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Galena-bearing grains from the Lenggang stanniferous placers, Belitung, Indonesia

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Abstract: In the rejects from the beneficiation of the now completely disorganised shallow stanniferous placers of Lenggang, Belitung, Indonesia, galena occurs in grains, which, as a result of examination in polished section, may, according to their mineral content, be classified as galena grains, galena/sphalerite grains, galena/copper-bearing sulphide grains, and galena/iron sulphides grains.

The galena grains may consist of primary and/or secondary sulphide, and when the latter is present the bodies are commonly botryoidal, and in polished section display a banded texture. In one instance what are just possibly galena framboids were noted.

The galena/iron sulphides grains are angular fragments of originally woody tissue whose lumina have been largely infilled with pyrite and/or marcasite, and which may contain pyrite framboids, and whose voids have provided sites for deposition of galena.

All but the primary galena grains may contain pyrite framboids, which are sometimes disrupted, and woody fragments whose lumina are infilled either with iron sulphides, or galena, or possibly sphalerite. In addition, inclusions of organic-rich mud are common, as are fragments of resistates, such as quartz, which may be fractured in such a way as to suggest that the fragmentation was due to forces that were generated during the crystallization of the sulphide gel host.

The earliest of the secondary sulphides to be formed were pyrite and marcasite, and these were followed, in the order given, by sphalerite, galena, and copper-bearing sulphides, but a wholly satisfactory reason for this paragenesis has not been advanced.

The evidence suggests that these 'secondary' sulphides were all generated by supergene processes in the organic-rich, oxygen deficient environment of a freshwater swamp, and in the vicinity of fragmented galena that had been shed from a lode or from a collapsed portion thereof. Furthermore, it is thought that the lead, copper and zinc required for the formation of the supergene sulphides were derived from those parts of an undiscovered but neighbouring orebody that were in an oxidising environment. It is believed that mobilisation of the elements was in part effected by direct oxidation and in part by solution of oxysalts by organic acids. The iron was largely derived from the swamp waters, whilst the sulphide and elemental sulphur components were produced, by biogenic means, either from sulphate ions liberated from the oxidising part of the ore-body and/or from sulphur-containing proteins.

As the sulphides under review were the products of a somewhat unusual combination of circumstances, it is held that the content of this paper provides but little in support of any likely supergene theory of genesis of large stratabound deposits such as those of Rammelsberg and the Kupferschiefer.

INTRODUCTION

A few years ago one of us (T.B.A.R.) collected grains of what, to the naked eye, appeared to consist essentially of galena, amongst the heavy components of samples from the stanniferous placers of a then active opencast mine (Kollong I-IX) at Lenggang, not far inland from the east coast of Belitung, Indonesia. Later, and after mining has been abandoned there, the site was visited by both writers and further samples that were rich in grains of galena were found where they had been dumped during the beneficiation of the tin ore. Samples of the galena and of other sulphidic grains that accompanied them have been examined in some detail and the results of the work, together with the field observations, form the basis of this paper.

THE LENGGANG AREA

At the outset it is pertinent to state that in the Lenggang area three kollongs (small, opencast mines) have yielded, from their placers, galena, whilst a further two have provided, from the same environment, native copper, bornite and chalcopyrite. This information has not before been recorded, and although material from all these kollongs would, if available, be well worth studying in detail, for various reasons, at this stage, it has been necessary to confine attention to material from the one kollong noted above.

The placers of Kollong I-IX occur on low ground at the base of the fairly steep Selumar hill. The bedrock, on which the placers rest, consists of clearly banded sandstone and 'clay-shale', the both containing many quartz veins and the latter superficially altered to soft white clay. This bedrock is intersected by narrow and shallow gullies.

The placers, which for the most part must have been shallow, have been worked and reworked so that no natural profile of them was available for study.

No *in situ* 'hard-rock' sulphide-bearing deposits were located in the placer area in question, nor have any been recorded in the immediate vicinity. However, a 'hard-rock' deposit consisting of magnetite and other iron oxides, cassiterite, and locally pyrrhotite, arsenopyrite, pyrite, chalcopyrite, sphalerite and galena, occurs in the neighbouring but long-abandoned Selumar tin mine. It is, therefore, not unlikely that one or more hard-rock deposits containing a similar assemblage of sulphides may exist, or may have existed, in the Lenggang bedrocks and/or in the hill immediately adjacent to the placers.

From what is known of the genesis of the stanniferous placers generally in Belitung it is probable that the Lenggang ones developed essentially during the Quaternary when, at one stage, swamps occupied parts of a local sluggish drainage system. There is no convincing reason for thinking that the placers were ever submerged by the sea, nor that the swamp waters were ever brackish during the placers' development.

THE NATURE OF THE GALENA-BEARING GRAINS

Under a binocular microscope, and at low magnification, the grains that appear to consist essentially of galena can be divided into the two following classes according to their shape:-

(i) Markedly botryoidal bodies that, although varying considerably in size, are commonly about 1–2 mm in diameter.

(ii) Angular grains, showing the characteristics of fragments that result when a crystal of galena is fragmented by a hammer-blow. These are rather small and the largest noted has a maximum dimension of *c.* 0.2 mm.

In the samples studied, which cannot be regarded as indicating the relative proportions of these two types in the placers, the botryoidal type is by far the more common.

Associated with the bodies noted above are pyritised/marcasitised fragments of stems and roots which are particularly relevant to this account as some of them are seen to contain galena, but only when examined in polished section.

The grains, as a result of being studied in polished section, may be classified, according to their mineral content, as follows:-

i. Galena grains.
ii. Galena/sphalerite grains.
iii. Galena/copper-bearing sulphides grains.
iv. Galena/sphalerite/copper-bearing sulphides grains.
v. Galena/iron sulphides grains.

In addition, study of polished sections of the grains provided the basis for that which immediately follows.

There is little doubt that both primary and secondary galena is present in the placers. The primary galena (that is galena that has been liberated from a hard-rock deposit) occurs as angular fragments of crystals, and even when reasonably well polished it generally displays well-defined cleavage traces. It may either occur as isolated fragments (Fig. 1) or as nuclei in the abundant botryoidal grains that largely consist of globular masses of galena, that may display a banded texture and, for reasons that are given later, is regarded by the writers as having been deposited in the placers by supergene agents (Fig. 2). It appears that these globular masses of galena may not require a primary galena or other nucleus for their development, although it has to be remembered that even when a nucleus is present it may not be revealed in a polished section.

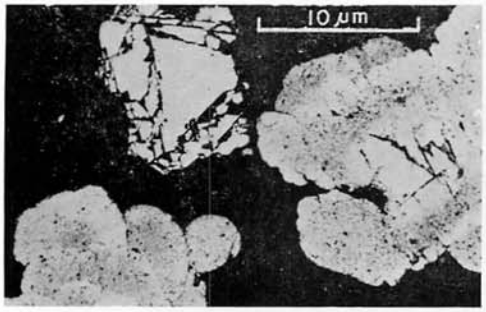
The bodies that consist primarily of banded galena are often reminiscent, in polished section, of bracket fungi both in shape, and because commonly bands of bright compact galena alternate with darker bands whose colour and general appearance is due in part to inclusions of one sort or another, that are discussed later, and in part to the somewhat spotly disposition of their galena units. On occasion these bodies are characterised by the presence of syneresis cracks and sometimes their peripheral parts shows a crude columnar texture. The texture of many of the bodies, that is often best appreciated after etching for *c.* 20 seconds with Fackert's HNO_3/ alcohol reagent (see Ramdohr, 1969, p. 638), is such that it is clear that the latter are composite and are the products of deposition of globules of sulphide gel which grew in close proximity to each other until they coalesced and eventually crystallised.

Whilst some of the botryoidal bodies are virtually lacking in inclusions, they, and indeed the other galena-bearing bodies (which may lack a marked banded texture) often possess them, and one or more of a number of varieties may be present. Minute inclusions of what may best be termed mud particles are locally wholly or in part responsible for some of the dark bands and patches in the galena. Dark areas are in some cases in part or wholly due to the presence of sphalerite, but this topic is deferred until later. Distinctly coarser fragments of resistate species may occur that may be either largely limited to certain galena bands or show random distribution. Of these, quartz fragments (Fig. 3) are by far the most common, but other species, notably mica and cassiterite, are occasionally present. Some of the quartz fragments are so disposed that it is difficult to escape from the conclusion that they are the products of fragmentation of what was originally a single grain entrapped within the sulphide, and that its fragmentation was effected by push-apart/pull-apart forces that were generated during the conversion of the sulphide gel to a crystalline state. Locally, large, irregularly-shaped masses of carbonaceous mud, with recognizable cellular fragments, are seen in the sulphide bodies. These provide evidence that the sulphides were developed within an organic-rich mud, particularly because, on occasion, a portion of cellular material can be traced from the mud inclusion into the galena. In the latter, cell lumina are commonly filled with galena whilst the cell walls remain, apparently, unaltered (Figs. 4 and 5). In many of the galena-bearing bodies under review it is not uncommon to see broken portions of cellular material completely surrounded by sulphide. Framboids of pyrite, often randomly distributed and consisting of well-ordered cubes are commonly encountered in the bodies under review (Fig. 6). On occasion the framboids are crudely linearly arranged and in certain instances a train of these bodies may be traced from muddy inclusions into the galena. In addition, polygonal masses of pyrite and marcasite are to be seen in some of the grains. These bodies may either occur in isolation when they may be simply entrapped iron sulphide crystals, or they may be assembled in the form of a mosaic, and it would appear that the mosaics have been derived from plant cells whose lumina had been completely filled with marcasite and which became entrapped by invading galena (or sphalerite) that, apparently completely replaced the cell walls. The iron sulphide bodies (single crystals, framboids and cell-fillings) persist in the galena without any sign of attack by the lead species, although the components of the framboids are sometimes separated from each other as a result of the forces associated with the crystallisation of the host. On the other hand one irregularly-shaped grain was seen to be composed of a core of polygonal sphalerite masses, that may occupy the lumina of cells, and of a peripheral zone that consists essentially of a mass of what may possibly be galena framboids (Fig. 7). It is just possible that these are the products of replacement of iron sulphides by galena and sphalerite. If this is so then the replacements have been complete as there are no iron sulphides in the grain now.

Sphalerite, which is yellowish under cross-polars, is found in a considerable number of the galena-bearing grains. It may occur as an irregularly shaped core surrounded by galena, or as irregularly shaped masses in galena (Fig. 8). The sphalerite masses often show a mottled texture that may have resulted from the dehydration of a gel (Fig. 9). Rarely, as noted above, this sulphide may take the form of plygonal masses, perhaps because it was deposited within the lumina of deformed cells. However, this texture may also be due to the development of syneresis cracks: the writers have not been able to decide which of these two possibilities is the more likely one. Pyrite framboids and cell lumina filled with marcasite occur in some of the sphalerite-rich areas.

The junction between a mass of sphalerite and the galena surrounding it may be quite clear cut, but on other occasions the galena has invaded the zinc species marginally and so nearly completely that the zone of invasion is not obvious under the reflecting microscope but the fact that a mixed lead/zinc zone exists has been demonstrated quite clearly by means of the scanning electron microscope.

In those cases in which the sphalerite occurs as polygonal or as mottled masses, the dividing material between them, be it originally mud or cell walls, may be locally



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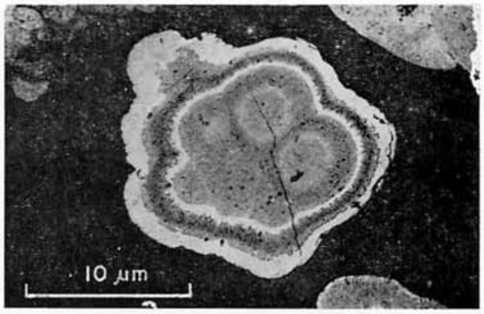

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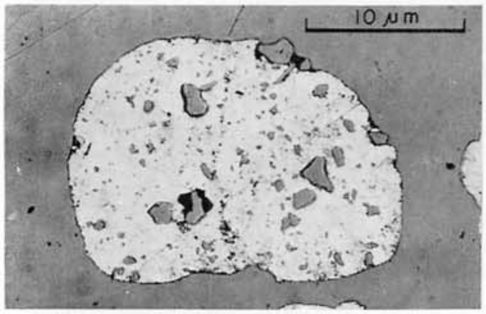

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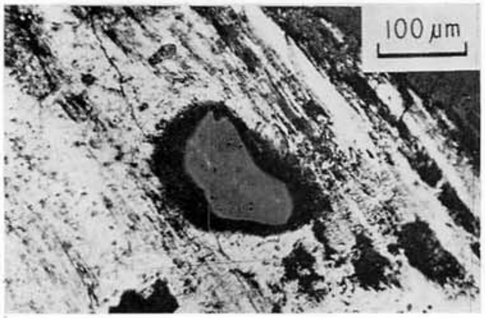

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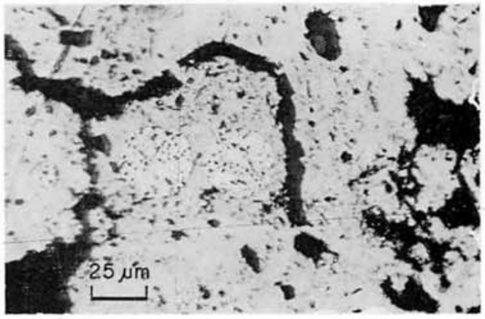

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Fig. 1. A grain of primary galena (top left-hand side) and two grains of secondary galena: the one on the right-hand side contains a primary galena nucleus.

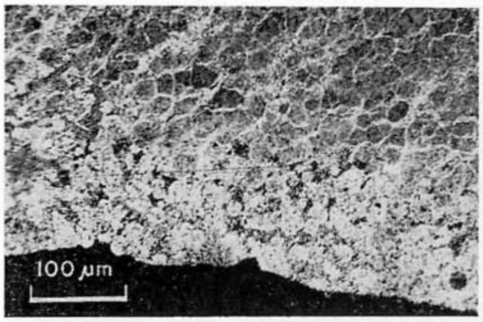
Fig. 2. A grain of zoned secondary galena (Etched).

Fig. 3. A grain of secondary galena with quartz inclusions.

Fig. 4. A mass of mud with woody tissue invaded and part enclosed by secondary galena containing quartz and other inclusions.

Fig. 5. A woody fragment largely replaced by galena.

Fig. 6. Pyrite framboids enclosed in secondary galena.



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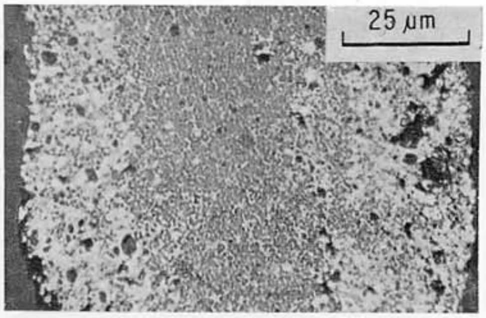

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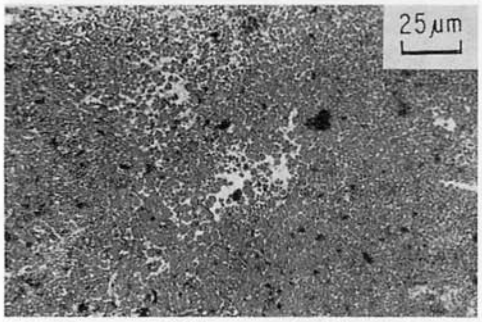

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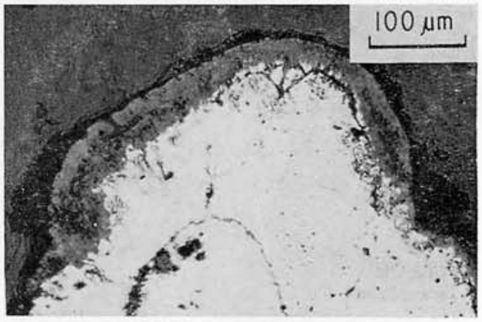

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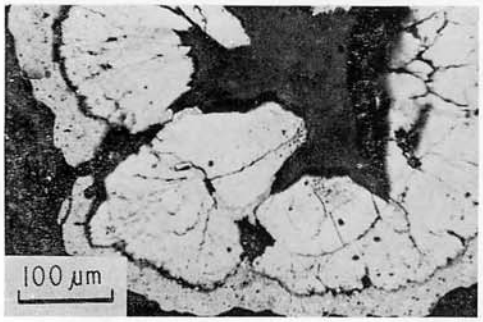

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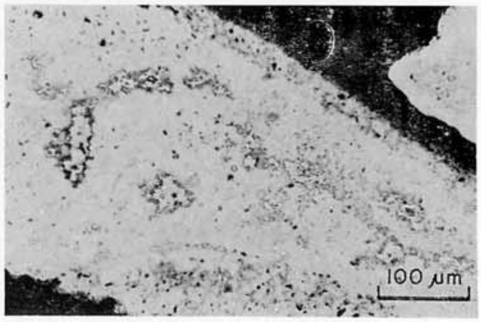

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Fig. 7. Portion of a grain consisting of a core of dark polygonal masses of sphalerite and a light rim of galena that in part consists of what *may* be galena framboids.

Fig. 8. Portion of a grain consisting of a mosaic core of sphalerite and veinlets of galena, and a rim of galena and darker patches of sphalerite.

Fig. 9. Portion of the core of a grain that consists of irregular masses of sphalerite (dark) 'veined' and perhaps replaced by galena (light).

Fig. 10. Portion of a grain of galena (light) that is rimmed by copper-bearing sulphides (dark).

Fig. 11. Portion of a grain consisting of a star-shaped core of mud surrounded by galena (light) that has been veined and rimmed by copper-bearing sulphides (medium grey).

Fig. 12. Portion of wood that has been replaced by marcasite/pyrite and in which voids have been infilled with galena that in the photomicrograph has generally a dark outline.

replaced by galena. In addition, galena veins intersect the sphalerite core, perhaps along fractures induced by gel dehydration.

Three grains that were examined also contain copper-bearing sulphides. In one the copper species are confined to a peripheral band that had been deposited on the galena. This band consists of chalcopyrite that is in an advanced stage of replacement by bornite, covellite and chalcocite (Fig. 10). The second grain (Fig. 11) is unusual in that it has a star-shaped core of mud. Locally galena adjacent to the core has been replaced by the copper-bearing sulphides which also occupy a number of radiating veins in the galena and, in addition, invest and possibly replace a peripheral part of the latter. The third grain consists of galena with a sphalerite core which has been part-replaced by the copper-bearing sulphides already mentioned. The copper-bearing core area is in contact with the surface of the grain by means of a vein that also contains the same copper species. Locally the galena of this body is coated and/or rim-replaced by the same copper species.

Amongst the samples examined there are a number of elongate iron sulphide grains, generally a centimeter or so in length, whose appearance, even to the naked eye, indicates that they are sulphidised plant fragments: stems and/or roots. In polished section some possess well-preserved cellular textures whilst in others the replacement is so advanced that such textures have been largely obliterated and, particularly in the latter case, irregularly shaped voids are common and the body largely consists of marcasite, often in the form of a mass of crystal rosettes. Perhaps the degree of preservation of the origin of cellular structure depends on the extent to which the wood had rotted before it was transported to a reducing environment. However, other fragments are solely pyrite or pyrite and marcasite. In a few of these iron sulphide grains galena has been deposited in voids (Fig. 12).

GENESIS OF THE GRAINS

That all the sulphides occurring in the grains under discussion can be deposited by supergene (or exogenous) processes is well-known (Ramdohr, 1969, pp. 447, 493, 516-517, 535, 648; Amstutz *et al.*, 1964; Rudenko, 1954) and there seems to be no doubt that the Lenggang grains have developed by such processes operating in the reducing environment of the organic-rich mud of a swamp. It is also clear that the development of framboids within the mud and in the hollow centres, etc., of fragments of stems and roots, and the pyritisation and marcasitisation of such organic fragments, represented the first phase of sulphide deposition. This was locally followed by the deposition of zinc sulphide, probably as a gel in the mud, and also, possibly, on occasion within cell lumina. The inclusion of framboids and other polygonal masses of pyrite within the sphalerite establishes the order of deposition. The presence of similar iron sulphide bodies within galena, and the fact that galena locally infills voids with pyritised/marcasitised organic fragments equally well establishes that the lead sulphide was deposited after the iron sulphides. In addition, whenever a grain contains both galena and sphalerite it is clear that the former was deposited after the zinc sulphide as it probably replaces it locally and certainly veins it. That the copper-bearing sulphides were the latest of the species to form is indicated by the fact that they both vein and replace the lead and zinc sulphides.

The development of the grains probably involved attempts to push out the components of the matrix occupying the sites in which they were developing. Sometimes this was not an entirely successful operation as is indicated, on occasion, by a dark galena/mud core in a grain. On other occasions it appears that the growing grain was successful, up to a point, in pushing ahead the components of the matrix, with the result that a clear band of dense galena was deposited. However, there seems to have been a limit to the load that it could so move, and when this limit was reached, the advancing sulphide cemented the components of this load thus producing a band that may be dark simply because of the presence of a fine mud component and small cellular fragments that have been stranded. On still other occasions, large inclusions of matrix have been bypassed by the accumulating sulphide, and it is from these that fragments of wood and grains of framboids can be traced into the sulphide mass. These, and other large cellular fragments that could not be moved by the developing sulphide, were simply engulfed in it, and in such a way that their cell lumina were completely filled with the invading sulphide. Larger quartz grains also resisted movement, but sometimes the forces operating when the sulphide gel underwent crystallisation were sufficient to fragment them. Also these forces of crystallisation may have been responsible for local fracturing of the sulphide grains themselves, but it is perhaps more likely that many such fractures are, in fact, syneresis cracks. It is, however, interesting to note that some galena grains are intensely crazed by what are believed to be syneresis cracks, whilst others are virtually devoid of them. This, of course, leads one to consider the possibility that some of the sulphides, in particular the galena, may *not* have passed through a gel phase. *A propos* of this, in one grain the galena is locally present as a mosaic of rather coarse crystals, with some well-developed faces, in a muddy matrix.

At this stage it is pertinent to consider the sources of the elements of which the sulphides are composed. One need spend little time on the question of the iron sulphides, as views concerning their genesis in environments similar, or identical to that at Lenggang, have been reviewed and discussed exhaustively by many, for example by Love and Amstutz (1966) and Hosking (1972) and there is no new evidence that might suggest any modification of the views already proposed. In short, they are, beyond reasonable doubt, the production of reaction between biogenically derived sulphide ions and elemental sulphur, and the ubiquitous iron ions. The other sulphides of the grains under review have also been developed by reaction between similarly derived sulphide ions, and ions, or soluble complexes of lead, zinc and copper (and iron). It is not known in what form these metals have been transported. There is also some doubt, in the case of the Lenggang deposits, as to what the parent source or sources of the sulphide ions were. If the swamp water had, during the time of development of the grains, been brackish, then an ample concentration of sulphate ions would have been available for reduction by bacteria to sulphide. But, in the writers' view that was probably not the case, and so the parent source of the sulphide ions would have to have been sulphur-bearing proteins, and/or sulphate ions that were developed by the oxidation of sulphides in a neighbouring mineral deposit or deposits and transported into the reducing environment of the swamp.

It is possible that the source of the lead, zinc and copper was a primary oxidising deposit in the close neighbourhood of the placers, and that it consisted essentially of galena with some sphalerite and minor amounts (perhaps) of copper-bearing sulphide. If the deposit was similar to the sulphidic part of the Selumar lode, noted earlier, then pyrrhotite and pyrite would also be present and their oxidation would probably facilitate mobilisation of the metals of the other sulphides. During the course of development of the placers some of the galena of the primary deposit was detached from the primary lode and incorporated into the placers. The angular fragments of galena, noted earlier, are surely primary, and have barely travelled, if at all, from their point of release. This release of galena may have been a result of rapid down-cutting of the river system through a lode during the development of the Pleistocene phase of low sea level. Alternatively it might have been due to collapse of a portion of a hillside lode into the swamp as a result of one of the all too frequent landslides that are experienced in the hilly regions of the Southeast Asian tin belt. Whatever the true story, it is certain that a portion of the parent orebody must have been so placed that it was subject to active oxidation because this seems to be the only reasonable way of mobilising the heavy metals. Certainly, oxidation of zinc and copper-bearing sulphides to readily soluble sulphates would be achieved by this process. Just how the lead was mobilised is not known. Possibly as Rudenko (1954) has suggested, cerussite ($PbCO_3$), that developed from the galena in the zone of oxidation, might be mobilised by its conversion to a bicarbonate by the action of water charged with carbon dioxide. Possibly, also, organic acids, derived from the decomposition of vegetation, were responsible for the mobilisation of the lead. That its mobilisation was effected is beyond doubt.

A further intriguing problem is why, if it is accepted that the samples examined are reasonably representative of the sulphide component of the placers, was sphalerite always deposited before galena and galena always before the copper-bearing sulphides. It seems possible to the writers that the zinc was the first to be deposited because the primary sphalerite was the most readily oxidised and the product was very mobile. By contrast, the secondary lead oxysalts, on the other hand, are rather insoluble, as far as one is aware, in the solutions likely to be available in the surface, or near-surface, oxidising environment. Possibly lead oxysalts may have been mechanically transported into the swamp where, by their solution, the lead ions needed for the generation of the supergene galena were made available. There is, however, no visual evidence in support of this suggestion as no lead oxysalts have been found in the samples examined.

The fact that the copper-bearing sulphides were the last to be deposited might be because, initially, the copper ions mobilised by the oxydation of the copper-bearing sulphides of the parent orebody were immediately absorbed on coming into contact with the organic components of the swamp. That this happens is, of course, well known. Only when the organic material between the exposed and oxidising parent orebody and the already developed galena or galena/sphalerite grains was saturated with copper, were ions of this element available for the partial replacement of the already developed sulphide grains. Initially chalcopyrite was deposited, but the continuing arrival of copper ions allowed copper enrichment to take place in much the same way as it occurs within an oxidising hard-rock orebody. Thus, chalcopyrite was replaced by bornite and it, in utrn, by chalcocite and covellite.

Whilst, as noted earlier, galena framboids may have developed by the replacement of pyrite ones, there is no direct evidence to be found in support of this in the Lenggang material, indeed all the evidence points to the conclusion that none of the agents responsible for the deposition of the lead, zinc and copper bearing sulphides had the slightest effect on either the pyrite or the marcasite.

The overall view of the sulphides under review, that is contained in the foregoing paragraphs, seems a reasonable one if it is accepted that the generation of the lead, zinc and copper-bearing grains was on a very small scale and was a very localised phenomenon. That this was the case is suggested by the kilograms, rather than tonnes of such sulphide grains that had been accumulated during the beneficiation of the placers.

CONCLUSION

The Lenggang material is of interest in that it provides further proof that sulphides, of a variety of types, can be deposited by supergene processes in a reducing environment, and because its study has served to highlight certain important gaps in our knowledge concerning the mobilisation and transportation of metals in the near-surface environment.

It goes without saying that the results of studying this very small sulphide deposit, which owes its origin to a very restricted and special chemical/mineralogical environment, cannot be used to support a syngenetic origin of vastly larger stratabound sulphide deposits such as, say, those of, Rammelsberg or the Kupferschiefer.

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