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STUDIES ON LEAD-ZINC MINERALIZATION IN KAREMPUDI AREA, GUNTUR DISTRICT, ANDHRA PRADESH

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Abstract

The geological formations near Karempudi area in Guntur District of Andhra Pradesh (Lat. 16° 20′ and 16° 26′; Long. 79° 38′ 40″ and 79° 45′) consist of slaty shales of Cumbum, Irlakonda quartzites, Kolumnala slates and shales with intercalations of siliceous dolomitic limestones and Sreesailam quartzites of Krishna Series, forming a perfect conformable sequence, all the formations striking N.E.-S.W. and dipping on average 25° S.E. The Srisailam quartzites are overlaid unconformably by Palnad limestones (Narjis) of Jammalamadugu stage of Kurnool Series with a constant dip of 8–12° in the same direction.

The Krishna Series were subjected to local but intense structural disturbances resulting in an overfold. Subsequent to the overfolding, lead mineralization has taken place in dolomitic limestones. The lead-zinc minerals of Karempudi consist of Galena, Sphalerite, Jamesonite, Tetrahedrite as primary minerals, and Anglesite as secondary mineral; there is association of chalcopyrite with Sphalerite. The textures are due to replacement and unmixing (?). The paragenetic sequence of the minerals is established to be sphalerite, chalcopyrite, galena, jamesonite, tetrahedrite and anglesite.

Correlation of field to laboratory studies revealed that the minerals are of hydrothermal (hypogene) origin. The structural and lithological favourability and controlling of the mineralisation are also explained. Anglesite owes its origin to the oxidation of galena due to air-water processes. The mineralization is surmised to have taken place in Pre-Palnads and Post-Krishna times.

Introduction

In recent years in the study of geology of the Puranas of South India, the stratigraphic position of Palnad formations received great attention from the officers of Geological Survey of Hyderabad and Geology Department of Andhra University.

The area around Karempudi under present investigation drew great interest because of the lead mineralization in the dolomitic limestone band. The old workings for lead in the area were first reported by King (1872). In the year 1955 teachers and scholars of Geology and Geophysics Departments of Andhra University carried out detailed prospecting in the mineralized zone with the financial aid provided by the Andhra Government.

Karempudi (Lat. 16° 20′ 30″ and Long. 79° 43′ 30″) is on the bus route of Gurazala-Vinukonda and is situated 12 miles south-east of Gurazala. The old workings for lead under investigation are located in the adjoining Waumykonda hill range 5 miles south-west of the village Karempudi.

METHODS OF STUDY

A compass survey was carried out on a scale of 1″ = 40 ft. (Fig. 1) in which boundaries of the various rock types have been demarkated. Geological traverses across the band were undertaken at suitable places to bring out the structural features.

Systematic sampling was carried out from all the pits for laboratory work. The polished sections were studied under the ore-microscope to determine the mineralogy, textural relations and paragenesis of the ore minerals.

Geology.—The various geological formations met with in the area are as follows (Fig. 2):

Recent			Kankar
Kurnools	Jammala-madagu	Palnad (Narji) limestone	Limestones
	Krishnas	Sreesailam	Quartzites
		Kolumnala	Ocherous shales and slates with intercalated dolomitic limestones
		Irlakonda	Quartzites
	Nallamalai	Cumbum	Slaty shales

Slaty shales of Cumbum.—The plains south of Waumykonda range are covered by the slaty shales. These are of various colours such as grey, purple, silvery and blue.

Krishna series.—The Krishna series is divisible into Irlakonda quartzites, Kolumnala shales and Sreesailam quartzites, forming a perfect

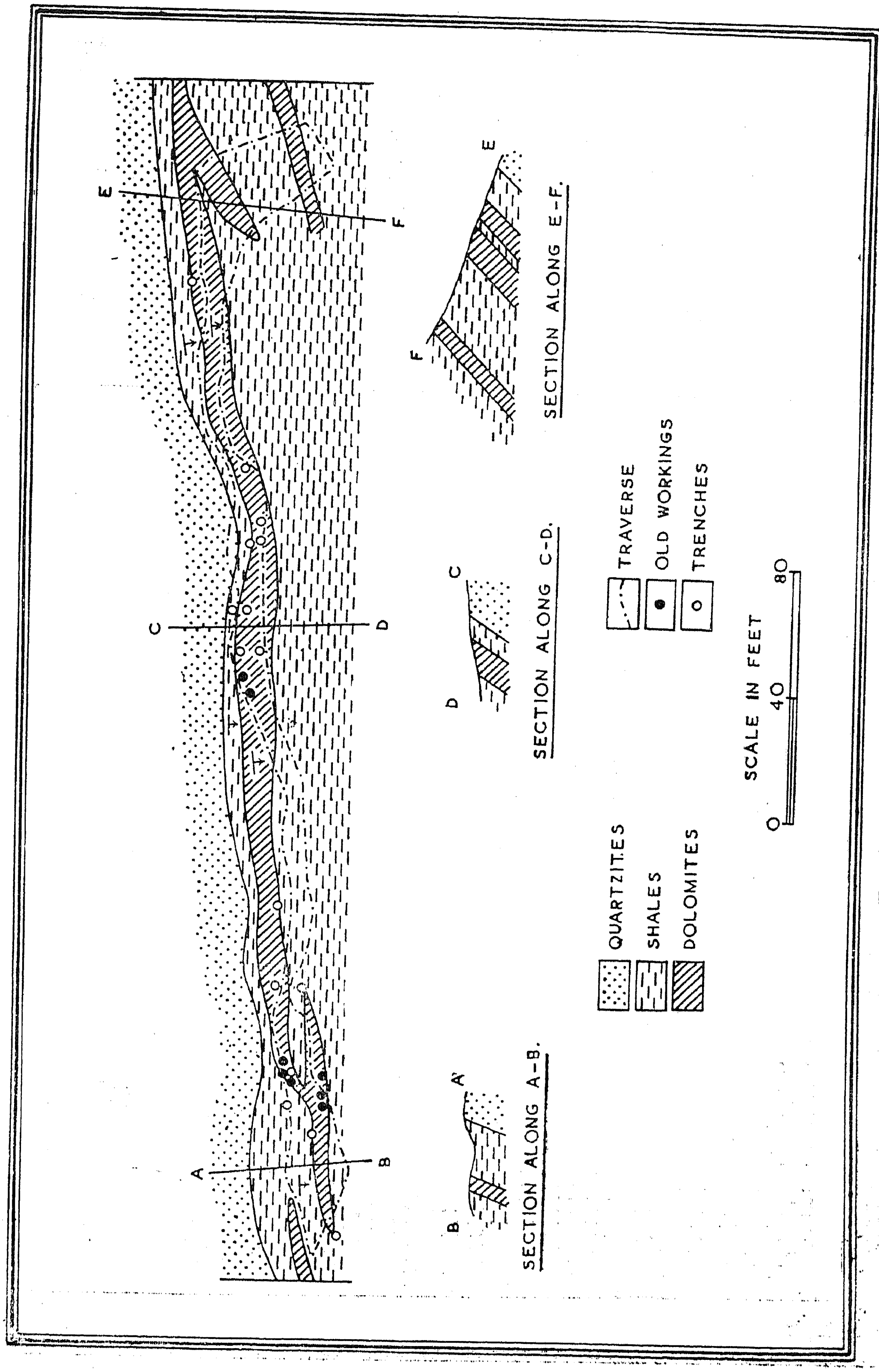

FIG. 1. The Lead Ore bearing Dolomite Band

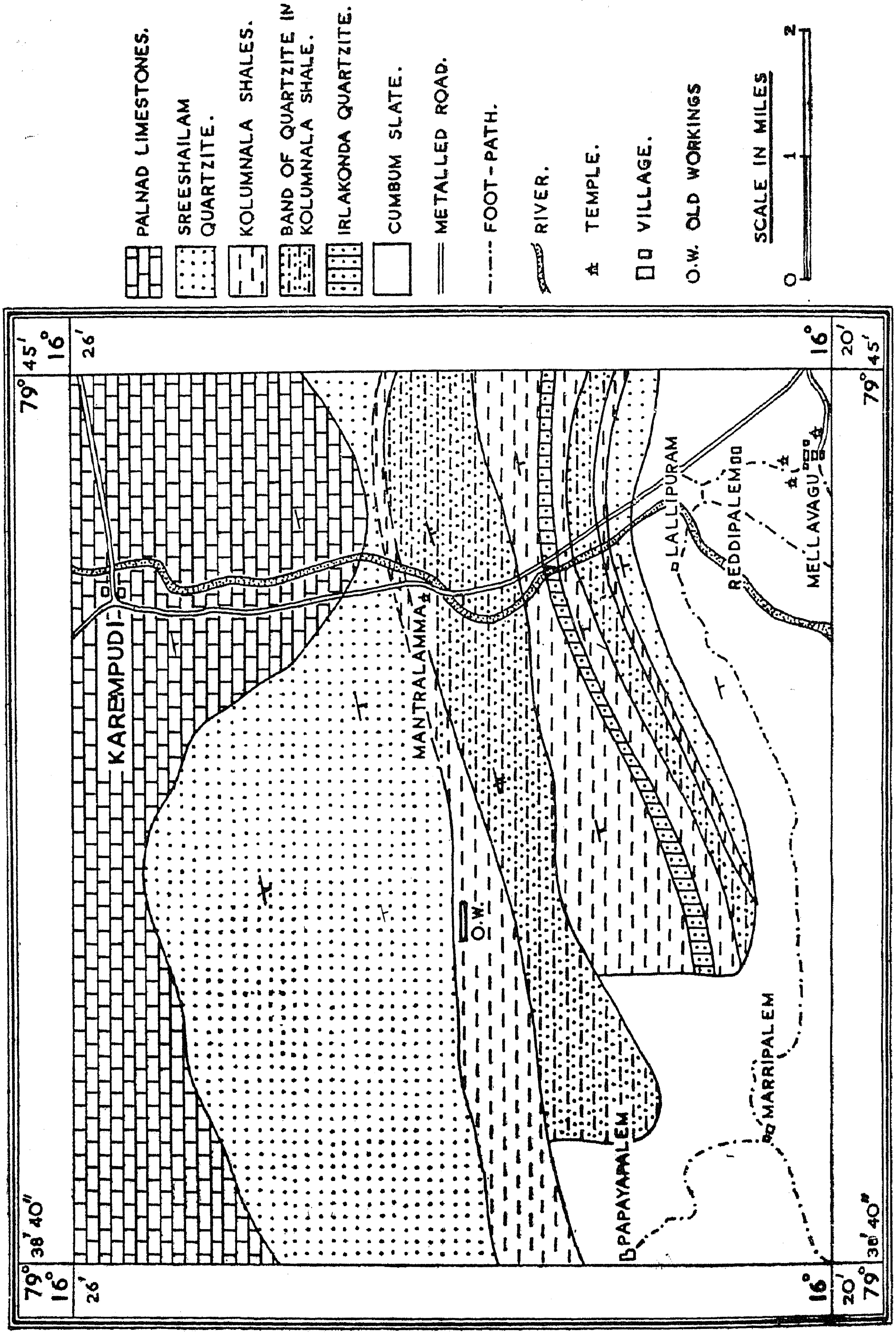

FIG. 2. Geological Map around Karempudi Area.

conformable sequence. The Sreesailam quartzites and Irlakonda quartzites are separated by a series of slates called Kolumnalas.

The Cumbums are not separated from the overlying Krishnas by any definite unconformity. Existence of such a break in sedimentation can be proved in the Palnad area where the Cumbum slates dip at 27–28° due south-east, while the overlying Krishnas show a dip of 46° due south-east. This angular unconformity is a result of the structural disturbance to which the Krishnas were subjected. The evidence for the structural disturbances is provided by an overfold which is clearly seen near Nayakuralu Alugu (Mahadevan and Umamaheswara Rao, 1950). This structure is seen extending all along the hill range of Waumykonda (Kondayya, 1949).

Intercalated galena-bearing dolomitic limestone bands.—In the western continuation of shales and just 5 miles S.S.W. of Karempudi is found a band of dolomitic limestone. In the dolomitic marbles disseminations of galena are seen. Long lines of old workings and a good number of old pits are found and these indicate that large-scale mining was in full swing in ancient times.

Palnad limestones.—To the north of Waumykonda hill range, limestones of various colours—bluish-grey, brown, etc.—can be seen. Yellowish-white crystalline limestones are found on the Karempudi-Mellavagu Road at 28/1 mile-stone. They have a dip of 8–12° to the south-east.

Nowhere in the area are found limestones overlying quartzites. They appear to tail up against the Cuddapah quartzites in the southern boundary. At Nayakuralu Alugu in the Waumykonda range quartzites are folded back over the Palnad limestones.

Kankar.—Pisolitic concretionary matter called kankar is seen above these limestones. This formation owes its origin to alternate rainy season and summer.

Extent of ore-mineralization.—Cross-trenching usually $10 \times 4'$ to the required depth were sunk near the old workings to reach the bottom and lay bare the mineralized band and trenches along the strike to trace the continuity of mineralization, were also put down.

The above investigation has yielded very valuable data regarding many aspects of mineralization. It has been found that the occurrence of lead ore is confined to the dolomite band. Detailed mapping has indicated that the mineralised band which forms a limb of a fold is in the northern extension of the anticlinal overfold (Mahadevan, 1951). The present work indicates hope in the proved extent of the dolomite band and the continuity of the mineralization all along its length for well over 2,000 ft., the width of the well-marked zone of mineralization being variable from 8–20′ (Fig. 1). Further it revealed the structural and lithological favourability of the area for a probable continuation of the ore in depth.

Nature of the ores.—In almost all the pits sunk, either in old fillings or just away from them, it has been observed that there is a well-marked zone of mineralization, the type of occurrence of the lead ore being in pockets, nests, impregnations and disseminations of galena. The mineral galena is often associated with quartz stringers which ramify the dolomite band in all directions. The chief ore mineral is galena.

Ore localization.—It must, however, be pointed out that nowhere is the occurrence of galena found to correspond to the typical lode type, in that the characteristic assemblage of the ore and the gangue mineral has not been found anywhere in the area. As such, it is doubtful whether the mineralization in the dolomite band corresponds to any lode type or vein type. The selective mineralization of the dolomite band in preference to the slates and quartzites can be explained by the lithological favourability of the former. The higher chemical susceptibility of crystalline limestones and dolomites to replacement is well known. The peculiar association of limestones with lead-zinc deposits has been noted all over the world, and this area affords another example.

Optical studies of the rock types.—Cumbum slates, slaty shales and phyllites: In thin section, various shades of colours are observed due to different amounts of iron oxides present. The minerals that can be discerned are scales of mica, quartz and felspar. The shales differ from slates in the cleavages which are not so perfect. The strain effects due to pressure are clearly seen in the wavy cleavage found in the phyllites. The mineral assemblage is same as in slates.

Krishna formations.—The Irlakonda quartzites are fine-grained, irregular in outline and very much crushed. Accessories of magnetite and biotite are present. Brushed extinction is exhibited by most of the quartz grains. The grain size of Sreesailam quartzite is much larger. The slates show perfect development of cleavage and are just like the Kolumnala slates of the type area.

Galena-bearing dolomite limestone.—This rock consists essentially of dolomite, calcite and quartz. Dolomite shows good rhombohedral cleavage and twinkling. Some quartz grains show undulose extinction indicative of the prevalence of pressure during or after its formation. The quratz ribbons ramifying in all directions are noteworthy. Dolomite grains near the quartz ribbons are much larger in size. Galena and other sulphide minerals are always seen associated with quartz ribbons.

Palnad limestones.—The typical Palnad limestones are cryptocrystalline, equigranular and show twinkling in polarised light. Generally a few quartz grains are present which are elongated and lie in a definite linear arrangement.

Ore mineral study.—A chip was taken from the sample and wet method of polishing was adopted as advocated by Short (1940). The optical properties, etch tests and microchemical tests are given in Table I.

MINERALOGY

Chalcopyrite.—This mineral is seen sparingly in light grey sphalerite as minute inclusions with smooth and sharp grain boundaries.

Galena.—Galena is the most abundant ore mineral which appears commonly as coarse-grained aggregates and occasionally toothed (Microphoto 1). It does not show any deformation in the cleavage planes or triangular pits. The contact between galena and sphalerite is (occasionally) seen as smooth and curving boundaries, sometimes with decided projections of galena into sphalerite. Jamesonite and tetrahedrite are the rare associates of galena. Small grains of tetrahedrite occur at the grain boundaries of galena.

Sphalerite.—It occurs as disseminations with galena. It is light resin yellow variety, and rarely shows inclusions of chalcopyrite. Galena and sphalerite are generally contiguous with smooth and curving boundaries. Some grains of sphalerite are seen replaced by galena.

Jamesonite and tetrahedrite.—Tetrahedrite occurs as small grains in cubic planes of galena when observed in oil and under high magnifications. Jamesonite occurs as thin and long needles in galena.

Silver.—No silver or silver minerals are observed, but the mineral galena responses to the test for silver.

Anglesite.—Anglesite is the secondary mineral observed as thin lining along the boundaries and cleavages of galena. In advance stages of replacement, residual grains of galena are seen in anglesite.

Textures and textural relations.—The textural types found in the ores under study can be genetically classified as:

(*a*) textures due to simultaneous deposition,

(*b*) replacement textures,

(*c*) textures due to unmixing, and

(*d*) oxidation textures.

TABLE I

Sl. No.	Mineral	Optical properties	Etch reactions	Microchemical test	Characteristic features
1	Chalcopyrite	Shows brass yellow colour with high reflectivity and weak anisotropism	HNO_3 tarnished slowly	..	Brass yellow colour with weak anisotropism
2	Sphalerite	Shows grey colour with low reflectivity and internal reflection of yellowish white colour	No importance	The mineral in solution gave white feathery crosses with 3% potassium mercuric thiocyanite solution	Grey colour and internal reflection
3	Galena	Shows bright white colour with high reflectivity and isotropism. Triangular pits along the cleavage planes are very typical	HNO_3—stains black FeI_3—tarnished irid Neg.—KOH, $HgCl_2$	The mineral in solution gave hexagonal lemon yellow pleochroic plates with solid potassium iodide	Bright white and high reflectivity with triangular pits
4	Tetrahedrite	Shows olive grey with moderate reflection and complete extinction	HCl (con.) 3 minutes tarnishes differentially blue irid	..	Observed with distinct olive grey colour
5	Jamesonite	Shows white colour with high reflectivity as galena and strong reflection pleochroism and anisotropism is strong grey	..	..	Galena white colour with reflection pleochroism and anisotropism
6	Anglesite	..	..	Test for lead	..

Textures due to simultaneous deposition.—Galena and sphalerite grain boundaries show smooth regularly curving contacts, generally without decided projections of one into the other. This is otherwise called mutual boundary texture (Bastin).

Replacement textures.—The replacement of sphalerite by galena is not generally regulated by any cleavage of weak plane. Some decided projections of galena into sphalerite reveals that some of the galena is later or of second generation.

Rim replacement.—Anglesite replacing galena along cleavage planes resembles comb texture.

Replacement relics.—In advanced stages of replacement of galena by anglesite this texture is commonly seen.

Textures due to unmixing (?).—Chalcopyrite grains occur as fine disseminations (emulsion) in sphalerite and have smooth and sharp boundaries but not arranged in any definite direction.

Textures due to oxidation.—This texture is seen in oxidised sphalerite grains due to the high solubility of the oxidised product (sulphate) of sphalerite. Triangular and irregular-shaped nests are the results.

TABLE II

Chemical data

Sl. No.	Sample in trench No.	Weight percentage of galena
1	Rich pocket ore	7·50
2	1	4·50
3	5	4·80
4	8	1·65
5	14	3·87
6	15	0·48
7	20	2·87

Test for silver.—Catalytic reduction of Mn^{iii} and Ce^{iv} salts. Limit of identification $0·4\gamma$ silver. Dilution limit 1 : 120,000.

The wide range of variation of percentage of galena is due to the fact that the ores occur as pockets, nests and disseminations.

DISCUSSION

Textures due to unmixing (?).—The question of inclusions of chalcopyrite in sphalerite has been discussed according to the criteria stated by Schwartz (1931, 1937). When a number of sections were examined with oil immersion objective, only one specimen has shown the presence of chalcopyrite whose characteristics are:

(1) The inclusions of chalcopyrite appear mostly plate-like forms characterised by curved boundaries.

(2) The occurrence of inclusions is not related to the grain boundaries, contact, cleavage planes or other localities where replacement characteristically takes place.

(3) Chalcopyrite forms quite irregular inclusions of disseminated and emulsion nature.

The above observations (of the criterion of Schwartz, 1931) suggest the interpretation of chalcopyrite as unmixing. Confining with other observations such as the limitation of chalcopyrite to only sphalerite and the absence of any enrichment of chalcopyrite suggest, or at least not opposed to the interpretation of inclusions due to unmixing.

According to Bragg (1937), the close similarity of sphalerite and chalcopyrite in crystal structure, in atomic diameters of zinc, copper and iron and in the valencies of the three elements is in support of exsolution texture. Even though the data explain the favourable conditions for the formation of exsolution textures, the orientation of chalcopyrite grains (Microphoto 2), is less uniform and they show wide range in size. Even though it shows a seriate arrangement to some extent, the texture suggests that it might be the result of progressive unmixing, and it might have taken place from the original melt itself. As this combination of chalcopyrite and sphalerite is not seen in any other samples, it is very difficult to conclude whether this texture is the result of progressive unmixing or due to successive crystallisation with or without replacement.

The distribution of jamesonite and tetrahedrite in galena showed deposition migrating towards the grain boundaries. This may probably suggests that the unmixing is of eutectic nature.

Oxidation textures.—Gottscholk and Buehler (1912) observed that the two minerals galena and sphalerite when in contact and moistened, act as batteries and that in a mixture of the two sulphides there is a large increase in solution of one of the lower potential ($ZnSO_4$), while there is also protective action exerted on the other (PbS). Further they have observed that there is no need for any sulphate solutions to oxidise galena and the moisture and oxygen in air are sufficient for this process.

The oxidation of sphalerite and galena in Karempudi ores also is brought about by air-water process rather than by ferric sulphate solutions because pyrite which would yield sulphate solutions has not been traced out.

Silver as solid solution with galena.—Galena is an important host mineral for silver and it can be explained from the point of view of crystal chemistry (Goldschmidt).

Paragenesis.—The paragenetic sequence of the minerals is determined by microscopic study and is shown below:—

Mineral	General decrease of the temperature		
Quartz ..	———	———	
Sphalerite ..		———	
Chalcopyrite ..		———	
Galena ..		———	———
Tetrahedrite ..			———
Jamesonite ..			———
Anglesite ..			——

The mutual relationships of the minerals and the evidence in support of this succession are discussed below:—

Quartz.—The main mass of quartz has crystallised first and the remaining mass has crystallised along with the sulphides. In some places galena shows idiomorphism in quartz. Recrystallization of dolomite into bigger crystals is seen near the quartz ribbons.

Sphalerite and chalcopyrite.—Bastin (1950) is of the opinion that small inclusions of chalcopyrites in sphalerite are probably in most cases due to unmixing of a solid solution of the two sulphides and the two minerals must be interpreted as being due to contemporaneous crystallization.

Galena and sphalerite.—The association of galena with sphalerite with smooth and curving boundaries (Microphoto 3) suggests that they are of simultaneous crystallization. In some cases, islands of sphalerite in galena suggest that some of the galena is crystallized later to sphalerite. From the above observations one can conclude that during the fall of temperature, chalcopyrite has come out due to unmixing of solid solutions of chalcopyrite and sphalerite when the crystallization of sphalerite has continued for sometime, to be followed later by simultaneous crystallization of galena. After completion of the crystallization of sphalerite, galena has continued further, replacing sphalerite to some extent as evidenced in some of the specimens.

Jamesonite and tetrahedrite.—These minerals are seen in galena which replaces sphalerite. The minerals might have crystallized along with galena during the last phases of crystallization of the ore minerals.

Anglesite and galena.—Anglesite is decidedly of later origin because it is seen replacing galena (Microphotos 4, 5 and 6) and this is the oxidised product of galena.

Origin of the primary sulphide minerals.—Lead in nature occurs as veins and lodes and as metasomatic replacement mainly in limestones and most of it is formed by low temperature hydrothermal solutions.

There are three views on the formation of lead minerals:—

(1) By descending surface waters.

(2) Ascending artesian meteoric waters.

(3) Hydrothermal solutions of igneous origin (Hypogene).

The first view was supported by Bain, Van Hise and Adams (1935), Buckly (1936), in explaining the origin of lead minerals of S.E. Missourie lead deposits, where the presence of organic matter has facilitated the re-deposition from the solutions. But in Karempudi, the galena-bearing dolomitic limestones do not bear any organic matter to facilitate such precipitation.

The second view of deposition of galena by ascending meteoric waters cannot be applied to this area for there are no indications of artesian water conditions. The persistence of the ore in depth is also doubtful.

The disseminated type of the sulphide minerals is, according to Tuck (1931), characteristic of the extreme mobility of the ore solutions. Niggli (1924) is of the opinion that this extreme mobility can be expected in hydrothermal juices alone. Ridge (1936) feels that the occurrence of chalcopyrite indicates a hydrothermal (Hypogene) origin of the ore deposits associated with it and this view was also supported by Wells (1914). Besides, the following mineral assemblages and textural features of the ore minerals when critically viewed in the light of the treatise of Schwartz (1931 and 1951) will point out to their hypogene origin:

(1) Large grains or crystals of galena.

(2) Irregular intricate replacement of sphalerite by galena.

(3) Presence of known hypogene minerals (as suggested by Bateman, 1952), like chalcopyrite, tetrahedride and Jamesonite.

(4) Mutual boundary relationships of galena and sphalerite and textures exhibited by chalcopyrite and sphalerite.

The association of galena with quartz ribbons may be thought as having been brought about during dedolomitisation that might have taken place under temperature-pressure conditions during the structural disturbance in Pre-Palnad times, when some silica has been released along with previously existing galena from the dolomites. But no such evidence is seen under the microscope or in the field. The grain size of the dolomites is uniform except near the quartz ribbons which show perfect crystallinity and larger grain size.

Secondary minerals.—Anglesite is the only secondary mineral and is characterised by the following criteria (Schwartz, 1951):

(1) Replacement of galena by anglesite is related to cleavages and grain boundaries only.

(2) Narrow rim of anglesite around galena.

(3) The replacement is of selective nature. Anglesite is not seen associated with any mineral other than galena.

The age of the mineralization.—The mineralization has taken place in Pre-Palnads and Post-Krishna times.

Summary and Conclusions

Lead mineralisation has taken place in dolomitic limestone band which is sandwiched in slates which forms a limb of an anticlinal overfold (in the northern extension).

The sequence of mineral of the Karempudi ores is sphalerite, chalcopyrite, galena, jamesonite, tetrahedrite, and anglesite.

The textures are due to unmixing (?), simultaneous crystallization, replacement and oxidation of the minerals.

From the field and the microscopic evidence, the ore minerals are believed to have been formed from hydrothermal solutions.

The mineralization has taken place in Pre-Palnads and Post-Krishna times (after folding).

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REFERENCES

Anderson, A. L. .. "Notes on oxidation of jamesonite, sphalerite and tetrahedrite," *Econ. Geol.*, 1932, **28**, 687–703.

——— .. "The incepient oxidation of Galena," *Ibid.*, 1930, **25**, 528–42.

Bastin, E. S. .. "Interpretation of ore textures," *U.S.G.S. Memoir* 45, 1950.

——, and Graton, L. C. *et. al.* "Criteria of age relations of minerals with special reference to polished section," *Econ. Geol.*, 1931, **26**, 561–610.

Bateman Alan, M. .. *Economic Mineral Deposits*, 1950, Chapter 5:1, pp. 24, John Wiley and Sons, Inc., New York.

Buerger, N. W. .. "The unmixing of chalcopyrite from sphalerite," *Amer. Min.*, 1934, **19**, 528.

Edwards, A. B. .. "Textures of ore minerals and their significance," *Australian Inst. of Min. and Met.*, 1947, 79–80.

Goldschmidt .. *Geochemistry*, Oxford at the Clarendon Press, 1954, pp. 406.

King William .. *Mem. G.S.I.*, 1872, **8**,

Kondayya, K. .. "Geology of Durgi area, Guntur District with special reference to the stratigraphy of Palnads," *M.Sc. Thesis* submitted to the Andhra University, 1949.

Mahadevan, C. and Umamaheswara Rao, G. V. "Overfolding of the uppermost Cuddapahs, south of Karempudi," *Curr. Sci.*, 1950, 179.

Mahadevan, C. .. "Structural controls in ore deposition," *Proc. 38th Ind. Sci. Cong.*, Part III, Abstracts, p. 130.

Niggli Pawl .. *Ore Deposits of Magmatic Origin*, 1924.

Schwartz, G. M. .. "Microscopic criteria of hypogene and superegne origin of ore minerals," *Econ. Geol.*, 1932, **27**, 533–53.

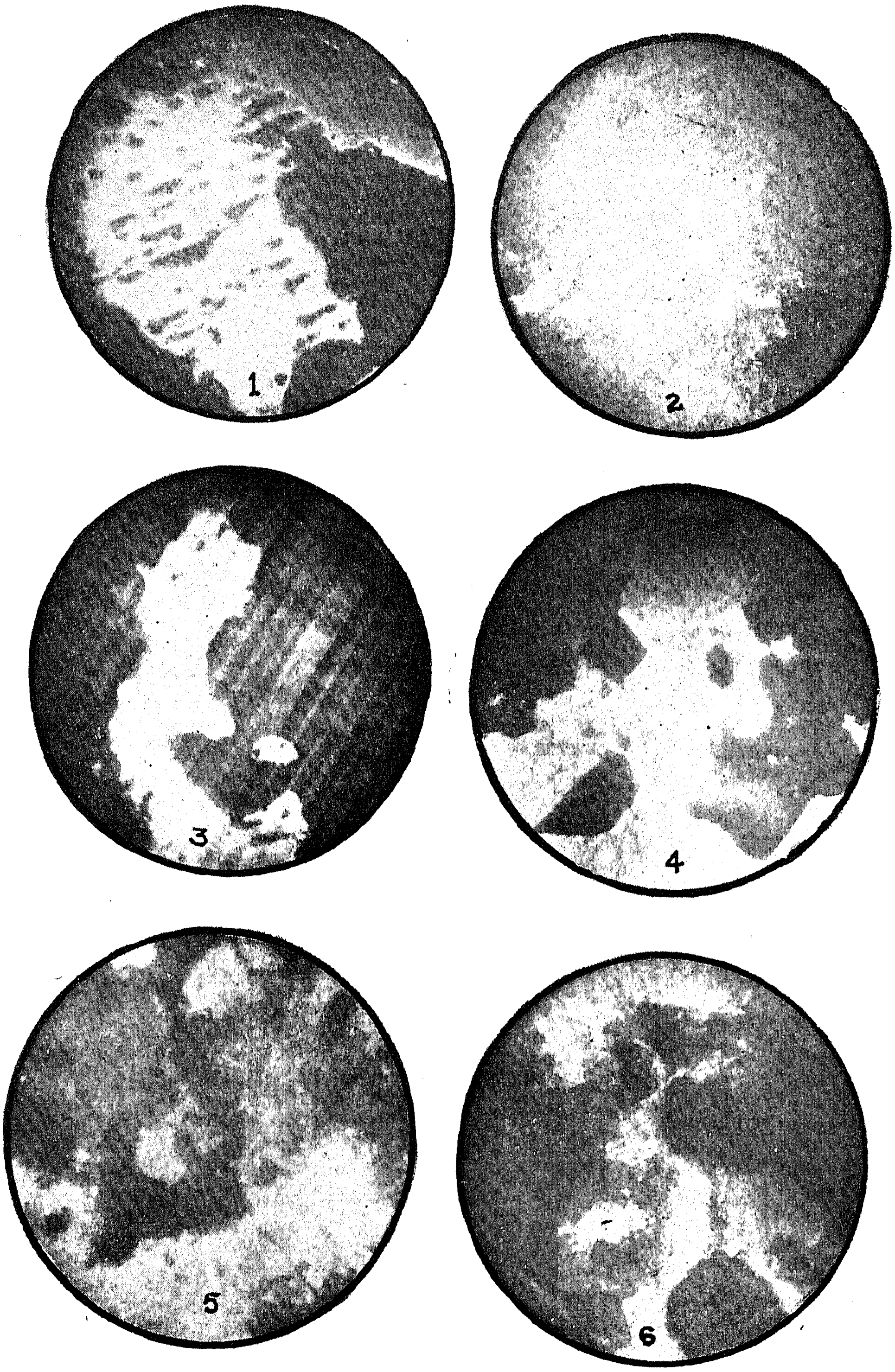
——— .. "Textures due to unmixing of solid solutions," *Ibid.*, 1931, **26**, 739–63.

——— .. "Progress in study of exsolution in ore minerals," *Ibid.*, 1942, **37**, 345–64.

Short, M. N. .. "Microscopic determination of ore minerals," *U.S.G.S. Bull.*, p. 914.

Utenbogaardt .. *Tables for Microscopic Identification of Ore Minerals*, 1951, Princeton University Press, Princeton, New Jersey.

Wells .. "Electrical activity in ore deposits," *U.S.G.S. Bull.*, 1914, p. 548.



FIGS. 1–6

Fig. 1. Galena (White) with triangular pits and saw-toothed borders in carbonate, ×125. Fig. 2. Chalcopyrite (White) and Sphalerite (Grey), ×540. Fig. 3. Mutual boundary relationship between galena (White) and Sphalerite (Dark grey), ×125. Fig. 4. Galena (White) goes metasomatically along carbonate (Black), ×125. Fig. 5. Replacement residuals of galena (White) in anglesite (Dark grey), ×125. Fig. 6. Anglesite (Dark grey) replacing galena (Grey) along contacts and cleavage planes, ×125.