suggest an environment of frequent flooding of sea water during deposition in inland lakes (Logan et al, 1964). It is seen from algal structures occurring in the Bijawars of the area that they might have been formed in an inland lake of small magnitude. The low amplitude ripples and the cross-bedding exhibited by the quartz-arenite suggest that they are formed in small bodies of water having small waves and low velocity. The observed undulations in the algal surface could have been caused by the lateral growth in the algal mat over the pre-existing irregularity of relief in the inland lakes.

(2) The formation of vertically stacked himispherials (SH-C type Collenia frequens Walcott) indicate littoral environment with periodic wetting and frequent flooding caused by storms.

(3) Conophyton type of structures might have been formed in quiet waters of intertidal headland, where wave action was not stormy (SS-C type – Conophyton cylindricus and Conophyton inclinatum). Sinian limestones of China, Lower Vindhyan Fawn limestones of Salkhan hill, India, and Shidogu limestones of North Korea contain Conophytums, which are considered in age to be between Sinian to Upper Algonkian. It is, therefore, suggested that attempts may be made to utilise Conophytums in stratigraphic correlation. Accordingly, the dolomites of the Joga area are correlated with the Lower Vindhys.

(4) Concentric spheroids (SS-C type) indicate continual motion of the spheroids.

(5) Compound structures that exhibit a change with vertical growth from one type of stromatolite to another are evidence of minor changes in the physical environment.

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STUDY OF A COPPER-IRON SULPHIDE MINERAL (Cu₁₃Fe₈S₂₂) FROM THE SULPHIDE ORES OF KOLIHAN SECTION, KHETRI COPPER BELT, RAJASTHAN

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Introduction: While investigating the sulphide minerals occurring in the sub-alkaline tholeiitic basalts of Kilauea volcano, Hawaii island, Desborough et al (1968) reported the occurrence of an unusual copper-iron sulphide mineral whose composition differs from known synthetic and natural sulphides having copper, iron and sulphur as the elemental constituents. Recently Clark (1970) established the presence of a similar mineral in the Ylöjärvi copper tungsten deposits of Finland. The present author, in the course of investigations of the copper ores of Kolihan section of Khetri copper belt, Rajasthan, has found the presence of a new copper iron sulphide
mineral whose chemical composition agrees well with the unusual copper-iron sulphide reported by Clark (1970) and Desborough et al. (1968). The present paper gives an account of the optical, electron microprobe and thermal studies of this mineral.

**Mode of occurrence:** The mineral under study occurs as a rare constituent of the copper ores of Kolihan and can only be observed under the microscope in the samples where chalcopyrite, pyrrhotite and cubanite are the major mineral constituents. It is generally found as small and thin lamellae orientated parallel or at an angle to the plates of orthorhombic cubanite exsolved in the host chalcopyrite. (Fig. 1). It is very rarely found as minute blebs exsolved within the plates of orthorhombic cubanite. The lamellar or bleb types show smooth boundary relation with the adjoining host sulphide. Moreover from their oriented nature of occurrence they appear to be products of exsolution.

**Optical properties:** The mineral is distinctly bireflectant in air from pale pinkish yellow to light bluish pink and shows strong anisotropism from bluish grey to very pale grey (more towards white). Though the bireflectance and anisotropism of the mineral bears some similarity to those of mackinawite, their intensities are very much less than in mackinawite. The reflectance of this mineral was measured at 546 nm in air by using 'Zeiss Mikroskop-Photometer and Ultraphoto II' and Zeiss's Silicon Carbide was used as standard for reflectivity measurement. The mean value at this wavelength is found to be 46.5 per cent (range 41.5 – 49.5 ± per cent). It shows close resemblance to reflectance data given by Clark (1970, see Table 1). Due to the very small size of the grains its microhardness cannot be determined. It is also very difficult to be isolated from the associated hosts; so its X-ray characteristics cannot be determined.

**Electron microprobe analyses and thermal studies:** Quantitative analyses of the
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mineral were carried out by an ARL microprobe analyser. Different standards and radiations used during the analyses are stated below:

<table>
<thead>
<tr>
<th>RADIATION</th>
<th>STANDARD</th>
<th>COMPOSITION</th>
</tr>
</thead>
<tbody>
<tr>
<td>FeKα</td>
<td>Pyrite (FeS₂)</td>
<td>46.4% (Fe)</td>
</tr>
<tr>
<td>SKα</td>
<td>&quot;</td>
<td>53.2% (S)</td>
</tr>
<tr>
<td>CuKα</td>
<td>Chemically pure copper</td>
<td>100% (Cu)</td>
</tr>
</tbody>
</table>

Determinations of the elemental contents of the mineral were done at 20Kv and at a specimen current of 2 x 10⁻⁸ amp. Standards were measured both before and after the analyses of the mineral sample as it is helpful in the construction of calibration curves. This procedure incorporates corrections for instrument drift and background counts (Desborough et al 1968). Interelemental corrections were calculated following the procedure of Springer (1967).

**Table I**

**SHOWING THE CHEMICAL COMPOSITION, OPTICAL PROPERTIES AND THERMAL BEHAVIOUR OF THE COPPER-IRON SULPHIDE MINERAL FROM THE PRESENT AREA AND FROM OTHER REPORTED OCCURRENCES**

<table>
<thead>
<tr>
<th>Locality and reference</th>
<th>Fe wt.%</th>
<th>Cu wt.%</th>
<th>S wt.%</th>
<th>Formula</th>
<th>Relative sulphur atomic ratio</th>
<th>Optical Properties</th>
<th>Thermal behaviour</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kelnaas, Hawaii island, Desborough et al (1968)</td>
<td>56.0</td>
<td>9.7</td>
<td>34.3</td>
<td>Cu₀.₁₅Fe₀.₉₅S,₀₀</td>
<td>1.0211</td>
<td>Pleochroism from yellowish pink to pale bluish pink. Anisotropic from dark bluish grey to greyish white. Mean reflectance at 546 nm in air is 45.5 per cent, range (41.5-49.5) per cent. Heating in vacuo for 6 hours at 125°C and subsequent quenching produced no change in the optical properties of the mineral. Annealing at 160°C and 200°C for 3 and 1 hours respectively caused a marked decrease in size of the lamellae and several lamellae are entirely absorbed into the chalcopyrite host.</td>
<td></td>
</tr>
<tr>
<td>Tlapa, Finland, Clark (1970)</td>
<td>56.77</td>
<td>9.37</td>
<td>34.46</td>
<td>Cu₀.₁₂Fe₀.₉₈S,₀₀</td>
<td>1.0671</td>
<td>Pleochroism from pale pinkish yellow to light bluish pink. Anisotropy from bright bluish grey to very pale grey. Mean reflectance at 546 nm in air is 46.5 per cent, range (41.5-49.5) per cent. Annealing at 250°C for 30 minutes causes a marked decrease in size of the lamellae and several lamellae are entirely absorbed into the chalcopyrite host.</td>
<td></td>
</tr>
<tr>
<td>Rollinan, Rajasthan, Present authors</td>
<td>55.00</td>
<td>9.12</td>
<td>34.79</td>
<td>Cu₀.₁₃Fe₀.₉₂S,₀₀</td>
<td>1.0951</td>
<td>Pleochroism from pale pinkish yellow to light bluish pink. Anisotropy from bright bluish grey to very pale grey. Mean reflectance at 546 nm in air is 46.5 per cent, range (41.5-49.5) per cent. Annealing at 155°C for 6 hours shows change in pleochroism and anisotropy of the mineral at 155°C. Heating in vacuo for 6 hours produces change in pleochroism and anisotropy of the mineral at 155°C.</td>
<td></td>
</tr>
</tbody>
</table>

Electron microprobe analyses show the presence of Cu, Fe, and S as the only constituent elements in this mineral. (Table 1). Chemical formula as calculated from the composition is found to be Cu₀.₁₅Fe₀.₉₅S,₀₀ indicating a metal : sulphur ratio 1.05 : 1.

Polished specimens containing the mineral were cut into the size of 5mm x 5mm x 4mm cubes for heat treatment. The cubes were heated in vacuum from a tempe-
nure range of 120 ± 2°C to 155 ± 2°C for six hours and then quenched. The mineral shows change in pelochroism and anisotropism at 155 ± 2°C, which indicates its upper stability.

Discussion: From the foregoing description it is evident that the new copper-iron sulphide mineral found in the Kolihan ores shows close similarity in optical properties and composition to the unusual copper iron sulphide described by Clark (1970). It shows a close resemblance in composition to Desborough et al's findings (vide Table 1, Fig. 2). From chemical point of view, the mineral contains a higher concentration of iron than the naturally occurring and synthetically prepared copper iron sulphide mineral. It resembles mackinawite, in some respects. The optical properties of this mineral show some likeness to mackinawite and they show more or less close atomic metal to sulphur ratio (Deb & Mukherjee 1969). Clark (1970 and personal communication) reported the presence of mackinawite with appreciable amount of copper (up to 8.8wt.%) in addition to Co and Ni. He further emphasised the natural existence of mackinawite with high copper and no Ni or Co. From his studies of the mackinawite from Norwegian sulphide ores Mukherjee (1971) could detect the presence of mackinawite containing 8.33 wt.% of Cu and 0.63 wt.% of Ni (but no Co). Mackinawite which occurs as a common minor mineral in the Kolihan ores is found to contain as high as 3.5 wt.% of Cu, 6.9 wt.% of Ni and 3.8 wt.% of Co in solid solution (Deb & Mukherjee, 1969). It is evident from the composition of the copper-iron sulphide mineral (Cu_{0.5}Fe_{0.5}S_{1.0} of the present area) that it can be regarded either as a separate phase in the ternary Cu-Fe-S system or as a member of an extensive cuprian mackinawite solid solution series (CuFe)_{1-x}S (Cf. Clark 1970). In the present case the mineral has shown an upper stability limit of 155 ± 2°C which is the temperature below which the mineral has exsolved from an iron-rich chalcopyrite solid solution. Moreover the existence of mackinawite in the present case with copper as high as 3.5 wt.% with insignificant amount of Ni and
sometimes with absence of Co and the existence of mackinawite with 8.3 wt% of Cu and minor Ni (with no cobalt) in other occurrences of the nature (discussed earlier) points to the possibility of classing this mineral as a member of the cuprian mackinawite series. However the study of the low temperature phase relations in the Cu-Fe-S system is now being conducted by the author and it is hoped that much light can be thrown on the phase relations of this mineral and the other associated sulphides after the completion of this study.

Acknowledgments: The author is indebted to NORAD for financial assistance for carrying out the electron microprobe analyses at the Technical University of Trondheim. The author is also grateful to the staff of Institute for Geology and Chemistry for offering laboratory facilities.

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SOME OBSERVATIONS ON THE NATURE AND TRENDS OF FOLIATIONS IN THE GRANITIC ROCKS OF GHATKESAR AREA, HYDERABAD, ANDHRA PRADESH

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Introduction: The area under investigation is part of the vast Precambrian Shield occupied by rocks of granitic composition which exhibit various degrees of gneissosity. Work in this area was previously done by the geologists of the former Hyderabad Geological Survey, and in recent years, this area, has been studied among others, by Balakrishna (1961 and 1964), Janardan Rao (1965) and Sitaramayya (1968 and 1969).

Present work: The present work is part of a detailed study of these rocks in an area of about 100 sq. miles situated east of Hyderabad city. An attempt is made in this paper to study the types of foliations present in these rocks and their statistical trends. The descriptive term foliation is used here to denote parallel surfaces determined by alignment (preferred orientation) of tabular or prismatic crystals (mica, hornblende, feldspar) and elongate inclusions, or by segregation of particular minerals in alternating streaks and bands.

Many types of foliations are present in these rocks and some of these are characteristically confined to certain types of rocks. These are briefly described below: