chekiang and Fukien. Its westernmost extension has recently been discovered by the author in the La Ki Shan range in S. E. Tsinghai.

According to lithology and structural features, this great volcanic series may be divided into two groups: the lower group is an andesite, agglomerate and tuff series with some occasional rhyolite, in which are often intercalated many beds of sedimentary or volcano-sedimentary rocks. In the Western Hills of Peking, this group is called the Tiaochishan series belonging to upper Jurassic and Lower Cretaceous and with a thickness of more than 1500m. In the coastal region of Chekiang and Fukien, this is named the Chienteh series with a thickness of 1000 2000m. The upper group is composed chiefly of rhyolite with some occasional intercalations of tuff and volcano-sedimentary rocks. In the Western Hills of Peking, this upper volcanic group is named the Tungliangtai series[7] of about

400m thick and maintains a distinct unconformable contact with its lower Tiaochshan series. The age of the extrusion is probably Middle to Lower Cretaceous. In the coastal region of Chekiang and Fukien, this group is collectively called the rhyolite series.

Up to now very little attention has been paid to the occurrence of minerals in this great volcanic series. It was only known that the widely distributed fluorite veins of Chekiang Province are found chiefly in the rhyolite. Besides, there are many deposits of lead, zinc, copper and molybdenum. Although found in the volcanic series, the origin of their mineralization is probably related to the granite intruded into the volcanic rocks.

The lead-zinc deposits of Tehhsing, Chienshan and I-Yang in N. E. Kiangsi are the only deposits that are now known to be genetically related to Mesozoic volcanism. They form veins and disseminations in rhyolite, tuff and agglomerate, representing probably the product of silicate-replacement in certain of the more permeable horizons. These deposits may have, therefore, a greater future prospect than those occurring in Chekiang and Fukien.

A most remarkable feature in the Mesozoic volcanic area is the development of the secondary quartzite, a special type of wallrock alteration. Besides an intensive silicification, this rock is often characterized by the development of alunite, pyrophyllite, kaolinite, andalusite and diaspore. All these minerals have been identified in the altered volcanic rocks of S. E. Chekiang and Fukien[8]. In fact there are many well known deposits of alunite, pyrophyllite, and kaolinite in this region that have been working since a long time ago. The mother rocks of the alteration are composed chiefly of rhyolite and granite, i. e. igneous rocks of acid composition. This is in close agreement with the conclusion of the Soviet geologists who maintain that non-metallic deposits such as alunite, pyrophyllite etc. are developed in the secondary quartzite that are related to the acid igneous intrusions or extrusions.

Another belt of secondary quartzite with the development of alunite and kaolinite occurs in the Lower Yangtze region from Lukiang in Anhui down to Nanking in Kiangsu. Here the Mesozoic volcanic rocks are composed of trachyte and andesite with many small intrusions of syenite and diorite. They are all igneous rocks of weakly acid to intermediate composition. Metallic mineralization is frequent in this region, the most extensive of which being the copper deposit of Lukiang which has already yielded good results in drilling. According to the conclusion of the Soviet geologists, the secondary quartzite developed from rocks

of weakly acid to intermediate composition are usually more hopeful for the metallic ores such as copper, lead and zinc. It is especially promising for the development of porphyry copper deposit. If this rule holds good, we should expect to find porphyry copper or other metallic deposits in this secondary quartzite area of the Lower Yangtze region.

(5) *Basalt and other volcanic rocks of Tertiary to Quaternary age*:

Tertiary basalts are widely distributed in the coastal region of China. They start from the Great Khingan and Changpei in Northeast China, pass interruptedly through Hopei, Kalgan, Inner Mongolia, Central Shangtung, the Nanking area, central Chekiang, Fukien and end in the South at Laichow Penninsula and Hainan Island. This is certainly a long and extensive belt. Within this belt the age of the basalt extrusion may vary to some extent, but in the main, they belong to Middle to Late Tertiary.

In NE China and Kalgan areas, the basalt usually lies on high mountain tops, forming plateau type basalt. To the south and along the coast, most of the basalt area has been deeply dissected to form interrupted hillocks, exhibiting at many places, typical mesa type topography. In a few places, relics of former craters may be observed.

Up to present, very little mineralization is known from the basalt rock. Traces of cobalt mineral in association with zeolite are seen in some basalt of Kiangsu, Chekiang and Fukien. After weathering, the cobalt minerals are concentrated to form nodules or concretions in the residual red clay. They are mined at some places. Some cobalt nodules in red clay are said to have originated from the weathering and alteration of the Mesozoic porphyry rocks. The most important mineral resource derived from the Tertiary basalt is the gibbsite deposit of Fukien and Kwangtung, among which the deposits of Changpu and Kingmen Island in S. Fukien are more important. These deposits have been formed by the intensive weathering of the basalt and redeposition of the highly desilicified and aluminized material in their neighbourhood.

Basalt extrusions of Quaternary age are known from Tatung, Shansi and Tenchung, Yunnan. They are volcanic extrusions of such young appearance that most of the volcanic craters and cones are remarkably well preserved. Volcanic extrusions of still younger age, i. e. in historical time, are also known in China. So far two examples have been discovered and both are located in NE China. No mineralization has ever been seen in the Quaternary basalt.

The famous gold-silver-copper deposit of Kinkashek in Northern Taiwan

occurs in the Tertiary volcanics and sub-volcanic rocks of non-basalt composition. Here the marine Tertiary beds are intruded by a quartz andesite in the form of volcanic necks or stocks. Ore veins or pipes occur either in the quartz andesite itself or in the Tertiary beds. The ore mineral is auriferous pyrite and enargite with gangues of barite, alunite and quartz. They are believed to be low temperature hydrothermal deposits formed mainly by fissure-filling.

III. Description of Some of the Deposits.

The following is a short description of some of the more important deposits that are known to be genetically related to the volcanic or volcano-sedimentary processes. The genetic relation is here understood either as the volcanic rocks itself to have furnished the material for the formation of the ore deposits or the volcanic or volcano-sedimentary rocks to have exerted certain influences in controlling the localization of the ores. Such influences are chiefly due to the high permeability and porosity of the tuffaceous, agglomeratic or brecciated rocks of the volcanic series. The ore deposits thus formed largely belong to the veinlet-disseminated replacement type.

(1) *The Pyritic copper deposit of the Chichlienshan, Kansu*:

This is a recently discovered copper deposit of great economic importance. The geological formation consists of phyllite, slate and quartzite about 2000m thick below and a thick sequence of volcano-sedimentary rocks of more than 5000m above.[9] By correlation with sections observed in other parts of the Chienlienshan range, the geological age of the lower series is tentatively assigned to Siluian, and the upper series, to Devonian. The entire sequence of the sedimentary rocks exhibit a typical geosynclinal character.

The ore bearing formation is a sub-marine volcanic to volcano-sedimentary series consisting of quartz keratophyre, spilite-keratophyre, rhyolite, tuff, agglomerate and phyllite. The ore occurs in forms of veins or veinlets, disseminations or massive body of lenticular shape. The last named occurrence, i. e. the lenticular shaped massive ore is the most important. Ore depcsit seems to be more or less localized along the tuffaceous beds, though mineralization occurs also in the lava flow as well as in the phyllite. The wall rock adjacent to the ore body is as a rule intensively sericitized, chloritized and silicified, and at some places also kaolinized.

The most abundant ore mineral is pyrite in which is frequently seen fine veinlets or disseminations of chalcopyrite, and some small amount of sphalerite, galena and magnetite. Pure chalcopyrite in forms of small-sized veins or dis-

seminations are also found. Besides, the ore contains invariably certain amount of gold and silver.

The ore deposit of the Chiehlienshan is marked on the surface by a tremendous cap of gossan, which usually forms a continuous, rich and compact mass if it lies above the massive pyritic copper ore. In the case of the disseminated and fine veinlet type, its oxidation cap is usually characterized by a poor gossan or by fine networks of limonite in sericitized and kaolinized rocks. The development of many different kinds of alum minerals together with some alunite is another characteristic feature of the oxidation zone. Below this zone and above the ground water level, there is developed a secondary enrichment zone of rich sooty chalcocite.

(2) *The manganese and copper deposit of Titzeyen, Kansu*:

Titzeyen is located some distance S. W. of Lanchow in Kansu. The geology consists of phyllite, slate and many intrusive and extrusive rocks of acid to intermediate composition. It may be broadly correlated with the formations observed at the Chiehlienshan and therefore belongs to the same geosynclinal type of deposits formed during the Variscian revolution. Manganese and copper ores occur in lenses, layers or irregular disseminations in the metamorphosed volcanic and volcano-sedimentary rocks. The primary copper mineral is chiefly chalcopyrite which has been extensively oxidized on the surface to malachite and azurite. Some chalcocite ore occurring in small nodular shape in limestone intercalations, may represent the product of secondary enrichment. The economic value of this deposit is to be determined by further prospecting.

It is to be noted that manganese ores also occur at the Chiehlienshan. Similar to the Titzeyen deposit, they are the product of the volcano-sedimentary processes. Because of the low manganese content, most of the primary deposits are not workable, but the oxidized manganese cap formed by weathering contains usually higher grade ore that needs our attention.

(3) *The iron deposit of N. W. Kansu*:

This deposit is located in the Tsiuchuan district in N W Kansu. The geology consists of slate and phyllite below and tuffaceous phyllite, phyllite and marble above with some andesite flow and diabase intrusion, all striking N W. and dipping northeast steeply.[10] The entire sequence attains an enormous thickness and exhibits typical geosynclinal deposition. It is temporarily assigned to Devonian or Siluro-Devonian.

Iron deposits in forms of layers and lenses occur chiefly in the tuffaceous

phyllite. Two iron ore districts have been discovered and each contains several important ore bodies of great dimension. The ore is chiefly hematite and specularite with a small amount of magnetite. Some pyrite and chalcopyrite are seen and on the surface the outcrop is marked by limonite and malachite.

The writer believes that this iron deposit is formed by volcanic and volcano-sedimentary processes, and may be closely correlated with the Lahn Dill type of Keratophyre-iron ore deposit of Germany. In genesis it is similar to the Chiehlienshan pyritic copper deposit and therefore should be found together with the latter in the Chienlienshan geosynclinal region.

(4) *The lead-zinc deposit of Tehhsing, N E Kiangsi*:[11]

This is an old mining district that has produced considerable amount of silver and lead during the Ssu, Tang and Sung Dynasties 605-1037 A. C.). On the Sinian or Pre-Sinian basement of phyllite and metamorphosed rhyolite is laid unconformablly the Mesozoic volcanic series which consists of andesite and agglomerate below and rhyolite, tuff and some sedimentary rocks above. Quartz porphyry, evidently the intrusive phase of the rhyolite flow, is seen at many places to form volcanic necks and dikes that cut the entire volcanic series. The youngest formation is the Tertiary red beds which overlie unconformably on the Mesozoic volcanics.

The ore deposits form veinlets and disseminations in the quartz porphyry and phyllite, being evidently the product of hydrothermal replacement. Galena is the principal ore mineral which usually contains high amount of silver. Sphalerite and pyrite are rarely seen. Dolomite and quartz constitute the common gangue, with a little amount of calcite, siderite, rhodochrosite and barite. Silicification is the chief type of wall rock alteration seen in the quartz porphyry. while in the phyllite, the rock is locally intensely pyrophyllitized and sometimes also kaolinized. In the rich ore shoot, the rock is usually intensely chloritized and also with abundant development of dolomite. Therefore, chloritization and dolomitization may be considered as intimately connected with the ore formation.

It is preliminarily concluded that the principal factors controlling the localization of the ore shoot is the contact zone between the quartz porphyry and the phyllite and the fissure and brecciated zone in the country rocks. The quartz porphyry plays not only the role of the ore carrier, but also actually contains most of the important deposits. Many outcrops show the presence of cerussite as well as galena, so the depth of oxidation is here very slight.

(5) *The Chienshan and I-Yang lead zinc deposits, N W Kiangsi*:

Near Chienshan, the geological structure forms a north-south trending and southward pitching anticline with Permain limestone and phyllitic shale as the core. Unconformably overlying the shale is the Cretaceous volcanic series consisting of a whitish tuffaceous rock at the bottom, coarse sandstone, conglomerate and tuff in the middle and a typical rhyolite on top. The sandstone and conglomerate series is in unconformable contact with the lower lying volcanic series. Some white aplite or quartz porphyry occurs as intrusive dikes or bodies in the volcanic series.

Ore deposits are marked on the surface chiefly in the forms of gossans. Four to five strips of gossan with length up to 1.3 km and an undertermined width were observed. They are all dip steeply. At another place a silicified zone, 30-40m wide and about 1 km long, was found. Traces of Pb-Zn minerals were seen both on the outcrop of gossan and silicified zone and also on the dumps which are very abundant here. According to the historical records, this place was worked for lead, zinc and copper in the Tang and Sung Dynasties. On the basis of our limited observation, we concluded that the deposits here belong to the mesothermal replacement type, while the ore-bearing rocks may vary from silicified volcanic rocks to sandy shale or conglomerate or even limestone. In the latter case it would be more hopeful, because we might discover massive replacement deposits of larger dimensions.

Stratigraphy of the I-Yang district in ascending order consists of: (1) Mica schist, phyllite and gneiss; (2) Metamorphosed rhyolite stands together with the crystalline series in a vertical position. It may be rhyolite of an older generation; (3) Sandstone, conglomerate and other sedimentary rocks of Jurassic or Lower Cretaceous Age; (4) Typical Cretaceous rhyolite, not metamorphosed but dipping steeply; (5) Granite of Yenshanian age being seen to intrude into the rhyolite; (6) Red sandstone and conglomerate of Tertiary Age.

The geological structure of the region is an asymmetrical anticline with the northern limb dipping more steeply than the southern one. The ore deposit is marked on the surface by a prominent gossan, 800m long and 80-150m wide. Old workings are all located in the gossan. Many dumps of waste rocks and slags contain lead and zinc minerals such as galena, chalcopyrite and tetrahederite. The original rock of the gossan can not be determined; it may be derived from the limestone, tuff or intrusive porphyry. At least a part of the ore represents replacement deposit.

IV. Conclusion

From what has been stated above, it is evident that the volcanic and volcano-sedimentary rocks are not only widely distributed in China, but also contain a remarkable mineralization, some of which such as the Chiehlienshan etc., have been proved to possess enormous economic value. Preliminary study shows that a great part of the volcanic eruption took place under water, so it is with these submarine eruptions that are favorably located most of our important mineral deposits. The following are some suggestions for a further study of the problem:

(1) The silver-lead deposits of Teh-hsing, Chienshan and I-Yang in N E Kiangsi and the copper deposit of Lukiang in Anhui Province should be seriously studied and prospected in order to determine the value of the deposits as well as their origin and genetic types.

(2) Further studies should be directed to the investigation of the Devonian and other Palaeozoic volcanics in the Variscian Mt. ranges such as Chienlienshan, Tienshan, Kunlun, Tsingling, Tapashan and W. Szechuan area, with the object to discover more pyritic copper deposits of the Chiehlienshan type as well as other types of deposits of the polymetal group.

(3) A more detailed study of the Omeishan basalt and its associated copper, lead and zinc mineralization is necessary, as it will eventually determine the economic value of the zeolite-copper deposit in this region and the actual relationship between the lead-zinc deposits and the Omeishan volcanism.

(4) Detailed study of the stratigraphy, structure, lithofacies, geologic history and metallogenesis of the Mesozoic volcanics and volcano-sedimentary rocks of E. China including the Great and Small Khingan in the Northeast, in order to discover more useful mineral deposits and to determine their types and origin.

(5) To find and study whether we have on our continent Tertiary extrusives or intrusives of non-basalt composition and its associated gold-silver-copper deposits as is now developed at Kinkashek, northern Taiwan.

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