

*The formation of supergene galena at Broken Hill,
Northern Rhodesia.*

(With Plate XXII.)

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Summary. Lead-zinc ore-bodies in dolomite at Broken Hill, Northern Rhodesia, consist of a sulphide core surrounded by an oxidized sheath. Oxidation has been proved to persist to a depth of at least 1150 ft. below surface. In the transitional zone between sulphide and oxidized ore galena forms a thin rim to relict masses of blende, and farther into the sulphide core it penetrates the blende along cracks and cleavages. Locally it comprises over 5 % of the ore. From its relations to smithsonite and willemite it is clearly supergene in origin and must have been deposited above the water table. This considerable migration of lead in the zone of weathering is believed to have occurred during a former period of aridity.

THE lead-zinc-vanadium deposits at Broken Hill, Northern Rhodesia, occur in dolomites of the Middle Bwana Mkubwa Series (Katanga System). The five ore-bodies at present being worked vary from vein-like to pipe-like in form (Taylor, 1954). They are more or less completely oxidized above the 180-ft. level: at greater depths an irregular oxidized sheath surrounds a core of primary sulphides, consisting mainly of blende and galena with some pyrite and very subordinate chalcopyrite, bornite, and tetrahedrite. The oxidized ore is composed predominantly of smithsonite, willemite, cerussite, limonite, and quartz with smaller amounts of hemimorphite, pyromorphite, malachite, vanadinite, descloizite, and rare zinc phosphates (for details of the mineralogy see Spencer, 1908, 1927, and Taylor, 1954). Drilling has shown the persistence of a substantial amount of oxidation down to a depth of more than 1150 ft. There is considerable post-mineralization cavernization in the dolomite extending at least to the 850-ft. level. As the ground-water at the time when mining was commenced stood less than 50 ft. below the surface it is evident that the bulk of the oxidation must have taken place during some past period of low water table. Most probably this corresponded with the general period of aridity during which the Kalahari Sands were deposited in late Tertiary times.

Mode of occurrence.

The earliest stage of oxidation of the sulphides takes the form of penetration of blende along cracks, cleavages, and grain boundaries by irregular replacement veinlets carrying smithsonite, willemite, and sometimes quartz. These veinlets are commonly margined by a narrow rim of galena between 0.005 and 0.02 mm. in width. Pl. XXII, fig. 1, shows such a stringer passing in the south of the field into a wider veinlet (0.08–0.15 mm.) in which galena predominates with subordinate smithsonite. The highly irregular margins of the galena and the presence within it of little islands of blende leave no doubt as to the replacement origin of the veinlet. In the north of the field another widely occurring relationship is visible, a smithsonite–galena veinlet terminating in almost pure galena. Commonly replacement can be seen to have followed the cleavage of the blende (pl. XXII, fig. 2). Elsewhere it is highly irregular, and, in addition to the narrow galena border, the oxidation products of zinc have much galena scattered through them (pl. XXII, fig. 3). Some of this can be seen to be the remains of partially replaced grains of hypogene galena, but much is probably supergene. Little veinlets of galena, free of oxidation products, are not uncommon (pl. XXII, fig. 3) and are difficult to distinguish from hypogene replacements save where they carry a few grains of covellite, a mineral widely associated with the smithsonite–willemite–galena veinlets though always in very small amounts.

With increasing oxidation the blende becomes more and more dissected by replacement veinlets. Commonly these carry central willemite bordered by smithsonite, margined in its turn by galena (Taylor, 1954, pl. II, fig. 3). In some cases smithsonite has pseudomorphed blende, preserving traces of its cleavage. The presence, between the smithsonite and the residual core of blende, of the usual thin zone of galena shows that galena is without question the latest mineral in the sequence.

Where oxidation has gone almost to completion, the only relics of blende are highly irregular islands set in a sea of oxidation products and bounded by a thin galena rim (pl. XXII, fig. 4). Occasionally the rim contains some very subordinate covellite. Throughout the highly oxidized ore the presence of irregular corroded remnants of primary galena surrounded by smithsonite, willemite, and quartz bears witness to the lead that has gone into solution.

Thin rims of galena separating blende from oxidation products have been observed from every level in the mine where sulphide ore is worked

and are the rule rather than the exception. In the highly oxidized ore above the 180-ft. level they are less widespread and residual blende is commonly in direct contact with the replacing smithsonite and willemite. There can be no doubt of the supergene origin of the galena and it appears that the downward-percolating solutions universally carried some lead which, wherever conditions ceased to be strongly oxidizing, was precipitated by blende, displacing the more active zinc.

Locally the transition from primary sulphide ore to completely oxidized ore is effected in a matter of inches. More generally it forms a zone several feet in width. Micrometric analyses show that, within this zone, 5% of galena of undoubted supergene origin is common and 8% or more not unusual. Among a number of specimens chosen for analysis one 7 ft. from the margin of the completely oxidized zone (No. 3/4 ore-body, 350-ft. level) yielded 5.3% of supergene galena, while another 9 ft. from wholly oxidized ore (No. 5/6 ore-body, 650-ft. level) carried 1.2%. On the conservative assumption of a zone 3 ft. wide and containing 2% of supergene galena, margining the sulphide cores of all the ore-bodies between the 180-ft. and 750-ft. levels in the mine, a rough approximation shows that something over 5 000 tons of lead has been transported in solution and reprecipitated as the secondary sulphide. This lead, however, is distributed over a big vertical interval and it does not necessarily follow that any of it has been transported a great distance. From the relations of the secondary galena to the oxidation products of zinc it is clear that it was formed above the water table at the advancing front of oxidation into the ore-bodies, in a manner which is familiar in the case of supergene copper sulphides and has been notably described by Lindgren (1915) at Tintic in Utah.

Other records of secondary galena.

As Lovering (1934) has pointed out, 'galena is tacitly assumed to be primary unless there is strong evidence to the contrary'. There are relatively few records of galena of undoubted supergene origin supported by petrographical details. It has been clearly described from Broken Hill, New South Wales, where Stillwell (1927) refers to blende being intersected by veins of zinc carbonate margined by galena. It occurs in the lead-zinc-vanadium deposits of Abenab West in South-West Africa (Verwoerd, 1957). Here the whole mineralogy, which includes willemite, vanadinite, and descloizite, as well as the mode of occurrence of the secondary galena, closely parallels Rhodesian Broken Hill. At Balmat in northern New York State, Brown (1936) has described secondary galena

which is accompanied by willemite, replacing blende and pyrite along cracks and cleavages. Each of these three cases is associated with a deep oxidation zone.

At Lake City, Colorado, Irving and Bancroft (1911) recorded the presence of a 'thin grey film, believed to be galena', deposited in cracks in shattered blende in the oxidation zone. At Breckenridge, Colorado, Ransome (1911) claimed that there had been substantial supergene precipitation of galena. He did not, however, produce any supporting mineralogical evidence and Lovering (1934) regarded most of the galena as primary. Wang (1916), in the course of a study of the oxidation products of zinc, described and illustrated galena rims to residual grains of blende surrounded by smithsonite, from an unspecified locality in north-western Arkansas.

Conditions of formation.

The limited mobility of lead in the zone of weathering is generally attributed to the formation of a sparingly soluble coating of sulphate or carbonate on galena preventing further oxygen from reaching it. In pure water the carbonate is the least soluble compound but in water saturated with carbon dioxide, as might be anticipated in the presence of a limestone or dolomite country rock, its solubility is considerably increased. Garrels (1954) has calculated the activity (at 25° C.) of lead ion in equilibrium with carbonate, sulphate, and sulphide on the assumption that the ground waters are saturated with carbon dioxide and the concentration of soluble sulphur is 10^{-1} mols per litre. The activity of lead ion in equilibrium with sulphate is much less than that with the other anions, so, for these conditions, lead sulphate is presumably the most stable (least soluble) mineral.

Garretty and Blanchard (1942) studied the effects of post-mine leaching on the ore at Australian Broken Hill and came to the conclusion that, contrary to expectation, the galena was being leached more rapidly than the blende. They attributed this to the fact that little or no anglesite was being formed and suggested that this might be in consequence of a general weakness of ferric sulphate solutions, resulting from the low pyrite content of the primary ore. Some confirmatory evidence of this comes from Mount Isa in Queensland where Grondijs and Schouten (1937) found that galena had been most completely leached from those parts of the ore-body poor in pyrite and pyrrhotine. Where these minerals were plentiful, on the other hand, galena remained behind partially altered to anglesite. Pyrite is a relatively minor constituent

at both Rhodesian Broken Hill and Abenab West and anglesite is rare or absent. It may be that the solution of lead is best accomplished in the absence of the concentrated ferric sulphate solutions so destructive to other sulphides. Where oxidation is the work of weaker and possibly less acid solutions, time and temperature must inevitably be factors of importance. At Rhodesian Broken Hill the ores crop out on the great central African plateau, an erosion surface of Tertiary date, or earlier, and in a position less than 15° S. of the equator.

The present-day mine waters at Rhodesian Broken Hill are carbonate-sulphate waters with the relatively low salinity of 98 parts per 100 000 and a pH of 6.6-7.2. They carry only 0.02 parts per 100 000 of lead. However, the region has recently emerged from a period of aridity when the water table was at least 1000 ft. lower than it is today. The effect of aridity on ground waters is normally to increase greatly the concentration of dissolved salts, especially that of chlorides (Robaux, 1953). The presence of chlorides substantially increases the mobility of lead. The widespread presence of pyromorphite and vanadinite at Rhodesian Broken Hill provides evidence that the chloride ion must have been present, as, from the mineralogy, it must have been also at Abenab West and Australian Broken Hill.

It has already been suggested (Taylor, 1954) that the development of vanadates and of willemite (in place of the more normal hydrated silicate hemimorphite) in the oxidation zone at Rhodesian Broken Hill are consequences of prolonged weathering under hot arid conditions. It appears that the widespread deposition of supergene galena was due to similar factors, aided perhaps by the relative scarcity of pyrite in the primary ore. These conditions would also explain its occurrence at Abenab West and Australian Broken Hill. At Balmat pyrite is plentiful and despite the great depth of the supergene zone there is no direct evidence of arid conditions or of chlorides in the ground-water. There is, however, no reason to believe that the formation of secondary galena is always related to one set of conditions. In humid climates it may well be some factor such as the concentration of organic acids that controls the stability of lead in the zone of weathering.

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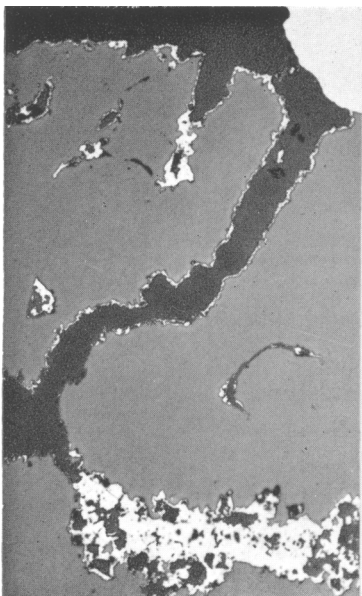
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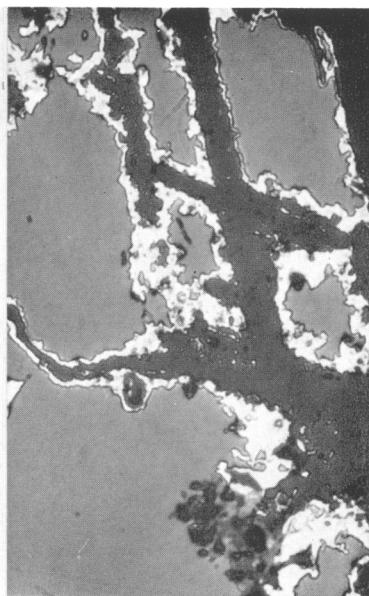
EXPLANATION OF PLATE XXII.

Photomicrographs of polished sections of ore from Broken Hill mine, Northern Rhodesia, showing development of supergene galena.

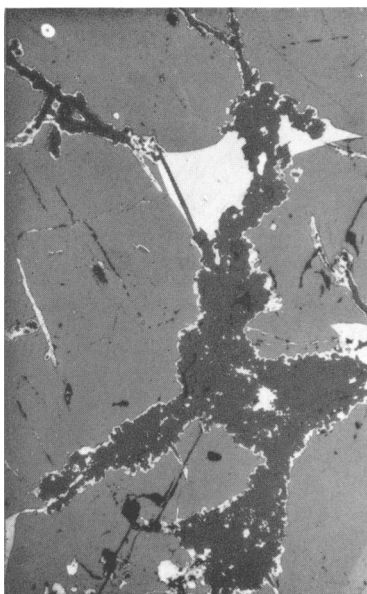
- FIG. 1. Blende (grey) is cut by 0.07 mm. wide replacement veinlet of smithsonite (darker grey) with narrow margins of galena (white). In the south of the field this passes into an irregular veinlet consisting largely of galena with subordinate smithsonite and a few residuals of blende. In the north a short smithsonite-galena veinlet can be seen to terminate in pure galena. Hypogene galena occupies the extreme north-east corner. No. 3/4 ore-body, 350-ft. level, Gut Drive east. $\times 75$.
- FIG. 2. Blende (grey) is replaced along cleavages by smithsonite and willemite (dark grey) with marginal galena (white). In the south of the field a little covellite (light and dark grey with a rather hazy appearance) is associated with the galena. No. 3/4 ore-body, 350-ft. level, Gut Drive east. $\times 180$.
- FIG. 3. Blende (grey) and primary galena (white) are replaced by smithsonite (dark grey) with narrow zone of supergene galena separating smithsonite from blende. Thin veinlets of pure galena are presumably also supergene. A considerable amount of galena is scattered through the smithsonite but it is difficult to say how much is supergene and how much merely relics of largely replaced hypogene galena. No. 3/4 ore-body, 550-ft. level, 11 west cross-cut. $\times 55$.
- FIG. 4. Highly irregular residual island of blende (light grey) surrounded by narrow border of (white) galena in a sea of replacing smithsonite (darker shades of grey). Where blende is replaced centrally by smithsonite the two are separated by the usual galena rim. In the south of the field replacement has followed cleavages of the blende. No. 1 ore-body, 550-ft. level, 8 west cross-cut. $\times 40$.



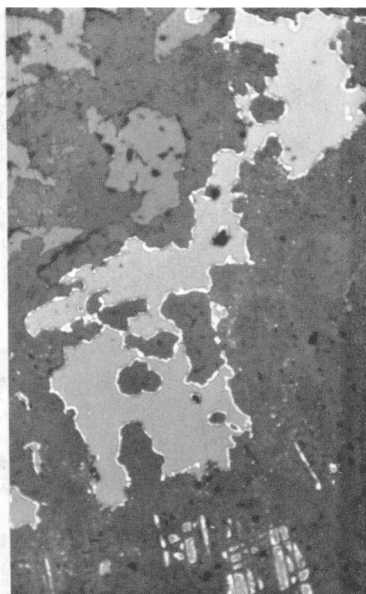
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