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THE GEOLOGY AND THE ORES OF

SÄVLIDENFÄLTET, VÄSTERBOTTEN.

SWEDEN.

CHRIS ROERING B.Sc. (ENG.) RAND.

JULY 1959.

Thesis
M.Sc.
W'Rand.
1959

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

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The Geology and the Ores of Råvlidenfältet, Västerbotten Sweden

by

CHRIS ROERING B.Sc. (Eng.) Rand.

JULY 1959.

THESIS SUBMITTED FOR THE DEGREE OF M.Sc. (ENG.) RAND.
IN THE BRANCH OF MINING GEOLOGY.

Thesis

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ABSTRACT.

The ores described are the Sture ore, and the A-, B-D, and C- ores of Rävlidmyran. The Sture and A ores are replacement ores occurring in a limestone milieu, and are pyritic ores with Zn, Cu and Pb, with minor Sb, Ag and Au.

The B-D and C ores are massive sphalerite rich displacement ores with Pb, Sb and Ag in the main.

The surrounding rocks are quartz schists (with sericite, chlorite and biotite) limestones, and graphite phyllites. The wall rocks show the effects of chloritization and biotitisation, feldspathization, and possibly carbonatization, the last only on a very limited scale. Tremolitic skarn is also related to the wall rock alteration.

The original nature of the rocks has been determined in general, and they represent metamorphic equivalents of GAVELIN'S (1955) transition sequence from the Skellefte volcanic series to the overlying Phyllite series.

Chloritic rocks at Sturemalmen are formed from limestones by regional metamorphic processes associated with the period of folding closing with the formation of the Revsund granites. The different quartz schists were also formed during this period and the ores introduced slightly afterwards.

Structural geology is of great importance in this area. The Rävlidmyran ores are located along the axial plane of the Rävlidsnfältet antiocline, the plastic limestones and graphite phyllites having flowed into a zone of weakness in the axial plane, and the ores occurring at competent-incompetent rock contacts. The Sture ore has been localized by a drag fold in a limestone horison. A large shear zone through this drag fold apparently also accounts for the structure of the ore.

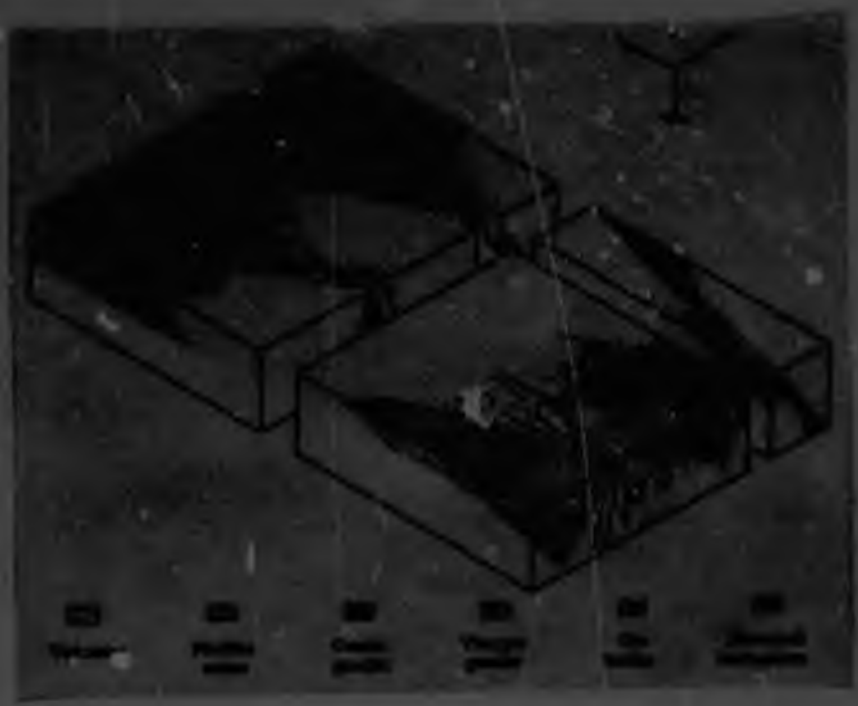

Fig. 1.

Block diagram of Kristineberg - Rävliden area (GAVELIN 1942).

1. Rävlidmyran - Sturemalmen area.
2. Rävliden.
3. Mörkliden.
4. Kristineberg.

A. INTRODUCTION.

This work discusses the orebodies of Rävlidenfältet.

Rävlidenfältet lies in the well known Skellefte district of Northern Sweden and refers to the ores containing the ores of: (1) Sturemalmen (the Sture ore), (2) Rävlidmyran, called the A-, B-, C- and D- ores and (3) the Rävliden ore. Rävliden itself is no longer worked so that only the Sture and Rävlidmyran ores are described in the following text. See Appendix 1 and also Fig. 1.

The following table gives an idea of the production and metal content of the Sture ore-body (for the years 1953 - 1957).

Year.	Tons.	Au g/t.	Ag g/t.	Cu%	Zn%	Pb%	S%
1953	16,151	1.5	54	1.15	3.81	0.62	22.3
1954	62,024	1.4	26	1.42	2.04	0.26	21.1
1955	111,879	1.0	33	1.47	2.31	0.28	22.0
1956	171,315	0.9	33	1.40	2.37	0.28	23.2
1957	184,771	0.9	34	1.48	3.61	0.27	24.4
	546,140	1.0	33	1.43	2.47	0.28	23.0

Similar data for the Rävlidmyran ores are not available for publication, because, as the author found when he visited the area, the ores were being prepared for mining operations. However, these ores have their own characteristics. The A ore is a complex ore with mainly copper, zinc and sulphur. The B, C, and D ores are compact sphalerite-rich ores (about 10% Zn) with high lead and silver content.

The information and data for this description were obtained during two visits to the area, one in November 1956, the other in March 1958. A large amount of geological information was already available due to very good geological mine plans, kept up to date by Messrs. Wistam and Andersson. This has reduced the task considerably and the local geological knowledge of these two persons has influenced the author's work.

Previous geological work on this area (apart from the routine geological mapping) is confined to short references to it in conjunction with more regional geological descriptions.

/... 2 /...

Those of most consequence are Du Rietz's work on the regional aspects of the Kristineberg district, (DU RIETZ, 1953), and Gavelin's references to the area in his description of the Pre-Cambrian in the Västerbotten county. (GAVELIN and KULLING 1955). Short reference has also been made by Gavelin to Kåvliämyran in discussing the relationships of ore deposition and structure in the Skellefte district (GAVELIN 1942). Of far greater importance have been several reports by Prof. Gavelin for the Boliden company which contain much unpublished data and which were very kindly passed on to this author for use.

/... 3 /...

B. GEOLOGICAL SETTING.

In order to understand the local geology it is, as with most geological problems, essential to consider the general aspects of the regional geology. Rävlidenfältet merely constitutes a minor locality in a large metallogenic province, namely the sulphide mineralization province of the Skellefte district. Thus a brief summary of the regional geology, and particularly of the Skellefte district will follow.

In Sweden the Pre-Cambrian division into three different orogenic cycles is accepted by most geologists. They are, beginning with the oldest: the Svionian or Sveccofennian cycle, the Gothian cycle, and the Karelian cycle. Following these cycles is a series of unfolded rocks, plutonic, volcanic and sedimentary, which are referred to as sub-Jotnian and Jotnium. (GEIJER, MAGNUSSON 1944, MAGNUSSON, GRANLUND, LUNDQVIST 1957).

Gavelin (1955) assumes the rocks of the Västerbotten county to be equivalent to those formed during Sveccofennian, Karelian, sub-Jotnian and Jotnian times. The following chronological table of the Pre-Cambrian of Västerbotten is cited from Gavelin's description of this county (GAVELIN 1955), as well as from an earlier publication (GAVELIN and GRIP 1946).

Rapakivi granite, diabase.	Sub-Jotnian and Jotnian eruptives.
Adak granite series. Sorsele granite series.	Karelian granites and gabbros (Sulphide ore formation in the N.W. part of Västerbotten e.g. Adak, Linsköld.)
Vargfors series. Sediments of varying types from conglomerate to shale. Intercalated basic volcanics.	Karelian sediments and volcanics.
UNCONFORMITY.	
Revsund granite series. Late or post orogenic Sveccofennian granites and gabbros.	Later phase of folding with thrust faulting and palingenesis. Sulphide ore formation. (Boliden, O. Hogkulla etc.)

/... 4 /...

Geology of the Phyllite series and the Jörn granite:

The Jörn granite series. A differentiated series granite-gabbro. Aplite and greenstone dykes.	Early orogenic granites and gabbros. Dominantly gentle folding. Weak sulphide invasion with the possibility of ore having concentrated.
The Arvidsjaur series. A differentiated volcanic series. Liparitic, keratophyric, dacitic, andesitic and basaltic lavas with subordinate tuffs.	Dominant vulcanism in the Arvidsjaur district; dominant sediment formation within the Skellefte district.
The Phyllite series. A thick sedimentary series in general of fine grained sediments containing graphite. Sandy, greywacke and conglomeratic sediments also developed. Intercalated basic effusives.	
The Skellefte volcanite series: A differentiated suite of liparitic, keratophyric, dacitic, andesitic and basaltic lavas and tuffs. Intercalated sediments.	Vulcanism within the Skellefte district.

The above classification is not accepted by Kautsky who has suggested certain modifications. (KAUTSKY 1957). Kautsky contends that the Vargfors formation is younger than the Revsund granite, and it should, in its lower parts, underlie the Phyllite series. Furthermore, the same author is of the opinion that the Adak granite is contemporaneous with the Revsund granite, with the implication that the Adak-Linsköld ores were formed under the same conditions that gave rise to the large sulphide ore belt of the Skellefte district.

The present investigation can throw no light on the above controversy. Both the above authors agree to the fact that the main period of sulphide mineralisation in the Skellefte district occurred in conjunction with the formation of the Revsund granite

/... 5 /...

and gneisses. This fact, which has been established (See GAVELIN 1955) together with the nature of the Skellefte Volcanic series and the overlying Phyllite series, are the consequent features of the regional stratigraphy affecting Rävlidenfältet.

Quaternary deposits have covered the bedrock to such an extent at this locality, that exposures are exceptional and one is compelled to assume rock types similar to those found in other areas in the aforementioned stratigraphic units. Thus from other areas the following facts may be learnt (GAVELIN, GRIP 1946; GRIP 1946; GAVELIN 1955).

The key to the early Svecofennian rocks of the Skellefte district is the graphite phyllite. These rocks invariably contain pyrrhotite which makes them a particularly useful marker horison that can be followed by geophysical methods, e.g. electrical and magnetic methods. Graphite phyllites are taken as the boundary separating the Skellefte volcanic series from the Phyllite series.

The Skellefte volcanic series comprises meta-liparitic, meta-keratophyric, meta-andesitic and meta-basaltic lavas and tuffs. (Stratigraphically from the bottom to the top). Differences exist at different localities but at the Vindelagransele-Kristineberg area (in which Rävlidenfältet is situated) the series is dominantly acid or intermediate. In contradistinction to some other areasein the Skellefte district, the volcanic rocks of the Vindelegransele-Kristineberg area have their emphasis on potassium instead of sodium (GAVELIN 1955).

Sediments may be present in this volcanic series. The changeover from the volcanic series to the overlying Phyllite series is transitional rather than abrupt. Limestones have their most significant development in this transitional rock sequence.

The Phyllite series is characterised by pelitic and psammitic sediments. Graphite pelites are widely distributed. These rocks are interpreted as sapropel-rich sediments essentially similar to the carbonaceous alum shales of Scandinavia (CAMBRO-SILURIAN). Apart from the carbon, the chemical composition is in general granitic, and the rocks are thus only to a limited

/... 6 /...

extent true clay sediments. Sediments similar to the graphite phyllites, but without carbon, also occur. Transitions to feldspathic sandstones, arkoses and greywackes are recorded. Conglomerates are likewise occasionally encountered. True quartzites are rare, and in general the sediments show a poor degree of differentiation. They are, according to GAVELIN (1955) a typical example of Pettijohns "greywacke series".

Finally the work of Du RIETZ (1953) on the Kristineberg region has a direct bearing on the more local geology of Rävlidenfältet. Appendix I shows the location of the Sture and Rävlidmyran ores in relation to the general geology. Outcrops are notably lacking. The geology consists in the main of a modified volcanic complex, originally of sodic quartz porphyry and albite porphyry (a sodic rhoylite with albite phenocrysts). Dacitic rocks also occur at Hornberget. These rocks are overlaid by the phyllites and subsequently folded. The Jörn granite to the east is later than the volcanic series and was either folded together with the volcanics, or was intruded simultaneously with the folding. Isoclinal folding with fold axes pitching towards the west dominate. The thickness of the volcanic series is estimated at somewhat less than 2 km.

These are schists differing in nature to the sericite quartz-schists, which appear in the southern part of the region. These contain much biotite, cordierite or andalusite in relation to the sericite quartz schists. Chlorite tends to be absent or of minor importance. This alteration is associated with the formation of the Revsund granite, and a distinct metamorphic zoning in relation to this granite has been established.

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Fig. 2.

Plan of the Mävlidenfältet anticline showing the positions of the ores. The diagram is based on geophysical maps of the area.
Scale 1 : 10,000.

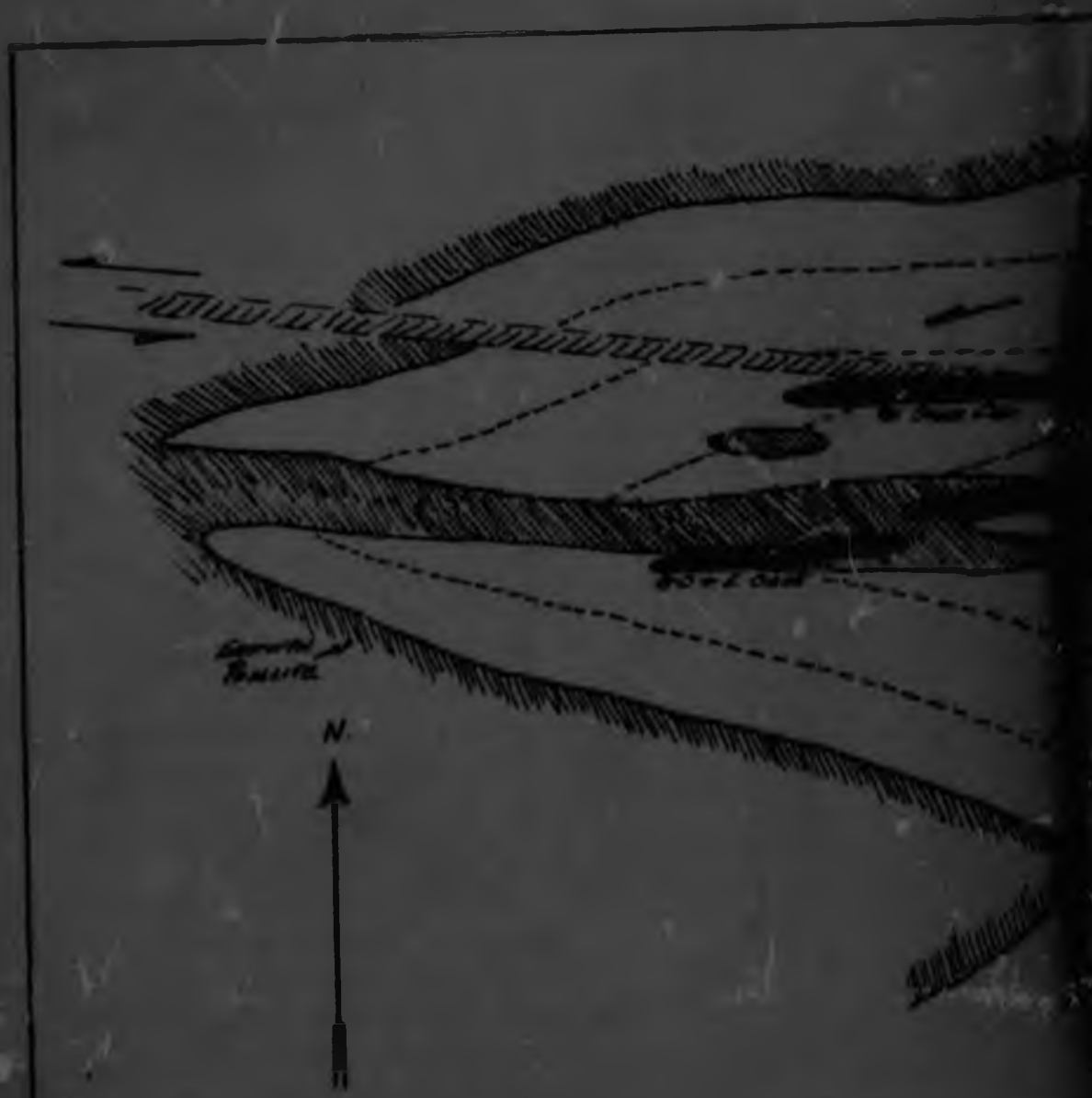
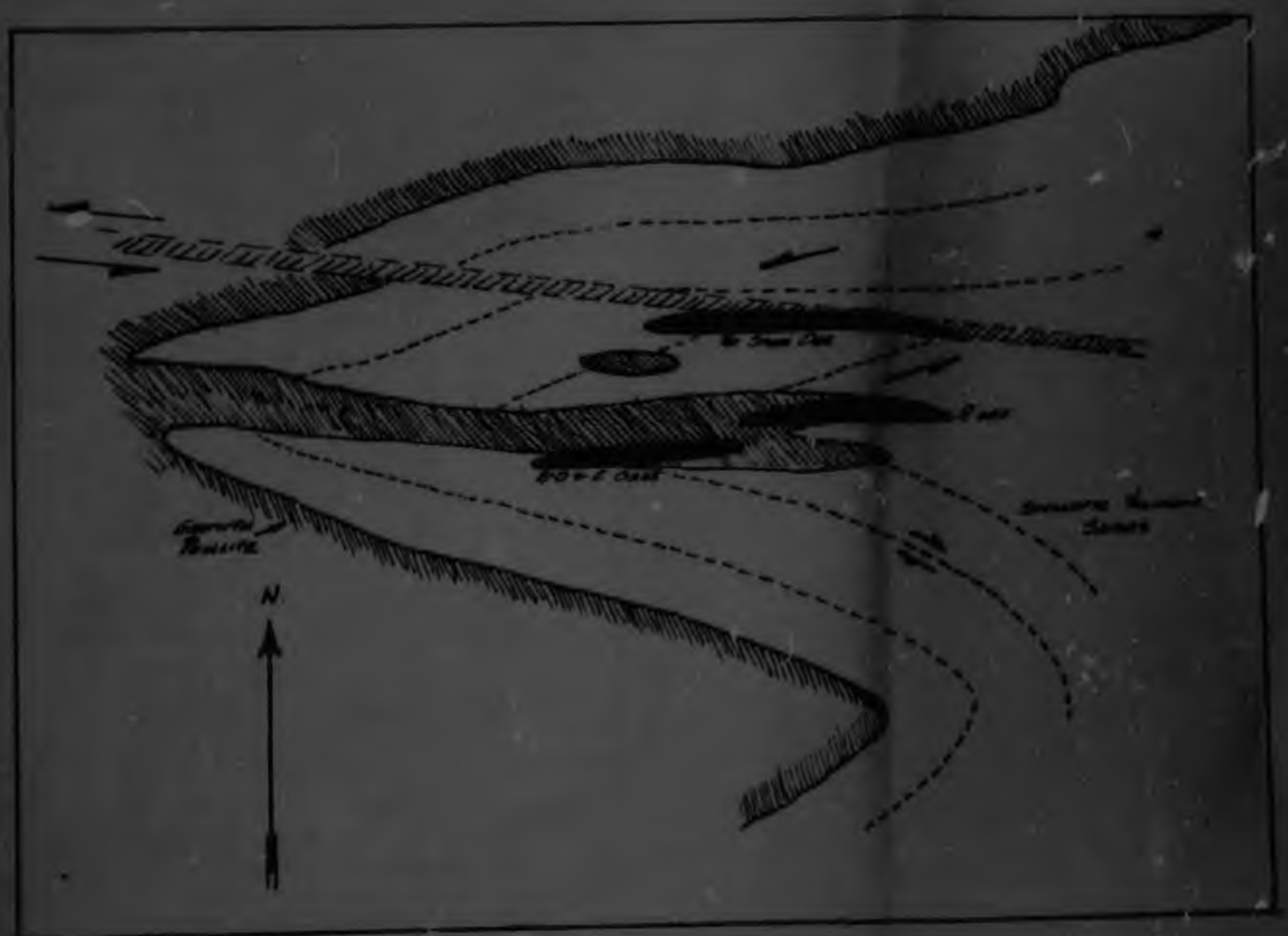


Fig. 2.

Plan of the Hävlidenfältet anticline showing the positions of the ores. The diagram is based on geophysical maps of the area.
Scale 1 : 10,000.



C. THE STRUCTURAL GEOLOGY.

1. GENERAL ASPECTS.

The structural geology finds its main interpretation in the geophysical maps of the area. Such were kindly placed at the author's disposal by Dr. Sture Werner of the Swedish Geological Survey. The information from the maps has been complemented by underground and borehole data.

Appendix I and Fig. 1 illustrate the broad structural trends. Here it can be seen that the Rävlidmyran and Sture ores are located in the anticlinal part of the Skellefte Volcanic series, very close to the contact of the overlying Phyllite series. The whole of the volcanic series is in the shape of a huge anticline which plunges flatly towards the west. A division of the major anticline into three smaller anticlines is evident. The mineralisation of the area is clearly related to these smaller anticlines, the Rävlidmyran and Sture ores having been located in the Northernmost one, which plunges at about 25° W.

Looking closer at the latter anticline, which will be referred to as the Rävlidenfältet anticline, several points are worthy of mention in the paramount control they have influenced on the ore deposition.

The Rävlidmyran ores are located along a thin strip of graphite phyllitic rocks and limestones which occupy the central axial zone of the Rävlidenfältet anticline. The presence of this strip has been deduced from geophysical measurements and has also been confirmed by underground observation as well as by borehole data. See appendix II.

Along the axial plane one has a series of rocks with low competence in comparison with the brittle altered volcanic rocks and quartz rich sediments. The graphite phyllites consist essentially of quartz and sericite and/or chlorite, and a variable graphite content, the graphite acting as a lubricant and thus allowing intergranular slip. Movement is also focussed along very definite planes along which graphite is concentrated giving the rock its platy or foliate character. Limestones are also incompetent in comparison with the quartzites. In considering the incompetency of these rocks one has to consider it in terms of flow. The limestones and graphite phyllites occupy a zone

/... 8 /...

of tensile stress, which most probably had resulted in an opening having ~~being~~ developed along the axial crest and part of the axial plane of the anticline; they have flowed, or have been squeezed into, a zone of stress minima in the overall tectonic pattern.

Fig. 2 has been compiled directly from the electromagnetic survey of the Nävlidenfältet anticline and shows the general location of the ores and the graphite phyllite zone along the axial plane, as well as the general location of the graphite phyllite horizon.

The zone of tension may appear to be unusually large when viewing Fig. 2, as this tensional opening in anticlines is generally confined only to the outer horizons of the competent rock complex. One must remember that this effect is somewhat exaggerated in this horizontal plan view, this being due to flat plunge of the fold axis (25°W). In relation to the huge anticline displayed in Du Riets' map (Appendix I) one sees that this phenomenon, is in fact, confined to the outermost layers of the volcanic series. From other parts of the world one has examples of ore having been located at the anticlinal parts of folds where tension has caused openings to form.

Tension in the anticline may be of two types. Due to the compression on the flanks of the fold, a lengthening in the direction of the axial plane might take place, and thus being under tension, openings in the different members of the stratigraphy, or at lithological contacts would form at the crest of the folds, i.e. saddle reefs would result. The other type is due to tension in the crests in the anticline which causes them to break open. This effect would be found in highly competent rock types. This latter type of mechanism is favoured for the Nävlidenfält anticline.

This zone of accumulation of incompetent rocks has been particularly favourable for the deposition of ore. It is clear that limestones have a direct influence on ore deposition merely as a result of the chemical nature of the rock which allows it to be easily replaced. However, even with this in view the dominant feature at Nävlidmyran has been openings that have existed at the contacts of the incompetent limestones and graphite phyllites, and the competent meta-quartzites. This structural feature has been supreme as we shall see in the

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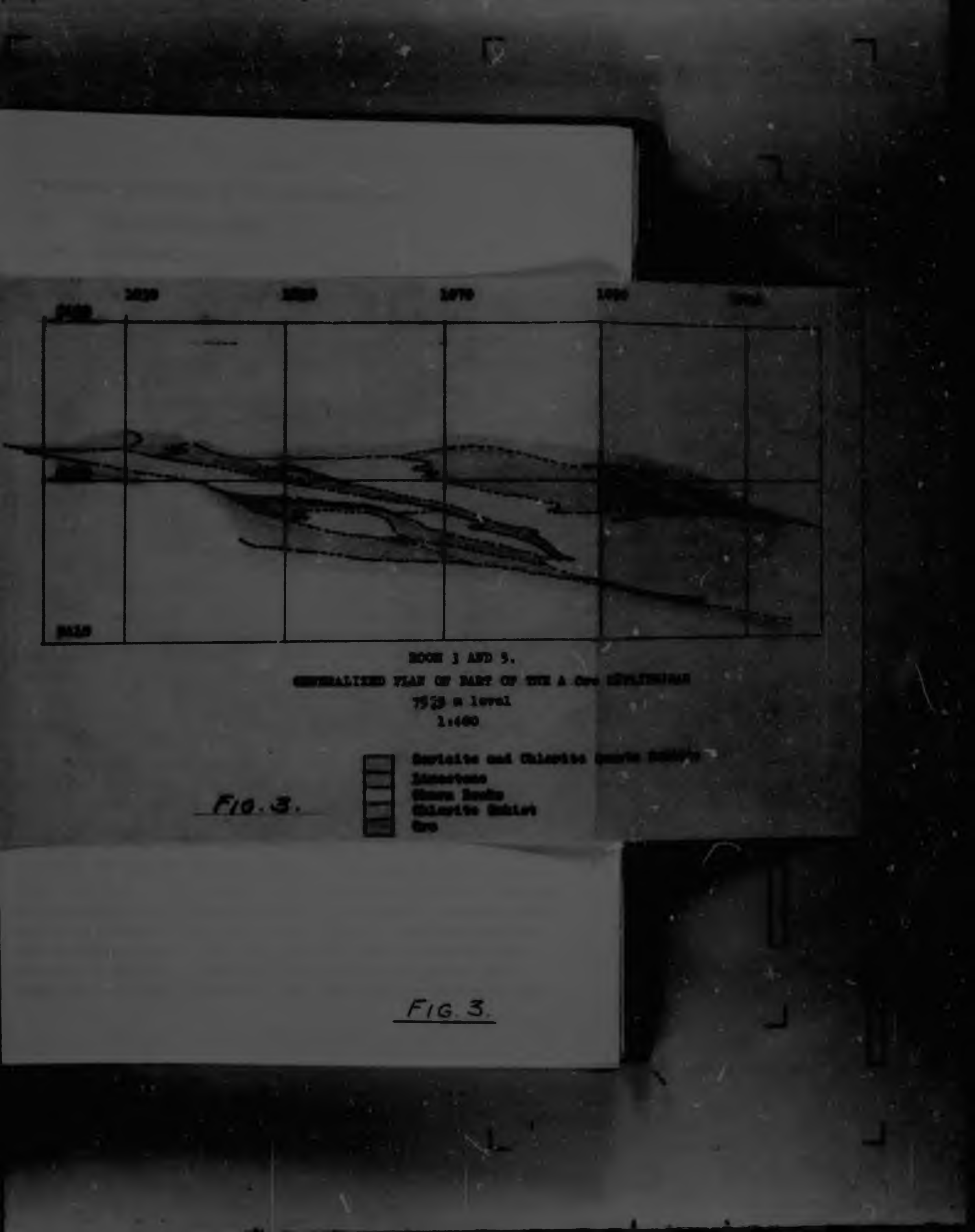
field


1070
1090
ROOM 1 AND 5.
GENERALIZED PLAN OF PART OF THE A Ore
level
1:400
Sericite and Chlorite
Limestone
Chlorite Schist
Ore
FIG. 3.
FIG. 3.

following description of the individual ores.

II. THE INDIVIDUAL ORES.

(a) [illegible]

The A ore consists of a number of small massive sulphide lenses occurring in a larger mineralised zone. See Appendix II. The ore is of a metasomatic type in that it has replaced the limestone, this occurring, however, at structurally controlled sites where ore solutions have been able to enter the limestone.

Fig. 3 has been constructed to show the nature of the A ore. It is particularly instructive in showing how there is a definite tendency for the ore lenses to occur at the margins of quartzite fragments, and the quartzite wall rock of the limestone. The effect is better appreciated if one can remember that generally tremolitic skarn forms from limestones, while the wall rock alteration of the quartzites is usually manifested by a small aureole of chlorite schist or chlorite rich rocks. Biotite may be formed in the latter case. Many chloritic boundaries are thus expected to give way to quartzite within a short distance from the ore.

The B-D ore is a narrow ore somewhat simple in its lense-like, and massive sulphide character, in comparison with the more complex replacement A and Sture ores. The 90 m level mine plan (Appendix II) shows that the B and D ores are separated, but this is only a local feature. From the borehole data it appears that the B-D ore tends to follow the lineation of the area, i.e. it plunges at about 25° to the west.

The C ore is essentially of the same character. It tends to follow the sericite-quartz-schist-graphite phyllite contact on the 90 m level. It is made up of two distinct zones of mineralisation one of which is relatively small. The ore also follows the lineation of the area. Mylonitization, or a definite recrystallisation of the ore has been observed underground as well as in the boreholes. This appears to follow definite zones in the ore, and indicates that movement was still in progress slightly after the introduction of the ore. These zones of recrystallization can be examined more fully only when the ore is observed over its full extremity. A general tendency for movement to have taken place in the direction of the fold axis is characteristic

/... 10 /...

for this area so that these zones are expected to follow the E-W schistosity of the area.

There is little information about the Rävlidmyran ores, but the main trends show that the ores have been localised in a definite zone, generally at the contact of competent and incompetent rocks. Carbonate rocks have had a great influence over the A ore, and even small traces are found in the other ores, or tremolitic skarn is found, which also indicates that limestone had been present in these areas. This also exemplifies the mobility of this rock.

(b) The Sture Ore.

The Sture ore presents a more intricate problem. One can gain an idea of its broad behaviour, while the detailed structure is highly confusing. Here again the replacement of a lime stone horizon is of importance and this accounts for the complexity of the ore's behaviour and shape. Regular well shaped boundaries, and the relationship of small massive parts to each other, cannot be reckoned with in detail. On the other hand, while considering the broader zones of mineralization one does find a structural influence on the ore.

A simplified and generalised block diagram of the Sture ore can be seen in Appendix III. The dominant feature is the thickening of the limestone which requires an explanation. This is even of greater importance when one considers that chlorite schist is mixed with limestone and tremolitic skarn, and derived from limestones by metasomatic alteration.

Another feature requiring an explanation is the anticline, or the anticlinal apophysy which is clearly seen in the diagram. This latter feature is anticlinal in the sense of the ore itself. The wall rock is highly modified so that no anticline can be observed in the stratigraphy. Also there is no tendency for a repetition on either side or flank of the anticline of the surrounding strata, i.e. there is no symmetry in the structure. It would seem then that the structure is a result of other causes than simple anticlinal folding, which would result in the limestones having flowed to, and collected in, the anticlinal crests. Furthermore, as has been pointed out in the previous description that the axial plane of the

/... 11 /...

Rävlidenfältet anticline is found in the zone in which the Rävlidmyran ores are located. Unfortunately this can be founded only on the maps of the geophysical surveys, no outcrops being present to allow well founded field criteria.

The actual shape of the Sture ore is difficult to put into words. One can refer to two major features:

(1) The "centre" of the massive sulphide accumulation. (The "centre of gravity").

(2) The anticline which has been referred to above.

These two features comply fairly well with the lineation of the area and thus follow the plunge of the fold axis, i.e. 25^{0}W. East of the "centre" the ore dies out into two mineralised zones. The northernmost will be spoken of as the "tail" of the main ore-body and it follows the contact of the limestones and the metaquartzites obediently. Again one sees the importance of the competent-incompetent rock type relationship. The southern mineralised zone constitutes the southern flank of the anticline which dies out fairly quickly as can be judged from borehole data.

West of the ore's "centre" one encounters highly complex structures. Individual slab like inclusions of limestone in the ore can sometimes be followed in an orderly manner through the mine. In other words they occupy definite positions in the ore. There is one such slab, or pillar, which occurs immediately to the west of the "centre", which divides the ore essentially into two major zones of mineralisation, and which has been followed from stope to stope through the mine. The lower contact of this slab (i.e. its eastern contact, with the massive ore in the direction of plunge) has been found to have the same trend as the plunge of the fold axis. In detail, however, this contact is undulatory and this is most likely due to the fact that the ore has impregnated the limestone to varying degrees, the general trend still conforming to the fold axis.

A glance at the mineralised zones west of the "centre" shows how irregular they are from the one level to the next. (Compare the Appendices II and IV; see Appendix III). The individual massive sulphide lenses are extremely complex and hard to follow as they pinch out, swell, join new zones, etc. These features are indicative of a replacement action of the

/... 12 /...



Fig. 4.

Stereographic projection of the pole of the schistosicity planes measured at Sturemalmen and RÅvlidmyren. 50 observations and a maximum at a strike of S 86 W and dip of 70°S.

ore solutions. The main features, however, i.e. the anticline, and the "centre" have been controlled by some important structure which conforms with the regional trends. Even here, however, it appears as though there is a splitting up of the massive sulphide ore concentration, on the 240 m level.

In order to account for the thickening of the limestone horizon which has in turn localised the Sture ore, fig. 2 is of use.

The differential movement on the N limb or F half of the Ravlidenfaltet anticline is such that N moves to the west (or upwards in relation to the shape of the anticline) while the southern parts (close to the axial plane) move to the east or downwards. Such differential movement is particularly suitable for the formation of a drag fold in the incompetent rocks such as the limestones. The mere configuration of the limestone suggests that it may have been thickened by a drag fold, and the configuration of the Rävlidenfältet anticline tends to support this. See Appendices II and IV.

The anticline of the Sture ore, however, appears to be the result of a shear zone which cuts over the general schistosity of the area. The general schistosity is shown in Fig. 3. In spite of the limited number of observations in Fig. 4 a clear maximum is obtained at N86°W, the dip being 70°S. A shear in the direction of the S limb of the anticline and combining the northernmost mineralised zone west of the "centre" strikes approximately N75W and dips at about 50 - 60°S. See 140 m level mine plan (Appendix IV) where this shear direction is clearly revealed. The block diagram also serves to show the flatter dip in section. Underground this shear plane has been encountered in the westernmost stopes where the ore suddenly bears off more to the N and the dip flattens. This fact has been used in compiling the block diagram.

Two possibilities exist for the explanation of the shear plane. It should be realised that this is a plane of compression and not of tension into which the limestones have flowed. The limestone that one encounters in the Northernmost zone of mineralisation west of the "centre", and the limestone in the S limb of the anticline, are in the author's opinion caused by the over-riding of the quartzites by the limestone along the shear

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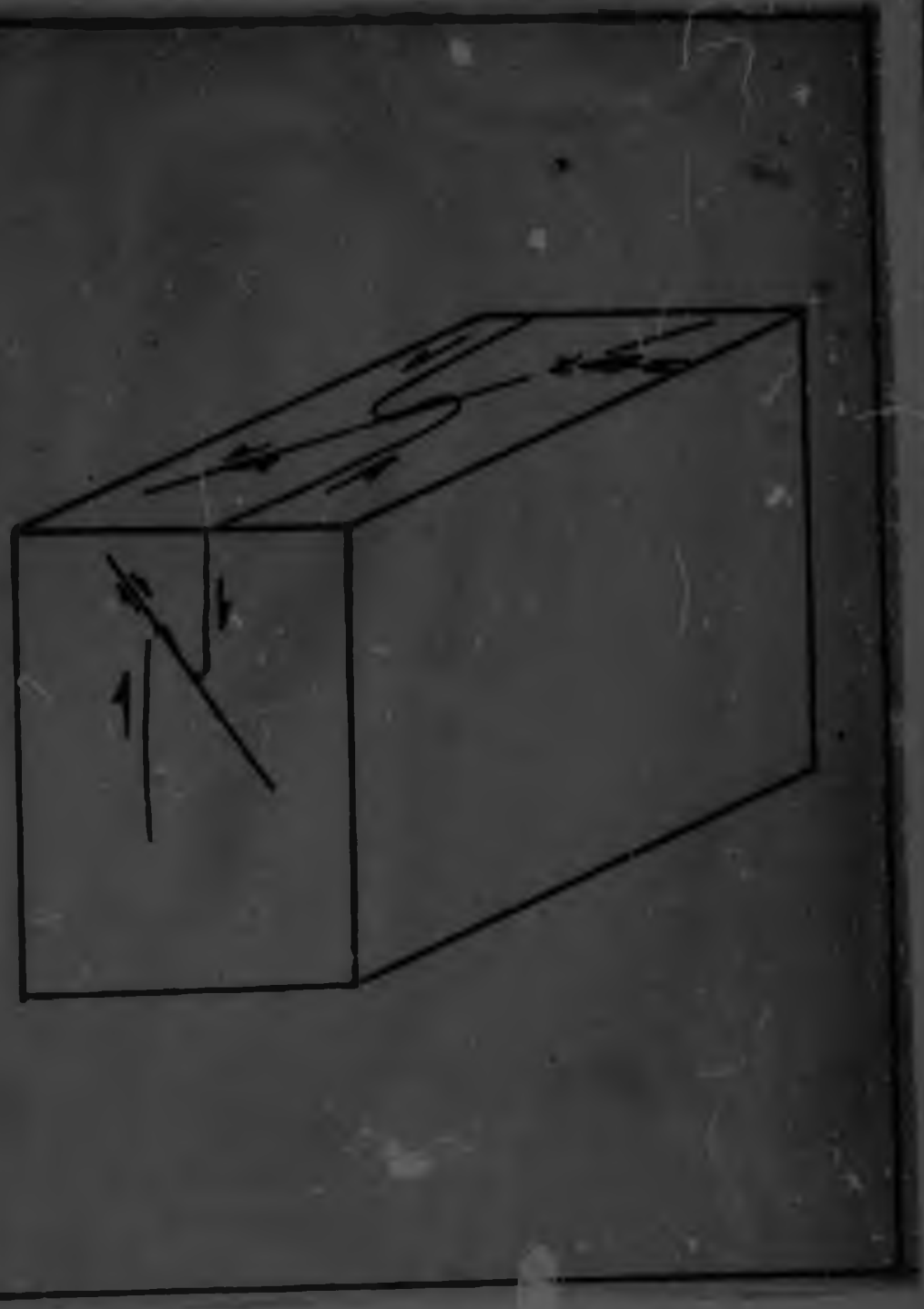

Fig. 5.
Principle sketch showing the major structures which have localised the Sture ore body.



Fig. 8.

Showing drag fold effects in ore region west of the Sture ore "centre" on the 140 m level. S.W. face of the N.W. - S.E. cross drive.

plane (See Appendix IV). The possibilities for the formation of the shear plane are either that the shear has developed as a direct cause of the drag fold, the difference between these two being little after a certain stage is reached in the drag fold; or else that a larger shear zone found in the Ravlidenfaltet anticline itself cuts across the Sture limestone. (See Fig. 2). The latter possibility seems the more favourable in accounting for the shear zone of the Sture ore. The features which have localised the ore can thus be diagramatically explained in the principle sketch opposite. (Fig. 5.) I am indebted to Dr. Erotsen for having pointed out the feasibility of the existence of this fault from the geophysical survey maps.

The existence of the shear zone in the direction indicated above reveals itself again and again by small apophyseal protrusions of the massive ore with essentially the same direction as the above discussed zone. See Appendix III where some such apophysies occur on the N side of the ore.

The explanation of the ore given above is intended to show the general controlling principles only. In actual practice the ore is more complex, the complexity occurring in the area west of the "centre". This is illustrated in Fig. 6 which is a map of the SW face of the NW - SE drive shown on the west side of the ore's centre in Appendix IV. Here the quarts veins as well as the N ore lense suggest a differential movement as shown in Fig. 6. That is, the N side has moved down with respect to the southern side.

This is completely contradictory to the principle diagram in Fig. 5. That such detailed data oppose the general picture shows the complexity of the structure. This latter contradicting structure finds its cause in the graphite phyllite lense which lies immediately to the SW of the Sture ore. It is recognizable on the geophysical maps (e.g. Fig. 2) and has been found underground (See 90 and 140 m level mine plans, appendices II and IV). This graphite phyllite lense may represent part of the enveloping anticline of Rävlidenfältet which has been folded into the sediments. The major anticline is not to be expected to have a simple form as that shown. One has drag effects on either limb, and it may also be en-echelon. The structure cannot be considered in greater detail because of

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Fig. 7.

Limestone inclusions in a chalcopyrite rich ore with chlorite.
240 m level Sturemalmen: "Tail" Region of ore.
The position of these fragments suggests a drag fold had existed in the replaced rock prior to the invasion of the sulphides.

the limited information based on geophysical data only. The interpretations given here thus lie in the realm of working hypotheses.

The "tail" of the Sture ore possibly shows, however, that differential movements in the direction indicated above in Fig. 5 have been in existence. See Fig. 7.

Extremely important pre-ore fractures are those which have given rise to the ore breccia or hard ore mineralisation found east of the Sture ores "centre". For an explanation of "hard ore" see page 66. These fractures and shears follow definite systems, the most important being themain schistosity of the area. Intersecting breaks make small angles with this direction and result in a network of sulphide impregnated veins, which, when the ore is abundant and the metasomatism effective, forms impressive ore breccias with well rounded metaquartzitic inclusions.

The schistosity of the area strikes essentially E-W and dips approximately at 70°S. Ore breccia mineralisation also reveals systems dipping at 75°N and vertically. Strikes of N70 - 75W and N70 - 57E have also been found as the main directions in the hard ore. The strikes can readily be divided into three directions while the relationships for the dips are not so clear.

Considering the Sture ore as a whole it is seen that the ore has been localised by limestones which due to their incompetency in the hard metaquartzites have undergone a considerable thickening caused by a drag fold during the formation of the Rävlidenfältet anticline. A shear zone through this area has also played an important part in the forming of the ore.

Post ore faults with small displacements are found in the Rävlidmyran ores on the 90 m level (See Appendix II). Otherwise no major post ore faults are found in the area.

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D. THE ROCKS OF RÄVLIDENFÄLTET.

I. GENERAL.

The successful establishment of a systematic local stratigraphy at Rävlidenfältet is not entirely feasible. This is largely due to the highly unrecognizable nature of the primary rocks and to the unreliable position of the limestones (in detail) which have been tectonically affected and now can occupy positions which are structurally controlled rather than true stratigraphic positions. In general the limestones occupy positions of stress minima in the overall tectonic pattern. The positions of the limestones are, however, more or less in order, i.e. they lie in the transitional rock sequence below the graphite phyllite (See page 5).

The graphite phyllite is the main lead in correlating the Rävlidenfältet rocks with the regional stratigraphy. The Rävlidenfältet rocks are in the main equivalent to Gavelin's (1955) transitional sequence from the Skellefte volcanic series to the overlying Phyllite series. According to Gavelin the changeover is transitional rather than abrupt. This latter statement is confirmed by the appearance of rocks at Rävlidenfältet which may be given a sedimentary origin, and rocks representing modified acid to intermediate volcanic rocks, interbedded with each other and occurring below the graphite phyllite.

The limestones in themselves suggest a rock of sedimentary origin. Other rocks, undoubtedly of sedimentary origin, lie in close proximity to the limestone and indicate that sedimentary processes have been operative in this succession.

Banding in metaquartzites which lie between the graphite phyllite and the Sture ore (about 72 m to the N of the Sture ore's most well developed portion) caused by more biotite rich bands (coarsening of grain size also given by the biotite) in a sericite-quartz-schist, are suggestive of a banded pelitic and psamitic sediment.

Evidence suggesting sedimentary rocks, is the occurrence of a probable conglomeratic rock type which occurs just N of the Sture ore; it has been observed on the 140 and 240 m levels at this position (on the 140 m level it occurs some 15 m N of the Sture ore near the central or massive part of the ore.) A conglomerate is also possibly present on the 190 m level some 5 m S

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of the antiklinal part of the Sture-ore.

The conglomerates appear to have been scattered pebble conglomerate without any rich concentration of the pebbles or rock fragments. The pebbles are now 1 - 1.5 cm in diameter, drawn out in the direction of the fold axis. In some cases the conglomeratic nature is well preserved while in others the pebbles are tectonically affected and highly metamorphosed, and thus almost unrecognizable. The pebbles now consist of a fine grained granoblastic aggregate of quarts with very small, widely distributed, flakes of sericite and/or chlorite. Biotite may also occur. Between the pebbles the "matrix" shows a higher sericite, chlorite or biotite content (or a mixture of these) in a granoblastic quarts mosaic. A bright green chlorite has been observed in these conglomerates. Accessories are: sphene, calcite, albitic plagioclase, epidote and sulphides.

Thus rocks of sedimentary origin are present in this area. Just what percentage of the sericite quarts schists are made up of sedimentary rocks, and what percentage is made up of volcanic rocks cannot be said.

That volcanic rocks have been among the original rock types is confirmed by blastoporphyritic quarts eyes (often opalescent) appearing occasionally in the sericite-quarts-schists. Under the microscope these quarts grains often show a wavy extinction indicating strain. The grains are frequently resorbed by the surrounding sericite quarts matrix, so that this matrix is often developed in these grains, filling small cracks and eating their way into the larger quarts grain. These quarts eyes are relict quarts phenocrysts of presumably fairly acid lavas as described by Du Rietz (op. cit.) e.g. quarts porphyries. The altered phenocrysts are thus in varying stages of breakdown and it is only the larger and more fortuous grains that have withstood alteration. (Plate I).

Large feldspar grains in the sericite-quarts-schists can be a point of discussion as to their mode of origin. It can be argued that such feldspar grains are of metamorphic or metasomatic origin. However, in the S reaches of the mine on the 90 m level a spotted biotite (and chlorite) quarts schist with varying feldspar content is present. This rock shows a somewhat complex

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mineralogy due to metasomatic alteration. Of greatest interest, are the relatively largish feldspar grains (plagioclase) up to about 2 mm in size. These grains are somewhat resorbed at their margins and where they have been fractured, are intruded by the normal biotite and chlorite quarts groundmass of the rock, as well as by calcite which has been introduced into the rock. Judging by the stout shape of the grains, which now have a modified euhedral outline, these could represent relict feldspar grains of a lava. See Plate II.

Those feldspars that are undoubtedly of secondary origin at Råvlidenfältet are commonly untwinned, though sometimes the different grains may penetrate each other. They also have a tendency to develop a crude zonary structure making universal stage determinations difficult. The feldspars occurring in the S part of the mine, however, are characteristically twinned and show the following twin laws and anothite contents:

Twin Law.	% An.
Karlsbad	40
Ala	20
Albite	35
Manebach	35

These feldspars often show excellent saussauritization. Epidote is developed as inclusions in the feldspar grains. They also show numerous inclusions of quarts derived from the breakdown of the plagioclases rather than representing poikioblastic feldspar grains. Gavelin, in discussing the Bjurtrack ores, says that the first trace of alteration of the plagioclases was the appearance of numerous inclusions of quarts in the original phenocryst. GAVELIN 1939.

Otherwise these rocks show a somewhat variable composition due to the influx of calcite which follows the schistosity, is associated with the ore minerals, fills cracks in the bleste-porphyritic feldspar grains, and which has undoubtedly been the cause of the formation of an extremely fine grained greenish amphibole mineral (tremolite - actinolite?).

It is thus concluded that these rocks are quite possibly modified equivalents of lavas proximating a dacitic composition.

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Another more unusual rock type for this area was the appearance of a true leptite immediately N of the limestone in the E part of the Sture ore. (Room 16, 140 m level). The rock is almost entirely of xenoblastic quartz and feldspar (albitic plagioclase; microcline ?) in a fine grained equigranular mosaic. The feldspar constitutes about 20% of the rock and the average grain diameter is 0.06 mm. Biotite, chlorite, sphene, flourite (metasomatic), and sulphides make up the accessory minerals.

Regarding the original nature of the rocks as a whole, very little can be established apart from the above details. Generalisations have to be made, and these, based on the regional stratigraphy, and the data observed underground, give a picture of a rock sequence of interbedded sediments and lavas, i.e. Gavelin's transitional sequence with limestones. Finally irrespective whether the rocks were either sedimentary (apart from the graphite phyllites and limestones) or volcanic they must have had a fairly similar chemical composition to give rise to the dominant rock type of the area - the sericite quartz schists. These rocks were then rich in silica and contained lesser and variable amounts Al_2O_3, K_2O, Na_2O, with minor quantities of FeO, Fe_2O_3 MgO.

The chlorite-bearing rocks, as we shall see later, are dependent on more complex processes for their formation.

With these facts in mind it is time to turn to the common rock types of the mine area, those recorded on the map as differing types of quartz schists, chlorite schists, graphite bearing rocks and the limestone and skarn rocks.

II. THE ROCK TYPES.

The quartz-rich wall rocks have the local name of "quartsites" and depending on their sericite, chlorite, or biotite content (not shown on the maps) are given the prefix sericite-, chlorite-, or biotite. These rocks are, however, schists and represented by sericite-quartz-schists, chlorite-quartz-schists and biotite-quartz-schists. The classification is not strict, as the rock types are for example, often seem to contain both sericite and chlorite, or chlorite and biotite. Furthermore, the rock types grade into one another and various intermediate types are thus possible. However, the classification

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is effective for practical reasons, as the chlorite- (and biotite)-quartz-schists are darker than the sericite-quartz-schists.

IIa. SERICITE QUARTZ SCHISTS.

Quartz which is developed as a fine grained equigranular mosaic, usually dominates and characterises these rocks. The grain size is variable but is generally of the order 0.04-0.06 mm in diameter. Fine flakes of sericite, which tend to have similar orientation, are fairly evenly spread in this mosaic when the amount of sericite is small. With increasing sericite content, a segregation of sericite into planes is evident. These planes conform to the general schistosity of the area, (See page). It is not uncommon to observe two different major prefer sericite orientations of two different ages. The post crystalline s-surfaces correspond to the fracture cleavage surfaces along which movement had taken place during the tight folding of the Rövlidenfältet anticline formation. See Plate III. The variation in the amount of sericite in these rocks is brought out in Table 1.

TABLE 1.

Mineral composition of sericite quarts schists given in volume percent.

Specimen No.	21	207	227	249	301
Quarts.	34.6	74.4	40.5	76.8	64.0
Sericite.	59.8	24.2	52.9	20.2	34.3
Sphene.	2.0	0.1	1.5	0.3	0.2
Plagioclase.	0.8	-	-	0.3	-
Chlorite.	1.3	-	4.3	-	tr
Tourmaline.	-	-	tr	0.1	tr
Epidote mins.	0.1	-	tr	tr	0.1
Apatite.	-	-	tr	-	tr
"Phlogopite".	0.3	-	-	-	-
Calcite.	-	tr	0.2	-	tr
Biotite.	-	-	-	0.1	1.3
Sulphides.	1.2	1.2	0.6	2.2	-

Chlorite is generally present though in small amounts. With increasing chlorite content the rock becomes a chlorite quarts schist (i.e. when the amount of chlorite dominates over sericite).

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PLATE I
X45 2 Nicols.

Blastoporphyritic Quartz Grain in a Sericite Quartz Schist.



PLATE II
X45 2 Nicols.

Resorbed Plagioclase Phenocryst in a Biotite Quartz Schist.



PLATE III
X8 2 Nicols.

Differing Sericite Orientations, presumably para- and post-crystalline, in a Sericite-Quartz Schist.

It is characteristically developed as fibrous flakes though larger xenoblastic grains have been found. Biotite may occur, though generally only in subordinate amounts.

Minerals that occur in small but persistent amounts are sphene and minerals of the epidote group. Among the latter sericite and clino-zoisite are the most frequent.

Another mineral that probably belongs to the epidote group displaying a strong tendency to develop idioblastic grains has been observed in trace amounts. Unfortunately it is always clouded with inclusions and alteration products so that optical determinations have been unsuccessful. It is biaxial positive with a small 2V. The relief is moderate and birefringence generally low. This mineral is unusual in that it is invariably developed with twins. The twinning plane is parallel to the elongation of the grain dividing it in two halves. The cross section of these prisms is usually rhombic, the twinning plane passing diagonally from corner to corner. From powder diffraction data many different phases were recorded but some of the lines suggested an epidote structure.

Sphene may occur as small anhedral grains widely spread in the rock, but it also has a tendency to concentrate into aggregates and porphyroblasts. The formation of sphene is apparently late in the rock's history; it is often related with the sulphide introduction into the rock; it often follows the structure of the rock implicitly, for example, where it is interleaved with sericite flakes of differing orientation. In other cases it completely disrespects the banding in the sericite and forces its way into this banding which is evidently due to its late crystallization. Leucoxene may be developed, generally as fine aggregates. It is a rare constituent.

Tourmaline is an important, though rarely encountered constituent of the sericite quartz schists. It is noted as extremely fine grains (0.05 mm) widely dispersed in some of these rocks. In some cases it is so fine grained that the only clue one has to its presence is the typical triangular cross section of the grains. It is sometimes found as larger needle-like grains with distinct pleochroism. Two varieties have been identified:

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n_o		n_g	
1,634 ± 0,003	Faint yellow	1,618 ± 0,003	Colourless.
1,643 ± 0,003	Bluish green	1,621 ± 0,003	Colourless

Other accessory minerals are rutile (exceptionally rare), calcite, sulphides.

Sericite is not the only mica in these rocks. Larger, tending to poikioblastic grains of muscovite are found occasionally. Another mica with a pale yellow (faint) pleochroism has been noted. It is an extremely rare constituent, usually much coarser than the other constituents of the rock. GAVELIN (1939), when discussing the wall rock minerals in the Malånäs district has described a muscovite which replaces biotite, and thus contains a certain amount of iron, which has a slight yellow tint in the highest coloured orientation (2V=36.5 - 38°). The Rävlidenfältet yellow mica on the other hand has a very small optic angle (almost uniaxial), and is found in rocks completely void of biotite. The mineral might be a Phlogopite ? Its occurrence is as larger porphyroblastic grains with poor crystal outlines. Inclusions of quartz are not uncommon.

Feldspar grains are to be found though only in very small amounts. They are generally porphyroblastic. However, in some cases small grains the same size as the ec granular quartz grains are encountered. The feldspars are typically zoned, with flamy and undulate extinction making the determinations with a universal stage only approximate. Polysynthetic twinning is unusual so that most of the determinations are based on cleavages. A list of more reliable feldspar determinations is presented in Table 2. These determinations, however, include feldspars found in chlorite-quartz-schists. In general the composition of the feldspars is An 30 - 40%.

These feldspar grains pose the problem as to which were formed in conjunction with the ore forming processes and which are modified grains of the primary rock. No answer can be given. In certain cases (see later) one can undoubtedly relate feldspathization to mineralization and under such conditions one can venture an opinion as to the origin of the grains, while in other cases one has no idea at all. Certainly both types are possible.

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TABLE 2.

Universal stage determination of secondary feldspars based on twin law or cleavage.

Specimen No.	Rock type.	Twinning Law.	Anorthite content
20.	Sericite-quartz-schist	Albite-Carlbad.	30%
22.	Chlorite-quartz-schist	-	35%
106.	Sericite-quartz-schist	Albite-Ala.	35%
201.	Chlorite-quartz-schist	-	35%
203.	Chlorite-quartz-schist	-	35%
311.	Chlorite-quartz-schist	Albite.	0%

Microcline is sometimes formed together with sulphide minerals that have entered the rock along suitable fracture planes, or more commonly, along schistosity planes.

A chemical analysis of a sericite-quartz-schist is given in Table 3. The analysis has been calculated in accordance with the method of Barth (BARTH 1948, 1955; ESKOLA 1954). The Epi-norm has been given and this requires an amount of water in excess of that given in the analysis. An approximate mode has been derived, and even in this a certain amount of extra water had to be incorporated. This extra water has to be included to form minerals that are hydrated.

In none of these rocks has an olivene or pyroxene been found. This is hardly possible in the low grade of metamorphism encountered at Rävlidenfältet. Similarly, no anhydrous aluminium silicates have been observed. It is cautioned, however, that cordierite may be present. This mineral has not been observed in these rocks under the microscope, but could be a certain small percentage of the minerals interpreted as feldspars. Feldspar and cordierite as dispersed grains can be confused in such rocks. Consequently the author has tried to make universal stage determinations on all suitable grains simulating feldspars, and although the determinations were not perfect, there was nothing to suggest the presence of cordierite.

Since the analysis represents 4.65 m of borehole core it serves admirably to illustrate a more "averaged" composition of

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the sericite-quartz-schists than an analysis of a selected hand specimen. On the other hand there is a greater possibility of having more minerals present which makes it more difficult to arrive at the mode. Secondly, in considering such altered rocks as these one should not expect perfect equilibrium to have been attained. That one cannot form strictly stoichiometric mineral assemblages is thus not so surprising. Mg^{++} can replace Al^{++} in the ideal muscovite formula and such substitution is highly probable in the sericite. The amount of sericite could accordingly be increased and less water used than has been done in the norm above. In other words less chlorite would appear. Substitution of this type has not been considered. Sericite is also likely to use up some of the alkalies of the feldspars if part of the chlorite is to be used in the formation of sericite. F substitutes for OH so that one can reduce the H_2O deficiency. It is interesting to record that ÖDMAN (1941) in calculating the modal composition of sericitic schists from the Boliden deposit found poor agreement in one of the analyses; there was a deficit in the amount of Al_2O_3 and H_2O in proportion to the alkalies.

/... Bd /...

TABLE 1.

Cation percent of a sericite-quartz-schist.
B.H. 630,0°.190 m level. 3.45 - 3.12 m.
analyst: H. Olefsen.

	Cation %
Si	81.81
Al	7.84
Fe^{+++}	1.87
Fe^{++}	2.49
Mg	2.52
Ca	0.42
Na	0.48
K	2.54
Mn	Tr
Ti	0.16
Mn	Tr
B	Tr
P	0.02
C	0.18
F	(0.44)
Cl	Tr
H_2O-	(0.13)
H_2O+	(2.22)
Cu	0.19
Zn	0.12
S	(2.42)
Cations =	100.00
O	182.74
OH	4.44
F.	0.44
S.	2.42
Anions =	190.04

Minerals.	Cations.	H_2O	
Q	67.3		
Cr	12.7		
Ab	2.4		
Kscl	6.7	3.4	Pyr is a mixture of
Se	1.2	0.1	pyrite FeS_2 and
Chl_1	2.5	1.0	pyrrhotite FeS,
Chl_2	2.9	1.2	FeS_2 = 0.8
Hyp	0.4	-	FeS = 0.5
Cpr	0.3	(0.3)	
Sph	0.1	(0.1)	
Pyr	1.3	(2.0)[1] x	
Mt	1.9		
Il	0.3		1 x Corresponding
Ap	0.1		sulphur.
	100.1	5.7	

Rock.	Cations.	H_2O
Quarts	70.8	
Orthoclase	1.2	
Sericite.	16.1	2.3
Antigorite.	4.0	1.6
Albite.	2.4	
Sphene.	0.5	
Zoisite.	0.6	0.1
Dolomite.	0.4	
Chalcopyrite	0.3	(0.3)
Sphalerite.	0.1	(0.1)
Pyrite + Pyrrhotite.	1.7	(2.0)
Magnetite.	1.9	
Apatite.	0.1	
	100.1	4.0

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The corresponding amounts of water incorporated in the ideal mineral formulae for smesite, antigorite, and sericite (muscovite) are shown in the table. It is clear that this amount is larger than that of the analysis, i.e. H_2O+ plus F.

If we were to apply some of the chemical criteria, which Mason suggests may be used to establish an originally sedimentary origin of a metamorphic rock one sees that some of his criteria, at least two, are fulfilled by the above analysis, i.e.

"$K_2O > Na_2O$ combined with $MgO > CaO$"
"a very high SiO_2 content (say greater than 80%, or more than 50% Q in the norm".) MASON 1958. The sericite-quartz-schist contained 82.4 wt % SiO_2.

Though this data may suggest a rock of sedimentary origin, which is by no means surprising in the sequence at Rävlidenfältet, it should be borne in mind that quartz porphyries have a high SiO_2 content, e.g. the quartz porphyry E of Maurliden published by SAVELIN (1939) has 79.84 wt % SiO_2. Also one of the characteristic features of the central Swedish Pre-Cambrian is a strong type of metasomatism, magnesia metasomatism, by which the feldspathic rocks such as leptites and halleflintas are altered to "quartsites" and mica schists. Minerals such as cordierite, almandine, andalusite and gerdrite are generally formed. One obtains an enrichment of Mg, Al and Fe while the alkalies are driven out of the rock. (GEIJER and MAGNUSSON 1944; MAGNUSSON 1953). Under less severe P T conditions and with sufficient water one might have chlorite forming instead of the above Mg bearing minerals (and skarn minerals in limestone rocks). Du Rietz points out that the Kristineberg region is characterised by a strong metasomatic alteration of the volcanic complex which was originally sodic. "The alteration of the whole region is characterised by a more or less complete removal of sodium and partly also of lime and an addition of potassium, magnesium, sulphur and iron." DU RIETZ 1953. Such conditions might easily account for $K_2O > Na_2O$ combined with $MgO > CaO$.

The sericite-quartz-schists are the dominant rock type of the area. They are derived from sediments and lavas which have undergone an effective low grade metamorphism which was certainly aided by the intense shearing of these rocks during the tight

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folding of the Rävlidenfaltet anticline, i.e. they were well prepared by tectonic agencies for alteration, and if necessary, influx of material. This metamorphism has effectively destroyed the primary feldspars with the formation of sericite which implies an introduction of Ok into the rocks. A recrystallization has also occurred.

IIb CHLORITE QUARTZ SCHISTS.

This group of rocks is essentially very similar to the sericite-quartz-schists. The only important difference being that chlorite dominates over sericite. We are immediately confronted with the problem as to the origin of the chlorite. As we saw before, two possibilities exist and to distinguish between these two is no easy matter.

At certain apophyseal portions of the ore, and often associated with the intrusion of chalcopyrite-rich fractions into the massive sericite-quartz-schists, one has an unquestionable introduction of chlorite into the wall rock.

Dacitic rocks may also give rise to a certain amount of chlorite when metamorphosed under conditions of fairly low grade. When chlorite is uniformly distributed throughout the rock it may be derived from the original components of the rock. Thus one can establish two extremes. There are certainly many intermediate cases and it has not been possible to obtain a quantitative idea as to the dominance of the one or the other source of the chlorite.

Quartz is developed identically with that found in the sericite-quartz-schists, i.e. a fine grained equigranular mosaic. Chlorite is developed as fibrous flakes widely distributed in the rock, the flakes showing similar orientation or two major orientations as described before. With increasing chlorite content the chlorite develops into bands (sometimes associated with sulphides, and is in such cases, most likely of metasomatic origin) and one may then have all transitions to pure chlorite schists. Table 4 illustrates the variation in chlorite content in some of these rocks.

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TABLE 4.
Mineral composition of chlorite quartz schists given in volume percent.

Specimen No.	22	105	141	147	239
Quartz.	39.7	38.4	68.2	41.6	69.1
Chlorite.	35.1	58.6	31.3	57.2	30.3
Sphene.	1.0	2.8	0.5	0.9	0.4
Biotite.	-	-	-	tr	0.1
Sericite.	1.3	tr	tr	tr	0.2
Epidote Mins.	0.5	0.1	tr	0.2	tr
Plagioclase.	21.9	-	tr	-	-
Calcite.	0.2	-	-	-	-
Sulphides.	0.3	-	-	-	0.1
Rutile.	tr	-	-	-	-
Apatite.	-	tr	-	tr	-

The chlorite is far too fine grained to permit optical determination. However, a massive chlorite schist has been analysed and here it is evident that the chlorite is a magnesian variety with an almost negligible amount of iron. See table 6.

Feldspar grains, again showing typical zoned structures, are developed as rare porphyroblasts. In one chlorite quartz schist (See table 4, No. 22) feldspar is present in unusually large amounts. This rock derives its feldspar from metasomatic processes. The composition of feldspars in the chlorite-quartz-schists is the same as for the previous rock group; from this group, however, albite has been recorded.

Sericite can occur as fine flakes sometimes. Talc is also found as a minor constituent. Biotite is a rare constituent in these rocks. The accessories are epidote group minerals, sphene, apatite, calcite, leucoxene, rutile and sulphides.

II.c BIOTITE-BEARING QUARTZ SCHISTS.

The biotite isograd is useful in metamorphic petrology, this being particularly so when comparing the same or equivalent rock types undergoing metamorphism. At Rävlidenfältet, however, there has apparently been sufficient K associated with the ore forming solutions, for the partial, and in some cases complete,

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conversion of chlorite to biotite. In the pertinent sulphide ores then the matrix of the ore can be entirely of biotite. The ore forming processes have a direct influence on the distribution of biotite, since the metamorphic grade is such as to allow its formation. This type of biotite is specially related to the ores, generally within the adjacent wall rocks and the ore itself.

In actual fact biotite-bearing quartz-schists are the previously described meta-quartzites, the main difference being the significant appearance of biotite.

Biotite may be formed as small flakes spread in the equigranular quartz mosaic. It may often be found together with sericite or chlorite. Larger xenoblastic grains, often poikoblastic, are not unusual in the mode of formation of the biotite. The biotite is a brown variety with pleochroism varying from colourless to dark brown.

The association biotite-chlorite, often along distinct bands, shows an intimate intergrowth of these two minerals. Such intergrowths are suggestive of the formation of biotite from chlorite either from the introduction of K by the ore solutions or else from reactions such as:

sericite + chlorite ⟵ biotite

K-feldspar + chlorite ⟶ biotite

Thus biotite in such rocks might not only be dependent on the ore solutions for its formation but could also be formed from the original minerals in the rock, the energy of the reaction being supplied by the ore bearing solution.

Once again two poles are possible as to the origin of the mineral, one with little exchange of elements in the rock, the other by metasomatism.

The question arises whether biotite was formed during the regional metamorphism or was only formed in conjunction with the sulphide invasion. The latter period would be the most feasible since if we look at the map of the Kristineberg region (Appendix I) it indicates that the main rocks in this area are sericite quartz schists with chlorite. In general the metamorphic grade has been too low for the complete biotite formation from chlorite and sericite. This is confirmed in the mine area by the dominance of sericite quartz schists with chlorite in varying

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amounts, and the appearance of biotite in close vicinity of the ore bodies (See also page 83).

Considering the meta-quartzites as a group they are seen to be rocks in which quartz, which is granoblastically developed and fine grained, dominates. Two dominant types can be distinguished, the sericite-quartz-schists and the chlorite-quartz-schists. Of these two types the former is by far the most important quantitatively. There is also a third group of quartzites; it is a small group and merely a variant of the previous types. The quartzites of this group are the biotite bearing quartz schists which together with the chlorite-quartz schists may be formed either by metasomatism in association with the ore forming solutions, or also as metamorphic derivants of sediments, lavas, and tuffs.

IIc CHLORITE SCHISTS.

These rocks, when typically developed, are almost monomineralic, comprised of virtually only fine grained chlorite. Macroscopically it is a dark green uniform rock sometimes containing more talc-rich schlier and bands. In general talc is subordinate to chlorite. Three purer chlorite schists have their mineral composition displayed in Table 5.

TABLE 5.
Mineral composition of chlorite schists given in volume percent.

Specimen No.	143.	208.	247
Chlorite.	96.9	94.1	93.8
Sphene.	1.9	2.2	1.5
Epidote Mins.	0.7	0.1	tr
Calcite.	0.5	tr	tr
Talc.	-	1.3	tr
Sulphides.	-	2.2	4.7

A look at the maps of the mine area (Appendices II and IV), shows that one has large areas of chlorite schists lying particularly close to the Stura ore body. The nature of these rocks is somewhat varied. Skarn (tremolite), for example, is

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often found in these rocks though in small amounts. They are made somewhat more complex by the fact that one can have all gradations from limestone, to limestones with bands, streaks and lenses of chlorite, to chlorite schists with schlier and lenses of limestone, to chlorite schists. This will be discussed more fully in conjunction with chloritisation on page 80. Quartzitic rocks can also be transformed into chlorite schists though this is generally a local feature close to the massive sulphide ores.

Microscopically the rocks are mainly of chlorite. The chlorite grains are invariably with similar optical orientation so that the whole slide extinguishes at the same time. Later s-surfaces are thus easily recognisable, and in the case of shear planes, the relative movement is discernible.

A consistent accessory is sphene. It has a habit of forming porphyroblastic grains which seldom attain good idioblastic outlines, and are often poikioblastic. Although it can occur as widely dispersed, almost uniformly distributed grains, it is also found in close association with the sulphides which have invaded the rock. In some of the larger porphyroblasts two minerals have been found together. There is a nucleus to the sphene grains in such cases, of a mineral with extreme relief and birefringence. This mineral has a brownish colour and the relief is higher than that of sphene. The mineral is possibly rutile.

The epidote group is also represented in these rocks. They occur in extremely small quantities and show certain interesting tendencies. They are found frequently together with the sulphides which have entered the rock, the time factor between the two minerals being small.

The mineral thought to belong to the epidote group, which shows excellent twinning (see page 20) is a regular, almost characteristic mineral of the chlorite schist paragenesis. It is frequently idioblastic and very commonly has a border of another epidote mineral about it (zoisite or clinozoisite). GAVELIN (1939-) describes a mineral which he considers is probably orthite, or an alteration production of orthite, which occurs in the chlorite rocks of the Bjufors ores. It too is

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surrounded by a colourless mineral displaying the properties of zoisite. This mineral is, however, not the same as that found at Rävlidenfältet. The optical characteristics do not allow orthite.

The chlorite schists intimately associated with the ores, however, i.e. the varieties that are derived from altered quartzites, and also in the chloritic matrix of the ore, contain a metamict mineral surrounded by a colourless epidote mineral border (zoisite ?) which could be an alteration production of orthite. SSARE (1957) in describing the skarn minerals of central Sweden has mentioned an orthitic mineral, which judging from the data and photographs presented, is similar to this metamict mineral.

The role of talc has been discussed before. Tremolite is found in the chlorite schists and one can have gradations to pure skarn rocks. Talc is often present in such cases. Tremolite has also been noted to be directly related to the sulphides which have entered the rock. Carbonates, quartz, and sulphides are among the accessories.

An analysis of a chlorite schist zone (6 m of borehole core) is presented in Table 6. More again it has been difficult to calculate the mode in strictly stoichiometric proportions due to a deficiency in H_2O. Extra water has thus been included into the mode so that all the magnesium has been used to form chlorite and talc. Once again one can point out that anhydrous minerals such as pyroxene and olivene are not possible in the low facies assemblage at Rävlidenfältet. Cordierite has not been found in these rocks so that it is unnecessary to form it in the mode.

With this in mind it is seen that the chlorite belongs to the antigorite - amesite group. Recent studies of these minerals show that one can consider the intermediate Mg and Al chlorites in terms of these two end members (NELSON and ROY, 1958). The composition of the chlorite as derived from the norm is then Sheridanite (after TRÖGER, 1956). However with increasing hydration talc in the mode would be converted into the antigeritic end member of the series thus lowering the Al:Mg ratio of the chlorite. This implies that it would push the chlorite composition to the clinochlore or penninite varieties.

Optical observations were unsuccessful in determining the

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composition of these chlorites due to their extremely fine grained nature. Refractive index determinations, and particularly birefringence determinations are only slightly better than guesses. (One grain lies on top of the other in the thin sections; the rocks are often monomineralic and one then has no mineral to define the thickness of the slide). These guesses have shown the chlorite to have an ameetic and clinochloritic composition.

The analysis of a chloritic rock from the Kristineberg mine is included for comparison in Tabl. 5. The essential difference between the two analyses is the higher water content of the Kristineberg sample and a higher content of alkali metals combined with a somewhat lower quarte content. The amounts $Al_2O_3 + Fe_2O_3$ and $MgO + FeO + MnO$ are essentially comparable.

Three different chlorites from different levels in the mine have been studied by X-ray methods. All of these gave identical photograms with a Debye-Scherer camera using copper radiation. One of the specimens, no. 247, was subjected to a more thorough analysis with a Guinier camera with a camera radius of 39.94 mm, using copper radiation and KCl as internal standard. This latter powder photogram was thus able to reveal the 14 Å d-value and gave more accurate values for the larger d values. The results are given in Table 7 together with values of clinochlorite according to the X-ray determination tables of Mikheev and Dubinina (1939).

The above data point towards a chlorite with negligible Fe content belonging to the series Amesite-Antigorite, with a composition of clinochlorite or close to it.

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TABLE 6.

Cation percent of a chlorite schist
B.H.642 0°.38.75 - 44.75 m.
analyst H. Olofson.

		NORM. Cation.		H_2O
Si	31.06			
Al	16.89			
Fe^{+++}	1.65			
Fe^{++}	1.38	Q	6.5	
Mg	40.99	Or	0.3	
Ca	1.21	Ab	0.3	
Mn	0.06	Chl_1	42.8	17.1
K	0.05	Chl_2	39.9	15.9
Na	tr	Ilo	4.5	0.3
Ti	0.33	Mel	0.7	
Mn	0.04	Cpr	tr	(tr)
S	tr	Sph	tr	(tr)
O	0.04	Pyr	2.1	(2.8)
C	0.0[illegible]	Il	0.7	
F	(1.25)	Mt	2.8	
Cl	tr	Ap	0.1	
H_2O^-	(0.47)		100.1	33.3
H_2O^+	(24.03)			
Cu	0.01	NORM.	Cation	H_2O
Zn	0.04	Amesite	50.1	20.0
S	(2.82)	Antigorite	16.9	6.7
Cations	100.00	Talc	23.5	3.4
	119.75	Tremolite	3.0	0.2
O.	48.06	Zoisite.	1.6	0.1
OH	1.29	Biotite.	0.4	0.1
F	2.82	Albite.	0.3	
S	171.80	Dolomite.	0.1	
Anions		Sphene.	1.0	
		Apatite.	0.1	
		Chalcopyrite.	tr	
		Sphalerite.	tr	
		Pyrite +	2.8	(2.8)
		Pyrrhotite.	99.8	30.5

	ANALYSES	
	A^1	B^2
SiO_2	35.1	30.32
Al_2O_3	17.0	17.67
Fe_2O_3	2.6	4.69
FeO	4.3	2.49
MgO	29.2	33.41
CaO	1.2	tr
Na_2O	0.03	0.40
K_2O	0.04	0.52
BaO	tr	
TiO_2	0.47	0.30
MnO	0.06	0.30
B	tr	-
P_2O_5	0.06	0.17
CO_2	0.04	-
F	0.42	0.00
Cl	tr	tr
H_2O^-	0.15	0.08
H_2O^+	7.65	11.44
Cu	0.011	0.00
Zn	0.05	0.13
S	1.6	0.94
	99.98	101.98

1. This sample.
2. Chloritic rock from Kristineberg mine. After Du Rietz 1953

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TABLE 7.

d values of 3 chlorites compared with corresponding values of clino-chlorite according to Mikheev and Dubinina.

CLINO-CHLORITE[1]		No. 10[2]		No.107[2]		No.247[2]		No.247[3]	
d	I	d	I	d	I	d	I	D	I
13,678	7							14,034	W
7,040	8	7.21	4.5	7.09	4.5	7.09	4.5	7,072	M
(5,250)	2								
4,680	9	4.74	4.5	4.74	4.5	4.74	4.5	4,724	M
								4,604	M
(3,922)	2	4.16	1	4.16	1				
		3.57	5	3.55	5				
3,509	10					3.54	5	3,543	M
(3,129)	1	3.12	1						
2,828	7	2.84	3	2.83	3	2.81	2		
(2,712)	½								
2,578	7	2.58	2	2.58	2	2.58	3	2,586	M
2,542	5	2.55	4.5	2.53	4	2.53	3	2,542	M
2,430	6	2.44	4	2.44	3.5	2.43	3	2,441	M
2,370	3	2.38	2.5	2.37	2.5	2.37	2.5	2,381	V.W.
2,247	4½	2.26	2.5	2.26	2.5	2.24	2	2,261	V.W.D.
(2,215)	½								
(2,064)	1	2.07	1	2.06	1				
2,021	7								
1,998	6	(2.00	4)	(2.00	4)	(1.99	4)	2,003	W
1,881	4	1.88	2	1 88	2				
1,825	4	1.82	2	1.82	2				
(1,731)	3			1.74	0.5				
(1,706)	3								
1,659	2			1.66	0.5				
1,562	10	1.56	3.5	1.57	3.5	1.55	2		
1,534	10	1.53	4	1.53	4	1.53	2.5	1,539	S
1,502	2	1.49	2	1.50	1.5	1.50	1	1,503	V.W.
1,460	2	1.46	1						
1,417	3								
1,390	10	1.39	3.5	1.39	3.5	1.39	2.5		
1,350	2								

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TABLE 7 (Contd)

d values of 3 chlorites compared with corresponding values of chlino-chlorite according to Mikheev and Dubinina.

CHLINO-CHLORITE[1]		No. 10[2]		No.107[2]		No.241[2]		No.247[3]	
d	I	d	I	d	I	d	I	d	I
1,319	4	1.32	2	1.32	1.9			1,322	V.W.
1,283	4	1.29	1	1.29	1				
1,251	½								
1,218	7	1,22	2						
1,191	½								
1,181	3								
1,131	4								
1,094	4								
1,040	5								
1,030	5								
1,013	3								
1,001	3								
0,987	4								

1. Values of chlino-chlorite according to Mikheev and Dubinina (1939)
2. Debye - Scherer camera.
3. Guinier camera.

2 and 3 are chlorites from Rävlidenfältet.

IIe LIMESTONES AND SKARN ROCKS.

The limestones and skarn rocks are here considered as one and the same group as they are genetically related, the latter are generally a variant derived from the former.

In the discussion on the structural geology it was seen that the limestone horizons have had a deciding influence on the sulphide ores at Rävlidenfältet. The dominating feature is the location of ore at the contact of competent and incompetent rocks and among the latter are the graphite phyllites and limestones. Nothing is known about the original composition of these limestones. Later (page 80) we shall discuss the formation of chlorite rocks from limestones, but it can already be mentioned here that it is

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not known whether Mg was an original constituent of limestone later to be fixed in the chlorite or whether some of the Mg was introduced during the main period of folding.

A. Wirstam who has logged most of the boreholes at Rävlidenfältet is of the opinion that dolomite and calcite occur in approximately equal proportions at Sturemalmen while at Rävlidmyran dolomite is presumably rare. (personal communication). Table 8 shows analyses of MgO and CaO of limestones from the Sturemalmen area. The ratio CaO:MgO has been calculated in each case on a molecular basis. The values are given in wt% and the values given in parenthesis are the molecular proportions of the four molecules CaO, MgO, CO_2, SiO_2 calculated to 100%. In virtually each case there is an excess of CaO + MgO in relation to the molecular amount of CO_2. The error in each case can be seen by comparing the molecular value of CO_2 in parenthesis with the sum CaO + MgO (which can simply be obtained by adding the two amounts given in parenthesis in the fourth column, i.e. CaO:MgO). These amounts have been arrived at after subtracting equivalent amounts of CaO and MgO to combine with SiO_2 to form tremolite.

In a few cases the molecular amount CO_2 is greater than CaO + MgO indicating yet other carbonates. In such cases SiO_2 is left as "free silica".

In spite of these small errors (one would require a complete analysis to arrive at more exact values of CaO and MgO combined with CO_2) the values should be fairly close to the true values. One can see that calcite dominates over dolomite. The ratios vary from pure dolomite (CaO : MgO = 1) to more calcite rich varieties of limestone (CaO : MgO = 2.3). The ratios are highly variable indicating poor equilibrium conditions, which is rather typical for wall rock alteration.

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TABLE II.

Approximate molecular ratio of CaO:MgO of some Sturo ore limestones

Sample No.	CaO	MgO	SiO_2	CO_2	CaO : MgO
B.H.603 0°					
39.60-41.40 m	24.8	16.7	17.6	21.8	1.6:1.0
	(26.9)	(25.2)	(17.8)	(30.1)	(22.4:14.1)
41.40-45.47 m	26.9	19.7	8.0	34.5	1.1:1.0
	(25.4)	(25.9)	(7.1)	(41.6)	(23.6:21.5)
45.47-47.65 m	22.6	16.7	22.3	21.0	1.7:1.0
	(24.2)	(24.9)	(22.3)	(28.7)	(18.6:11.0)
58.10-61.60 m	28.2	16.8	11.8	27.2	1.5:1.0
	(29.0)	(24.0)	(11.3)	(35.6)	(26.2:17.0)
B.H. 604 0°					
12.10-15.75 m	27.9	12.6	9.4	33.6	2.1:1.0
	(28.8)	(18.1)	(9.0)	(44.1)	(26.5:12.5)
15.75-19.98 m	26.4	14.4	6.1	37.0	1.3:1.0
	(26.6)	(20.2)	(5.7)[x]	(47.5)	(26.6:20.2)
19.98-24.50 m	25.1	10.7	9.8	34.7	1.7:1.0
	(26.9)	(15.9)	(9.8)[x]	(47.4)	(26.9:15.9)
24.50-28.52 m	25.2	14.5	8.2	34.3	1.3:1.0
	(26.1)	(20.8)	(7.9)	(45.2)	(25.6:19.8)
			(6.0)[x]		
28.52-33.55 m	22.7	15.1	7.9	28.7	1.3:1.0
	(25.9)	(24.0)	(8.4)	(41.7)	(23.8:18.7)
B.H. 605 0°					
1.28-5.05 m	33.1	11.2	6.4	32.7	2.3:1.0
	(34.4)	(16.2)	(6.2)	(43.3)	(32.8:14.3)
5.05-8.05 m	25.2	19.4	8.2	31.7	1.1:1.0
	(25.1)	(26.9)	(7.6)	(40.3)	(23.2:22.1)
8.05-12.07 m	24.0	19.9	12.2	29.5	1.0:1.0
	(23.8)	(27.5)	(11.3)	(37.3)	(21.0:20.4)
12.07-15.45 m	28.2	13.2	10.9	26.5	2.1:1.0
	(31.2)	(20.3)	(11.3)	(37.3)	(27.4:13.2)

[x] Approximate value of "free quartz". This is SiO_2 that will be incorporated in other silicates if they are present and will form free quartz if it cannot combine with other molecules in the absence of such.

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In the more tectonically unaffected area the limestone is still, however, sheared, but contains few bands and schlier of chlorite and talc. In the more intensely folded areas the rock is even more sheared and richer in chlorite, until chlorite dominates, and one has a massive chloritic rock with limestone fragments and schlier. Limestone and chlorite can thus be so intimately mixed that a spotted chlorite schist may result in which limestone inclusions of approximately 3 cm in size lie in a chloritic matrix. It was interesting to observe that in this latter rock, the matrix was of talc and chlorite, which was extremely fine grained, while the chlorite which lay in contact with the calcite grains had a tendency to be much coarser and often developed as a coarse grained rim around the calcite grains.

This mixing of chlorite and talc and limestone is such a common feature that one cannot help avoiding the thought that the chlorite schists were derived from the limestone.

The limestones in themselves are dominantly of carbonates which form an equigranular mosaic like texture. An elongation, though only slight, in the main or local direction of schistosity can be detected. Chlorite and talc may occur in varying amounts as discurred above.

Sphene again is present in one rock it had grown as borders around dark opaque centres in the form of small eyes. The central parts are white under reflected light and have an amorphous nature. It is thought they might be of leucoxene.

Skarn rocks are developed at both Hävlidmyran and at the Sture orebody. The skarn mineral developed is tremolite-actinolite.

One such amphibole gave the following characteristics with sodium light:

$$N = 1.613 \pm 0.001.$$
$$N = 1.626 \pm 0.001.$$
$$N = 1.637 \pm 0.001.$$

According to Tröger's tables this corresponds to a grammatite (TRÖGER 1956).

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In general, the skarn needles formed as greenish grains macroscopically, but are colourless under the microscope. One has transitions of limestones with scattered skarn needles to massive tremolitic rocks often having sulphides associated with them. The individual amphibole needles have frequently been fractured; the fractures being most commonly healed by calcite and ore minerals.

In the chlorite-limestone rocks tremolite develops in the silicate layers possibly from reactions like:

Chlorite + calcite + quartz ⟶ tremolite + CO_2.

Talc + calcite + quartz ⟶ tremolite + CO_2.

The large amount of limestone and the highly acid nature of the wall rock are particularly suitable to reaction with the formation of amphibole skarn under suitable P.T. conditions. Looking at the mine plans one sees that with this type of reaction skarn does in fact form. In general however, the metamorphic grade has been rather low in that tremolite is the only skarn mineral to form. One does not have minerals such as cummingtonite, garnet, cordierite and antnophyllite, such as have been formed at the Adak mine and which have been described by GAVELIN (1948 and 1952).

Sometimes limestones have invaded the meta-quartzites during the main period of folding. That a relocation of limestone has taken place is almost certain, and in conjunction with this, the plastic limestones have entered the massive quartzites and formed banded rocks, e.g. we do know that a tremendous thickening of limestone has occurred at the Sture ore. Banded rocks of similar nature might well have formed by a primary banding of psamitic and calcareous sediments. These banded rocks also give rise to tremolite skarn which is often so fine grained that it cannot be definitely identified.

Gavelin had recorded the presence of zoned limestone inclusions in the Sture ore and had collected a specimen of one which was given to the author. See Plate IV. The zoning of these inclusions is due to the following:

(a) differences in composition (dolomite and calcite),

(b) differences in grain size and texture,

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(c) concentration of extremely fine inclusions in the carbonates into zones which are poorly defined under the microscope, but well defined to the naked eye. These bands of inclusions conform with the general outline of the limestone inclusion but are quite independent of the grain boundaries continuing from one carbonate grain into the next. This latter phenomenon speaks well of pulsating solutions entering a cavity at different times, and being of slightly differing nature.

The cause of the zoning thus would seem to be from crustification, crystallisation proceeding inward to the centre of the inclusion. The limit of each pronounced zone has a tendency to have a fine grained border separating it from the next. These fine grained zones represent mixtures of the carbonates of the already crystallised zone and carbonates of the new zone. Re-solution and -precipitation of the already crystallised zone may explain this.

IIf. GRAPHITE PHYLLITES AND GRAPHITE BEARING ROCKS.

These rocks have their most pronounced development at Råvlidmyran where a huge wedge of graphitic rocks appears in the quartzites. In hand specimens these rocks are typically schistose often being easily cleaved along planes of schistosity. Often a primary s-surface can be observed under the microscope, as well as in the hand specimen.

The graphite phyllites reveal a fine grained rock under the microscope essentially of equigranular quartz, and flakes of sericite (or chlorite) with graphite which is scattered throughout the rock as extremely small grains, i.e. they resemble sericite quartz schists simply clouded by finely disseminated graphite. The graphite can also be concentrated along definite bands. Sulphides are typically present in varying amounts usually as fine streaks or even discontinuous broader veinlets. The sulphides are mainly of pyrrhotite and pyrite. Accessory minerals are sphene, epidote minerals, (including the twinned variety) talc, and calsite. Highly altered feldspar grains have been rarely found, and are most likely altered plagioclase grains. Another variety of feldspar has been found but is evidently related to the sulphide

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mineralisation; it is microcline.

A grain of sphene in one case was of interest in that it had grown around a (detrital?) rutile grain. See plate V. Sphene also has a tendency to have its wedge shaped grains oriented with the longer axis of the wedges parallel to the schistosity.

Another variety of graphite rock consisting mainly of chlorite and graphite is present in the Rävlidmyran area. Talc, calcite, sphene and sulphides were the main accessories found. These rocks might represent metasomatised equivalents of the type of graphite phyllite described above.

IIg. QUARTZ VEINS.

Quqrtz veins of varying types are found in the whole area. Broadly one may divide them into two main types; the barren quarts veins containing laggely quarts and, less commonly, with other silicates such as chlorite, talc, and amphodelite; the mineralised quarts veins generally with subordinate chalcopyrite and pyrrhotite, and on the 240 m level, with sphalerite, galena and terrurides, and several silicates.

The age relationships of the veins are not clearly established. Some of the barren types are pre-ore which is revealed by the fact that they have been involved in the folding, and also on the 240 m level, veins of quarts (with vugs containing quarts crystals) cut across the schistosity, and are in turn traversed by the mineralisation of the ore breccia which proceeds right across them. Some quarts veins are intimately associated with the ore and are derived from the unconsolidated fractions of the ore which were squeezed out of the main ore. These are the copper bearing veins with chalcopyrite and pyrrhotite. Finally a huge quarts vein on the 240 m level appears to be late- or post-ore in age.

The silicate bearing quarts veins are of interest in that the mineral amphodelite has been observed in some of them. This mineral has been found in veins in the hanging wall of Sturemalmen, and also in smaller veinlets near the A orebody at Rävlidmyran. It was best studied at Sturemalmen where it occurred in large amounts. Amphodelite is easily characterised

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by its red violet colour to the naked eye. Under the microscope it resembles sericite but generally has a brownish colour associated with it. It was found together with sphene, calcite, talc and of course, quartz. Sphene had obviously crystallised before the quartz; quartz has forced the sphene grains apart that formerly fitted together (See Plate VI). Veinlets of quartz and calcite are seen to cut across the amphodelite grains. The order of crystallisation is thus: Sphene, amphodelite, quartz and calcite.

GAVELIN (1942) has given a detailed discussion on the paragenesis and origin of this mineral in the Skellefte district. It is an alteration product of anorthitic plagioclase. It has been found in two differing parageneses, one with veins of quartz calcite and subordinate tremolite, the other in lime silicate rich bands in the supra-crystal rocks of the leptite series. The composition is surprisingly similar to the ideal formula of muscovite, the essential difference being a lower water content in amphodelite.

The formation of amphodelite from anorthite implies that CaO is replaced by K_2O and H_2O. This stage of alteration Gavelin has related to the closing stages of hydrothermal mineralization, which is contemporaneous with the sulphide formation in the Skellefte district. The anorthite may be a reaction skarn mineral or also derived from the sulphide bearing solutions. The colour remains an unsolved problem.

At Rävlidenfältet, amphodelite is also found in the lime silicate parageneeis. The rock as observed in this area was a meta-quartzite with quartz, calcite, tremolite and amphodelite. Sphene is an accessory. Feldspar is rare, and the variety identified on the universal stage gave an anorthite content of 70 - 80%. This rock occurred some 11 m away from the quartz vein described above. One then wonders if amphodelite has not been mobilised and enriched in these quartz veins from the adjacent wall rocks? Gavelin's examples show, however, that in many of the amphodelite specimens he has examined, amphodelite is a mineral that has often formed in situ from previous feldspar grains. The Rävlidenfältet amphodelite shows a rather arbitary distribution. The small veinlets at Ravlidmyran suggest a secretion origin for both quartz and amphodelite.

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PLATE IV.

Crustified Limestone Inclusion in the Sture Ore.



PLATE V.
X45. 1 Nicol.

Sphene Grain with an Inclusion of Rutile at the Apex of the Grain. Graphite Phyllite.



PLATE VI.
X8. 1 Nicol.

Sphene (black) and amphodelite (grey) which have crystallized earlier than quartz (light grey). Quartz veinlets often contain calcite.

The ability of quarts veins to mobilise wall rock material was also displayed in Room 3 on the 190 m level at the Sture ore-body. Here, within the ore, a quarts vein was noted to contain a dark grey to blackish carbonate. Under the microscope the carbonate was found to be normal calcite and the dark colour due to numerous exceptionally fine inclusions, presumably of graphite. Carbon in the form of graphite is found in the graphite phyllite horizone and would thus be derived from there.

The galena bearing late- or post-ore quarts vein of the 240 m level shows an interesting mineral assemblage. Quarts and cordierite dominate among the silicates. Chlorite is generally found associated with the sulphide minerals often as poorly radiating aggregates. Calcite occurs as independent grains, and also as small irregular veinlets at quartz-cordierite contacts. The quarts is often riddled with extremely fine grained inclusions, some of which are needle like. Among the ore minerals the following have been identified: galena, sphalerite, pyrrhotite, chalcopyrrite, boulangerite, altaite and hessite.

The most interesting feature of the vein is the cordierite. It shows complex twinning, the different sets of twins which are parallel to (110) and (130) as VENKATESH (1954) has described. See Plate VII. Pseudo-hexagonal outlines are often developed. The optic angle is surprising in that 2Vx is only 20 - 30°. X-Ray data does not check too well with the data published. The best check was with an artificial magnesian cordierite described by RICHARDSON and RIGBY (1949).

As a final note on veins, it is of interest to record that thin pencil like veinlets with baryte have been found on the 240 m level.

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E. WALL ROCK ALTERATION AND PETROLOGICAL FEATURES ASSOCIATED WITH THE SULPHIDE INVASION.

Features associated with the sulphide invasion are best considered under the following sub-titles:

I. Carbonatisation.
II. Chloritisation and biotisation.
III. Feldspathisation.
IV. Association of other silicates with the ore formation.

Many of these features can be studied only under the microscope whereas others have been complemented by underground observations. Those rocks where alteration can be studied best are the immediate wall rocks of the pyritic veinlets of the ore breccia. Transitions from ore to unaltered wall rock can often be observed in one and the same thin section.

A common form of wall rock alteration described from other sulphide ores is sericitisation. See GAVELIN 1939, ÖDMAN 1941 (particularly well developed at Boliden) SCHWARTZ 1955. Looking at Du Rietz' 1953 map of the Kristinaberg region it becomes evident that sericitisation is to be reckoned as a regional phenomenon rather than a local manifestation of sulphide introduction. As a result, in the discussion of wall rock alteration at Rävlidenfältet one cannot relate a zone of sericite formation to the individual ore-bodies. What one can study, however, is the alteration of the sericite quartz schists and limestones, by the ore forming solutions, which is important, as it gives an idea of the composition of the ore solutions.

I. Carbonatisation.

This type of carbonatisation is not a usual form of wall rock alteration, in that one does not have a large aureole of carbonate rocks that have developed around the sulphide ores which have metasomatised the surrounding rocks. What is meant here is a mobilisation of the limestone, largely mechanical, which has penetrated the adjacent wall rocks that were strongly sheared. On a microscopic scale, however, it has been observed that small sulphide bearing veinlets that have cut across the meta-quartzites, have had carbonates with them, and precipitated them as calcite together with the sulphides. Smaller macroscopic

/... 45 /...

Fig. 2. Scale 1 : 50.

Stura Ore. Room 4. Showing the nature of the ore and the influence of limestone on the localisation of the ore Plan of the N face of N zone of mineralisation west of the ore "centre".

1. Limestone with pyrite impregnations.
2. Pyritic ore with protrusions into the wall which locally contain quartz and calcite.
3. Sericite quartz schist with rare opalescent quart "eyes" (Altered quartz porphyry?)
4. Chalcopyrite with tremolitic skarn.
5. Irregular zone with intense tremolite formation often as radiating aggregates. Chalcopyrite is enriched here. Sphalerite and chlorite also present.
6. Pyritic ore in dominantly carbonate matrix. Chalcopyrite enriched irregularly at base.
7. Folded limestone.
8. Massive tremolite skarn rock.
9. Pyritic ore.
10. Chalcopyrite enrichment.
11. Pyritic ore in dominantly carbonate matrix with tremolite and chalcopyrite irregularly and locally enriched at margins.
12. Limestone.





Fig. 4. Not to scale.

Generalised sketch of the anticline on the 140 m level at Storemalmen. Chlorite tends to develop from the wall rock alteration of the meta-quartzites while tremolitic skarn tends to form the same alteration of the limestones.

veinlets generally with galena mineralisation and carbonates reveal the same feature.

In general then, the carbonitisation one observes at Rävlidenfältet in the wall rocks adjacent to the ores,(i.e. banded and mixed limestone and quartzitic rocks often with tremolite having developed) should not, in the author's opinion, be confused with important carbonitisation associated with mineralisation, as it is mainly a tectonic feature.

II. Chloritisation.

In the discussion of chloritisation here only the chloritisation related to the sulphide invasion will be considered. The mass of chlorite rocks at Rävlidenfältet are thought to be formed from two closely linked, but sufficiently different, processes: (1) Their formation from limestone; a process supposedly preceding the ore formation and most likely related to the metamorphism and folding of the whole area, and (2) chloritisation related to the sulphide invasion. See the genetical discussion on page 80 where this is more fully treated. The latter type has a slightly differing character to the former type in that alkali metals are usually also associated (feldspar and biotite). This form of alteration to the quartzites at least, is only of a local character and does not continue for any greater distance from the sulphide ores. In the limestones it often gives rise to a narrow border of massive tremolite skarn rock. (See Figs. 8 and 9.)

Local chloritisation of this nature is particularly noticeable in those regions where apophysal portions of the ore project into the quartzites and are generally rich in chalcopyrite and pyrrhotite. The same applies to the under side of the anticlinal part of the Stura-orebody where much of the copper rich fraction has forced its way into the acid wall rocks in the form of numerous veinlets, giving rise again to chloritisation of this rock.

The ore breccia exemplifies this principle. Here the pyritic veinlets have sharp contacts with the quartzites, while the chalcopyrite rich veinlets corrode and chloritise the quartzites resulting in more irregular contacts. This one can frequently observe in exposures of less than 1 m^2 in size in

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the ore breccia. Similar phenomena in other parts of the Skellefte district have led Gavelin to suggest that chalcopyrite and pyrrhotite rich ores give rise to the origin of altered rocks rich in iron and magnesium while the pure pyritic ores occur together with the sericite quartzites. GAVELIN 1939.

Ödman in discussing the chlorite bearing schists at the famous Boliden deposit states, "It (the chloritization) is always of a local nature and it is evident that it occurred in close relation to the mineralization" (ODMAN 1941).

Before proceeding further with chloritization, biotization should be mentioned. Often the significance of biotite is marred visually by the dominance of chlorite. Biotite is frequently associated with this type of wall rock alteration. It is particularly well developed in the massive crestal part of the Sture orebody, i.e. in the massive sulphide ore immediately above the contact of ore and quartzite in the anticlinal part of the ore. It is also frequently found in the "tail" part of this ore. Potassium has evidently been present in sufficient amounts to allow biotite to form instead of chlorite.

In its earliest stages chlorite and biotite formation are noted to occur in the quartzitic rocks along their s-surfaces. Chloritic bands are thus developed and these are invariably associated with sulphides. That the chlorite is a late metasomatic product is revealed by the way it resorbs the surrounding rock minerals, quartz, and feldspar more effectively when it is present.

Details of this alteration are seen in the ore breccia. Here the adjacent wall rocks are fairly normal looking quartzites, but they frequently contain biotite together with chlorite. In such cases sericite is probably responsible for the K contained in the biotite. (In other cases where the ore lies in a biotite matrix an influx of potassium together with MgO is required). In the more metasomatised parts of the rocks, where chlorite and biotite are enriched, feldspar is often encountered. It is poikioblastic containing about 35% An.

The ore bands of the ore breccia may show abrupt or

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transitional boundaries with the quartsites. A general feature is the coarsening of the quarts grain size. Quqrts is also formed with the ore.

The ore itself may show chlorite or biotite to dominate. These two minerals are intimately associated. Biotite has often been seen to have grown around the sulphide grains. Talc may also be present. Plagioclase is often developed with good albite twins. The composition is generally 35% An. Epidote minerals are nearly always found in these ore types and the altered wall rocks. The trends in the altered wall rocks are identical with the trends in the actual ore.

Microscopic investigation of the other chloritic ores confirm the above features found in the hard ore region. Biotite, however, is less important and frequently absent. Talc is usually present though in small amounts. Sphene and epidote are always present though only as subordinate constituents. Feldspar, calcite and tremolite have been found in these ores and their wall rock and on one occasion a Na rich scapolite was found. The assemblages are mixed and varied indicating differing environs and differing condition of formation - i.e. a poor equilibrium.

Thus this type of alteration as observed at Sturemalmen shows that the ore forming solutions have introduced varying amounts of MgO, Al_2O_3, FeO, Na_2O, K_2O and OH into the surrounding rocks. The quartsites have been altered to chlorite and biotite bearing schists while at the limestone contacts a thin border of tremolitic skarn reveals the fixation of MgO, Al_2O_3, SiO_2, and OH (these are essentially similar to the elements which are listed above, showing one and the same process). The alkali metals show a preference of being incorporated in the chloritic milieu where biotite can then be formed.

That such an alteration does not proceed far in the quartsites is not so surprising in that it requires great amounts of MgO, FeO, Al_2O_3 and OH. C. VITALIANO (1957) has made a detailed study of the wall rock alteration of the rhyolite porphyrry wall rock along a vertical fissure at the Broken Hills Range in Nevada. Here distinct zoning has produced sericite-talc-chlorite. Chemical analyses showed

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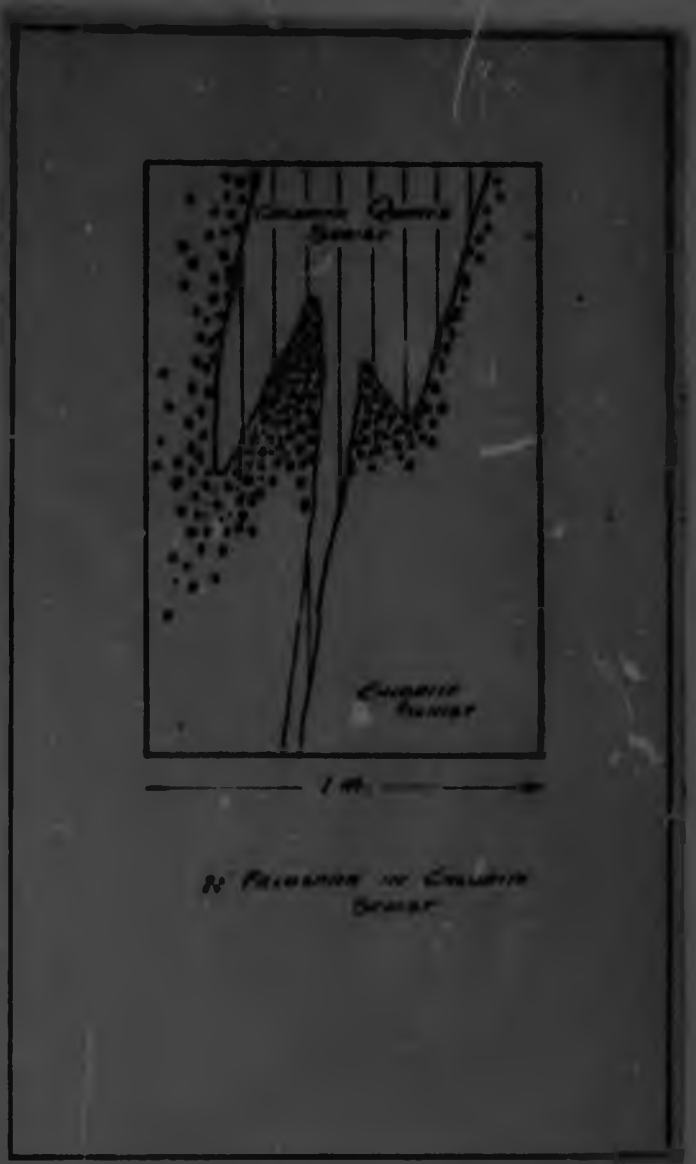

Fig. 10.

Showing localisation of feldspathisation to the boundary of competent and incompetent rock.

a progressive enrichment of MgO and a corresponding impoverishment of SiO_2, Al_2O_3, K_2O, and Na_2O. Chlorite should be the final equilibrium phase but since mixture with the other minerals were observed this was taken to indicate that equilibrium was never attained.

III. Feldspathization.

Feldspathization in the country rock is of two types and these are difficult to distinguish. During the regional metamorphism and sericite-quartz-schist formation, porphyroblastic feldspars may certainly have developed. Another stage of feldspar formation is related to the ore forming processes as well and the evidence for this follows below. This latter stage of feldspar formation is not easy to define in its distribution largely due to the fact that it is quantitatively small.

However, critical examination has revealed that feldspathization closely related with the sulphide mineralization has existed, as is clear from the association of albitic rich plagioclase often associated with the chloritization, described above. On a microscopic scale, in the adjacent wall rocks where chlorite and sulphides have entered the rock, the mineral microcline has been found. This mineral, observed as fresh grains, often surrounded by sulphides, has been identified on the universal stage.

A rather good example of the conditions governing feldspathization is provided by fig. 10. Here a quartzitic rock tapers out into the chloritic schist. Related to the shape of the original metaquartzite is a zone of feldspathic spotting in the chlorite schist. The meta-quartzite is a typical chlorite-quartz-schist made up almost entirely of granoblastic quartz and small flakes of chlorite which are evenly dispersed throughout the rock and which make up a very small fraction. Sericite and sphene are accessories.

The chlorite schist is almost entirely of fine grained chlorite flakes of similar orientation. Calcite, sphene, and epidote minerals make up the accessories. The feldspathised schist then, is merely the latter with rounded feldspar aggregates frequently showing interpenetrated types,

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thus not representing interpenetration twins in the majority of cases examined. The feldspar is highly modified being altered and replaced by sericite, talc and chlorite. Quartz is sometimes found as granoblastic aggregates. The composition of the feldspar is shown below.

The question arises as to whether the feldspathised chlorite schists is a transitional stage in the chloritisation of the sericite quartz schists: a detailed front of metasomatism? This, if so, should always be found associated with the chloritisation of the meta-quartzites, which is not a general rule or feature. Secondly, these quartzitic fragments as we see them now are tectonic manifestations rather than results of metasomatism. They represent blocks, fragments or lenses that have been mechanically forced into the chlorite schists and/or larger banks that have been drawn out.

It seems more probable thus that feldspathising solutions have entered into the chlorite rock at a site that was controlled by openings due to the relative competency of chlorite schists and the brittle quartzites. This example is described from an occurrence in the hanging wall rocks of the Sture orebody. Spotted chlorite schists of a similar nature have also been found in the A ore area. The anorthite content of these plagioclases from both these localities have given variable results with the universal stage e.g.

Based on cleavages 36 - 60% AN.

Interpenetration twins:-

Twin axis of pairs.	law.	An content.
1-2	Albite Carlsbad	35%
2-3	Carlsbad	35%
1-3	Pericline Acline	30% (slightly off)

Refractive index determinations indicate an An content of 35%.

Other microscopic features have testified to the existence of this feldspathisation. In sericite-quartz-schists feldspars have been developed along, and in the sericite bands. These are shear planes, and in detail, would be where solutions could enter the rock. They would not flow through the granoblastic quartz bands. When sulphides and chlorite appear

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together with the feldspar then a metasomatic origin of the feldspar also seems highly feasible.

Indisputable evidence of feldspathization is supplied by a quartzite lying in the anticlinal part of the Sture ore-body, where veinlets of feldspar cut diagonally across the schistosity of the rock. In this same locality one has observed the chloritization of the quartzites adjacent to the massive ore; chalcopyrite rich quartz veinlets which have been squeezed out of the ore; and now even further away from the ore - feldspar veinlets. (30% An)

Feldspar formation as a whole then is complex as we have differing origins for this mineral. What can be established is, however, that there has been a small though noticeable formation of feldspar in conjunction with sulphide formation. In general the feldspar is a zoned, often altered, plagioclase and having an average composition of 30 - 40% An. Simple albitic twinning is not uncommon. Microcline has also been observed. The limits of this process appear to be close to the altered rocks of the sulphide ores and in some cases there is strong evidence to suggest that they (the feldspars) are very late in the paragenes of the different rock types found, possibly due to a squeezing out of a residual solution from a semi-consolidated ore.

IV. Association of other Silicates with Ore Formation.

Amphiboles are often found in the ores where limestone has been present. It is generally a tremolitic variety and thus indicates that MgO, Al_2O_3, SiO_2 and OH were introduced into the rock. MgO, of course, is more uncertain, as one knows nothing of the original composition of the limestones.

Frequently the epidote group minerals have been found associated with sulphide minerals, generally together with them, as has been described in the preceeding pages on the differing rock types. In the ore breccia, and in the chloritic ores, reference has been made to the appearance of epidote minerals together with chlorite and/or biotite. A more definite relationship of this feature is given by the C ore. Here an altered remnant lying in the ore was found to consist almost entirely of zoisite - a zoisite fels in other words. Under the

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microscope the rock revealed the following constituents; zoisite, chlorite, muscovite (2V = 40°), tremolitic ekarn, calcite, a highly altered feldspar and sulphides. Zoisite and muscovite had a poikioblastic form.

Here then, is an example of a previous rock of unknown composition, changed to zoisite and muscovite by the action of the ore solutions. Zoisite, developed as such, is a skarn mineral, its mode of formation being similar to tremolite.

Sphene is found together with the sulphides in the more unaltered rocks. This association of sphene and sulphides in the differing rock types might possibly be interpreted as a physical, rather than a genetical relationship. Sphene grains are often porphyroblastic, and as they tend to form late in the paragenesis, they have often forced the other minerals away, and in so doing have formed openings which were the loci of the sulphide bearing solutions. The time relations of the accessory minerals are difficult to establish and the conclusions one draws are possibly far reaching.

Concluding the wall rock alteration and the features associated with the sulphide invasion several points can be established but their relation in time is more difficult to determine. Chloritization is pre- and para- ore in age, and very closely related to the main period of folding. The presence of biotite and feldspars indicate that a small but certain amount of alkali (K, Na) metals were also brought along with the mineralising solutions. CaO and CO_2 have been the major constituents that were removed. Unfortunately this description is only on a qualitative basis. However, for a strongly founded quantitative study the most important requirement is an area with good zoning and clear cut wall rock alteration. At Rävlidenfältet certain trends may only be brought out and left on a qualitative basis.

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B. THE ORES OF RÄVLIDMYRÄLVET.

I. ORE MINERALOGY.

In discussing the descriptive mineralogy there is very little point in giving the mineral characteristics in each of the ore bodies as this will only give rise to a repetition of data. Therefore, the mineralogy of all the ores is treated as one. The features peculiar to each ore body follow on page 65.

ARSENOPYRITE.

In general this mineral is rarely encountered. It appears to be more frequent in the Rävlidmyran ores than in the Sture ore where it is very rarely encountered. The mineral occurs as euhedral grains so that paragenetic relationships are difficult to establish. The data established shows that it is both earlier and later than pyrite. In the Sture ore, arsenopyrite was noted to contain rounded inclusions of pyrite similar to those found in the centripetal replacement of pyrite by later minerals. In the A ore remnants of a mineral which might be arsenopyrite have been found in pyrite. (These grains are so small that they do not allow a definite determination of the mineral). In the B ore, however, it was established that arsenopyrite was in fact later than pyrite and corroded it.

The other sulphides are later than arsenopyrite as is shown by the way these later sulphides fill cracks in the arsenopyrite grains, where it has been subjected to stress and fractured, e.g. the C ore. In the B ore clusters of fine grained arsenopyrite lie in a sphalerite matrix. (Plate VIII).

It can thus be established that arsenopyrite is one of the first minerals to crystallise, possibly being slightly later than pyrite.

PYRITE.

Pyrite is widely spread and occurs in all the ore-bodies, though it is of greater importance in the A ore and Sture ore. In the zinc rich B-D and C ores pyritic bands are sometimes developed, and often diffuse, being well co[illegible]ded by the sphalerite. This mineral is also one of the first to

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Fig. 11.



Fig. 12.

py = Pyrite.
gal = Galena.
cpr = Chalcopyrite.
sp = Sphalerite.
G = Gangue.

Fig. 11 x 55. Replacement of pyrite by sphalerite, chalcopyrite and galena.

Fig. 12 x 55. Caries texture of pyrite.

Fig. 13.



Fig. 14.



py = Pyrite.
cpr = Chalcopyrite.
G = Gangue.

Fig. 13 x 55.

Pyrite attacked by chalcopyrite giving rise to isolated rounded grains.

Fig. 14 x 280.

Chalcopyrite attacking pyrite, the pyrite forming characteristic rounded grains under these conditions.

form and thus is highly corroded. Its manner of occurrence is highly variable. When found virtually freefrom other ore minerals it is generally crystalline displaying cubic forms. The ore breccia of Sturemalmen provides a good example of this feature. Pyrite occurs as independent scattered grains, invariably euhedral, with a grain size which varies 0.06 x 0.07 cm^2 to 0.005 x 0.005 cm^2. Under similar conditions pyrite may occur as massive rather irregular clusters of grains, the individual grains still pertaining to their cubic habit.

When associated with other sulphides pyrite is typically corroded giving rise to irregularly shaped grains which are extremely common. Inclusions of a single sulphide mineral, or sometimes of a mixture of two or more sulphides are quite a usual feature, e.g. centripetal replacement by chalcopyrite and pyrrhotite. These inclusions are usually rounded to subrounded in shape (Figs. 11 and 12).

Typical buret bomb textures are observed, and with more intense corrosion by the later sulphides, the pyrite may quet occur as small (0.01 - 0.1 mm) rounded, isolated remnants, scattered throughout the surrounding sulphides. (Figs. 13 and 14).

Replacement in the early stages is confined to the individual grain contacts. In fractured grains the metasome is found along fractures. Where such pathways, or channelways are not so easy to locate, one can observe that the metasome forces its way along definite crystallographic directions in the pyrite grain. In the more completely altered pyrite grains all that remains is a boxlike framework. (Plate IX).

Some pyritic individuals in the A ore reveal a rather peculiar feature. These individuals have a definite zoned structure. The edges are noted to have a higher relief than the central parts of the individual. It appears also that the peripheral parts are coarser grained than the central parts. A white grained mineral with an extremely strong anisotropism has been found in both cases. The anisotropism is strong and suggests that the mineral might be arsenopyrite or else marcasite. The coarser peripheral parts show a hardness that is comparable to that of the white mineral while the finer

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PLATE VII
X45 2 Nicols.

Cordierite.
Interpenetration Twins
and fine Polysynthetic
Twins.



PLATE VIII
X200 1 Nicol.

Arsenopyrite (white)
attacked by Pyrrhotite
(light grey) and Sphalerite
(medium grey). Gangue is
dark grey.



PLATE IX
X 0 1 Nicol.

Boxlike framework of
Pyrite which has been
replaced by phalerite.



Fig. 15.

Showing zoned pyrite shapes from the A-ore.

grained zone is definitely softer. See Plate X and fig. 15 shows some of the differing shapes of the zones that have been observed in these individuals. No explanation is offered. It is suggested, however, that this feature might be related to supergene processes of some type.

Anisotropic effects, sometimes rather strong, varying from a buffish yellow colour to a bluish buff colour are frequently encountered. Recent studies by R.L. Stanton have shown that pyrite is generally anisotropic. The octahedral planes are, however, isotropic. He also showed that there was no apparent relation between the anisotropism and the temperature of deposition. It is an interesting fact that the anisotropism could be obliterated by harsh polishing methods, and also that one can render the pyrite isotropic or anisotropic by simply varying the polishing method. R.L. STANTON 1957.

GAVELIN (1939) was able to classify pyrites (broadly) according to the fact that the pyrite of the Zn ores were considerably more anisotropic than the pyrite of the copper ores. No such classification is tenable at Rävlidsnfältet.

Pyrite is one of the first minerals to form and is clearly corroded by sphalerite and chalcopyrite. Galena and the antimony sulphides are distinctly later. Pyrrhotite is approximately of the same age.

PYRRHOTITE.

This mineral is a fairly common constituent of all the ores. Its paragenetic position is fairly similar to that of pyrite though it can be seen to replace it. Plate XI. However, relations such as those displayed in Plate XI are unusual. Pyrrhotite is frequently found with a coarse grained granular texture. Sometimes the texture is similar to that of the quartzites, i.e. an equigranular mosaic. This often indicates a recrystallisation; the recrystallised parts have a grain size about one quarter that of the neighbouring grains which escaped recrystallisation.

Pyrrhotite is closely related to sphalerite. This is rather a relation of time than an enrichment of pyrrhotite in sphalerite ores. In fact pyrrhotite is quantitatively a more common associate of chalcopyrite. In all those specimens

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PLATE X.
X180 2 Nicols.

Zoned Pyrite from the A Ore with inclusions of a Mineral with extremely strong anisotroplem (3 light grey grains in the upper central part of plate)

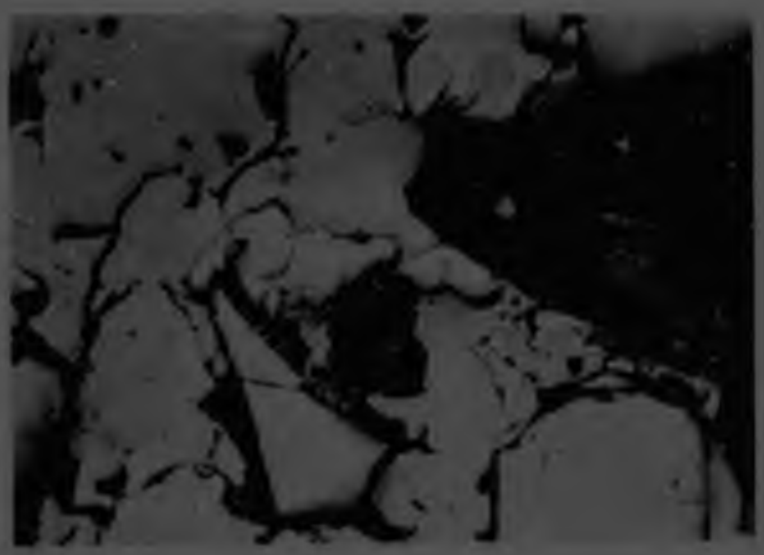

PLATE XI.
X215 1 Nicol.

Pyrite (with relief) replaced by pyrrhotite. Dark Grey is gangue.



PLATE XII.
X175 1 Nicol.

Exsolved Pyrrhotite in Sphalerite.

examined only once could it be established that sphalerite was later than pyrrhotite. The intergrowths of these two minerals are as such that they can only be regarded as mutual.

Another reason for this close relationship is genetical. At higher temperature sphalerite is able to dissolve a certain amount of pyrrhotite which is dependent on the temperature and pressure. With lowering temperature and increasing order in the sphalerite lattice a certain amount of pyrrhotite is driven out of the crystal structure because it can no longer be accommodated, and segregates as independent grains. These products of exsolution are fine elongate needles, broader staves, globules and blebs, often showing similar orientation guided by the sphalerite structure. Plate XII.

Pyrrhotite is replaced fairly effectively by chalcopyrite. With advanced replacement small wormlike bodies of pyrrhotite in chalcopyrite are all that remain.

In the larger pyrrhotite grains where pressure has acted, translation lammelae are developed. These are identical to those described by GAVELIN (1939).

Under supergene conditions pyrrhotite is the first mineral to decompose and is seen to form marcasite (See plate XIII.)

SPHALERITE.

Sphalerite is encountered in all the ores but has its most important development in the B-D and C ores. It is not a true sphalerite, and due to a certain amount of iron sulphide mixing is really a marmatite. The amount of iron in one specimen of sphalerite was 8.5 wt %. (BIZOUARD 1958). It was originally intended to use Kullerud's (KULLERUD 1953) method of iron content of sphalerite as a geological thermometer, but one variant of this method, i.e. using the unit cell lengths as a measure of the iron content proved to be unsatisfactory. (See Bizouard op.cit.)

Above we saw that pyrrhotite is exsolved from sphalerite developing characteristic forms. (Plate XI.) As regards the exsolution of chalcopyrite however no general tendency has been observed. One may observe chalcopyrite

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grains in sphalerite which show a certain alignment. Closer examination shows that if one follows the trends of these grains they sooner or later give rise to larger chalcopyrite masses and thus represent replacement action. Under high power magnification minute veinlets of chalcopyrite in sphalerite can occasionally be observed. These too could be mistaken for exsolution products. However the veinlets enlarge where they intersect each other, and secondly, little islands or fragments of the sphalerite have been found in these veinlets where they swell out.

On the 240 m level however a mineralised quartz vein (ore pegmatite) gave evidence of chalcopyrite having exsolved from sphalerite. This however, is more of a curiosity than a general feature of the whole area. SUGAKI and YUMAE (1952) were able to show experimentally that lattice shaped and globular chalcopyrite diffuse into the sphalerite lattice at a temperature of 350° C and a heating time of 10 hours. This illustrates that solid solution between these two minerals is possible, a fact that had been established by N.W. BEUGER in 1934.

It seems thus, that exsolution of chalcopyrite from sphalerite is not common at Rävlidenfältet, although it is such a well known phenomenon, often found in other parts of the Skellefte field.

Sphalerite is seen to attack pyrite more severely than does pyrrhotite. Genetically it is later than arsenopyrite, pyrite and in some cases pyrrhotite.

CHALCOPYRITE.

Chalcopyrite is one of the late minerals in the paragenesis. Chalcopyrite is later than pyrite, pyrrhotite and sphalerite, and is noted to attack the first two more effectively than does sphalerite.

This mineral reveals some interesting exsolution structures. Vallerite is nearly always found as exsolved in chalcopyrite, though in extremely small amounts. The shape of the grains is highly variable, from almost prismatic to lense shaped grains. Where these grains are concentrated one can

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Fig. 16. x 600.

Vellerite exsolved from chalcopyrite (cpr).



usually find a definite orientation and alignment of the exsolved vallerite according to crystallographic directions in the chalcopyrite. (See Fig. 16). According to EDWARDS vallerite included in chalcopyrite is converted to pyrrhotite and chalcopyrite if heated above 325°C. This temperature is the temperature at which chalcopyrrhotite becomes unstable and transforms to vallerite.

Cubanite is also exsolved from chalcopyrite in the chalcopyrite from the whole area. It generally occurs as fairly rare long laths. The Sture ore revealed much cubanite in a copper rich ore from the 240 m level. See plates XIV and XV. Chalcopyrrhotite transforms to cubanite at 235°C. EDWARDS 1954 (after BORCHERT).

Another example of exsolution in chalcopyrite is afforded by sphalerite which is exsolved in the shape of stars; the sphalerite lammelae are generally parallel to the crystal faces (100), (001) or (111) and other peculiar shapes. See plates XV and XVI. EDWARDS states that solution of sphalerite in chalcopyrite develops at higher temperature than does chalcopyrite in sphalerite, and unmixing occurs at about 550°C. Higher temperatures have also been indicated by SUGAKI and TASHIRO who found no change of similar sphalerite stars after leaving them for 24 hours at 400°C. However, at 425°C for 24 hours they began to diffuse into the chalcopyrite, and at 450°C for the same time, the change was significant. They showed also that massive sphalerite diffuses into the surrounding chalcopyrite at 530°C for 6 hours and forms a solid solution in the contact zone. When such a solid solution was annealed at 350°C and 400°C for 24 hours sphalerite was made to appear again. SUGAKI and TASHIRO 1957. It would thus seem that one is able to reduce the exsolution temperature by increasing the time at this lower temperature. There is a lower limit to this as well, however, as one cannot cause the diffusion to proceed without sufficient energy, no matter how long the time.

Polysynthetic twinning is encountered fairly often in chalcopyrite and this may be complex as is shown in Plate XVII.

In a banded sphalerite and pyrite ore an interesting feature was noted and this was that the chalcopyrite tended to

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PLATE XIII
X300 1 Nicol.

Pyrrhotite (Pyr) altering to Marcasite (whitish, high relief) which develops as slender needle like grains. Sp = Sphalerite Gal = Galena.



PLATE XIV
X200 2 Nicols.

Large Grain of Cubanite (cub) exsolved from Chalcopyrite (Cpr) G = Gangue. PY = Pyrite.



PLATE XV
X175 1 Nicol.

Poorly developed Sphalerite Stars (Blue) and a Cubanite Exsolution Lath in Chalcopyrite.

confine itself to the pyritic bands. It did attack, or permeate the sphalerite band to some degree, but microscopical investigation showed that this was only confined to the marginal zone, e.g.



Chalcopyrite invaded zone in sphalerite band.

This fact, that chalcopyrite and pyrite tend to occur together is revealed in fig. 21.

Chalcopyrite attacks pyrite more effectively than do the other sulphides. Although such vigorous replacement takes place, perfectly euhedral grains can still be found, and this is due to the strong crystallization power of pyrite.

Some unusual occurrences of chalcopyrite are also encountered - unusual in that it is closely related with galena. Copper rich ores are generally differentiated from the zinc rich ores which contain galena. This unusual association is particularly well brought out in the A ore, and is explained by the fact that chalcopyrite is a late stage reaction product associated with the galena stage of mineralisation. Tetrahedrite follows galena explicitly. A reaction between tetrahedrite and remnant pyrrhotite results in the formation of gudmundite and at the same time the chalcopyrite forms by the copper released.

These reactions in nature have given rise to complex intergrowths. Thus chalcopyrite, gudmundite, pyrrhotite, galena and a little tetrahedrite may occur together. These paragenetic relations have also been recorded from other parts of the Skellefte district, e.g. See GAVELIN 1936.

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GALENA.

Galena is one of the last minerals to form. Along with it occur several antimony and silver minerals which are very intimately associated with this stage of mineralisation.

The galena which is most free of other minerals is found in the Sture orebody, where only occasionally, does one encounter the latter suite of minerals.

Galena is intimately associated with the zinc ores. This trend is shown in fig. 21. GAVELIN has shown very clearly how this relationship holds in the Ravliden mine which occure to the south of Rävlidenfältet. This work was based on a large number of analyses and confirms some of the visual trends that had been assumed before. GAVELIN 1943. A similar recent statistical study by R.L. STANTON shows similar relations. STANTON 1958.

Galena corrodes all the previously mentioned minerals when it occurs in sufficient amount . A common site of deposition, in the complex ores, is at the pyrite grain contacts.

TETRAHEDRITE.

This mineral always tends to occur together with galena. Myrmekitic intergrowths between these two minerals are rare and have been observed only in the A ore. It would seem that such intergrowths are due to the simultaneous deposition of these two minerals . Plate XVIII. Such intergrowths have been observed in chalcopyrite, pyrrhotite, sphalerite and also in the gangue. In general, however, tetrahedrite occure as small rare grains tucked away in the corners of larger galena masses. On other occasion it occure with other sulphides in complex intergrowths as have been described above. Tetrahedrite is probably one of the chief carriers of silver, pyrargyrtite also being important as regards silver.

GUDMUNDITE.

Gudmundite is not altogether a rare mineral in these deposits though it occurs in very small amounts. It has been found in all the ore bodies although it is not so frequently encountered in the Sture ore.

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PLATE XVI
X300 1 Nicol

Exsolved Sphalerit in Chalcopyrite. Note the well developed ephalerite star on the left.



PLATE XVII
X200 2 Nicols

Twinning in Chalcopyrite.



PLATE XVIII
X150 1 Nicol

Myrmeketic Intergrowth of Tetrahedrite (darker) and Galena. Cpr = Chalcopyrite. Pyr = pyrrhotite. Sp = ephalerite.



FIG 17. FIG 18



FIG 19.

sp = sphalerite. gud = gudmundite. tet = tetrahedrite. G = gangue. pyr = pyrrhotite.

Fig. 17. x 375.

Gudmundite formed from boulangerite and an iron bearing sulphide. Note galena which has formed as a result of this reaction.

Fig. 18. x 625.

Galena later than boulangerite which it corrodes.

Fig. 19. x 175.

Same phenomena as fig. 17. In this case there is almost a perfect rim of galena around the gudmundite grain formed as a reaction product.

This mineral is also late in the ore genesis, and is again associated with the galena stage of mineralisation. A fractured grain in the C ore was seen to be earlier than galena, indicating that the galena stage on mineralisation continued after the introduction of the antimony minerals.

The mineral is characterised by its hardness, whitish colour with a pinkish tint, its strong anisotropism and its faint but distinct reflection pleochroism. It also commonly contains inclusions of pyrrhotite. (Plate XIX). Twinning has been found in a few cases only.

Gudmundite paragenesis and origin have been discussed in other ores from the Skellefte district by GAVELIN 1936 and ÖDMAN 1941. In the Rävlidenfältet ores it is also noted to develop from a reaction of the late antimony sulphides and an earlier iron rich mineral. Pyrrhotite appears to be the most favourable. Tetrahedrite is most commonly responsible for the formation of gudmundite due to its relative abundance in the antimony suite.

The author has drilled holes in pure tetrahedrite crystals and filled these with powdered pyrrhotite and then heated them in order to similate the above reaction in the solid pyrrhotite phase. Cubes of tetrahedrite and pyrrhotite were clamped together and also heated. Copper apparently moves very quickly as chalcopyritic and chalcopyrrhotitic looking minerals are obtained at relatively low temperatures and short heating times. (e.g. 1 hour at 390°C, 72 hours at 240°C). Extremely fine specks of a whitish mineral which showed strong anisotropism were formed in the chalcopyrrhotite in one case. Unfortunately the quantity of this white mineral that formed was so small that no identification, other than optical under high magnification, could be done. This might possibly be gudmundite, although to draw any conclusive results from this identification is not possible.

Time.	Temperature.	Products.
93.0 hours.	460°C ± 20°	Mineral similating cubanite + whitish material.

That not only tetrahedrite is responsible for the formation of gudmundite is revealed by figs. 17, 18 and 19.

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Hess that after the antimony has been used up in the gudmundite, a reaction rim of galena forms, the lead having been released from the altered boulangerite. Gudmundite has also formed as a reaction product of bournonite and pyrrhotite. It is of interest to note that the texture is apparently dependent on the reactants. A ramification texture is developed (with bournonite), and this has only been observed when gudmundite forms from this mineral. Plate XX. The same feature is recorded by GAVELIN 1936 and 1939. GAVELIN however, suggests that gudmundite forms from the breakdown of bournonite when it is replaced by galena. An iron bearing mineral is still required, and to differentiate in this case whether the galena is replacing the bournonite or is a reaction product caused by the breakdown of bournonite (the antimony being incorporated in gudmundite, the remaining Cu and Pb and Sb and S forming tetrahedrite and galena) is not possible.

BOULANGERITE.

Boulangerite has been found in all the ores though it is rare in the Sture orebody. It has been found in all the Råvlidmyran ores in fairly important amounts in the galena phase of mineralisation. Amounts as high as 6 volume % have been recorded in polished sections taken from the B-D ore.. That this mineral is boulangerite is certain, because it has been identified by diffraction X-ray photograms and then compared with photogram done on a standard sample from Cleveland Mine, Stevens Co., Washington. This mineral is also related to the galena phase of mineralization but was deposited before the close of the galena phase of mineralisation as galena is seen to corrode it.

BOURNONITE.

Bournonite is a rare mineral. This mineral has been observed in relatively large quantities in a polished section of a calcite vein that GAVELIN had collected from the 60 m level at Ravlidmyran and given to the author for investigation. This vein was also rich in boulangerite. It has been found on one other occasion in the zinc rich B-D ore. Here it gave rise to the gudmundite ramification texture described above.

In the calcite vein bournonite occurs intimately inter-

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Fig. 20 x 600.

Pyrargyrite (pyrarg.) veinlets cross cutting tetrahedrite (tet) and galena (gal). G = gangue.



grown with galena. Boulangerite may occur as well and can be distinguished by being softer than bournonite and having a stronger anisotropism. Tetrahedrite is likewise found with bournonite and galena. Twinning has been observed in bournonite and consisted of extremely fine polysynthetic twin lamellae. Again this mineral is associated with the galena stage of mineralisation.

PYRARGERITE.

Pyrargerite had been observed in several instances in the C orebody and also in the Sture orebody while it is less common in the B-D ores. It has not been found in the A ore. This mineral occurs in such small grains that no positive determination can be made. However since arsenic is not a common element of these ores it is probably quite safe to rule out proustite.

Pyrargerite is often observed intergrown with tetrahedrite. It is sometimes seen in more complex intergrowths, e.g. galena, tetrahedrite, pyrargyrite, chalcopyrite and pyrrhotite. Finally, it has been observed as veinlets filling minute cracks in galena, and as discontinuous veinlets in galena.

From fig. 20 it can be seen that pyrargyrite is later than both galena and tetrahedrite. This mineral along with tetrahedrite is a quantitatively small constituent but a mineral of economic importance in that it is silver bearing.

BISMUTH.

Bismuth has been found in all the ores. It has been found most frequently in the A ore. Here it occurs as separate rounded to subrounded grains in tetrahedrite-galena intergrowths. In general it appears to follow the tetrahedrite and is thus also related to the galena phase of mineralisation. It may also appear with other sulphides which are complexly intergrown, e.g. galena, tetrahedrite, chalcopyrite and gudmundite. It has also been found as minute rounded blebs in galena.

GOLD.

A grain of a bright yellow mineral with exceedingly high reflection power was encountered in a grain of galena in a specimen from the Sture ore. It was harder than galena and

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softer than sphalerite. The mineral was isotropic and is thus probably gold.

[illegible].

Occasionally, bright white, extremely small, generally rounded grains can be observed under high power magnification in galena. These grains too have a high reflecting power, are isotropic, and do not display the tarnish commonly seen in bismuth. They are so small that positive determination is not possible. They are thought to be native silver (electrum?).

DYSCRASITE.

This mineral was observed in a polished section of a calcite vein taken at the 60 m level at Rävlidmyran by Gavelin. It occurs in galena as exceptionally small grains with a pure white colour, being distinctly anisotropic.

ALTAITE.

Altaite has been identified in the galena rich quartz vein on the 240 m level. It occurs as small bright white isotropic grains which are harder than galena. It might occur together with hessite and/or boulangerite.

HESSITE.

Hessite has been observed in the same quartz vein described above. It is faintly brownish grey in colour, with a weak but observable reflection pleochroism, and is strongly anisotropic. It is softer than galena and altaite, and frequently shows twinning. It may be found together with altaite and boulangerite as described above; these minerals merely occurring next to each other rather than having been intergrown.

RUTILE.

This mineral is rarely observed but has been noted in some of the polished sections from the A ore. Its mode of occurrence was as irregularly shaped grains often with a bad polish.

MARCASITE.

Marcasite was one of the first supergene minerals to form, forming commonly from pyrrhotite. Plate XIII. It

/... 64 /...

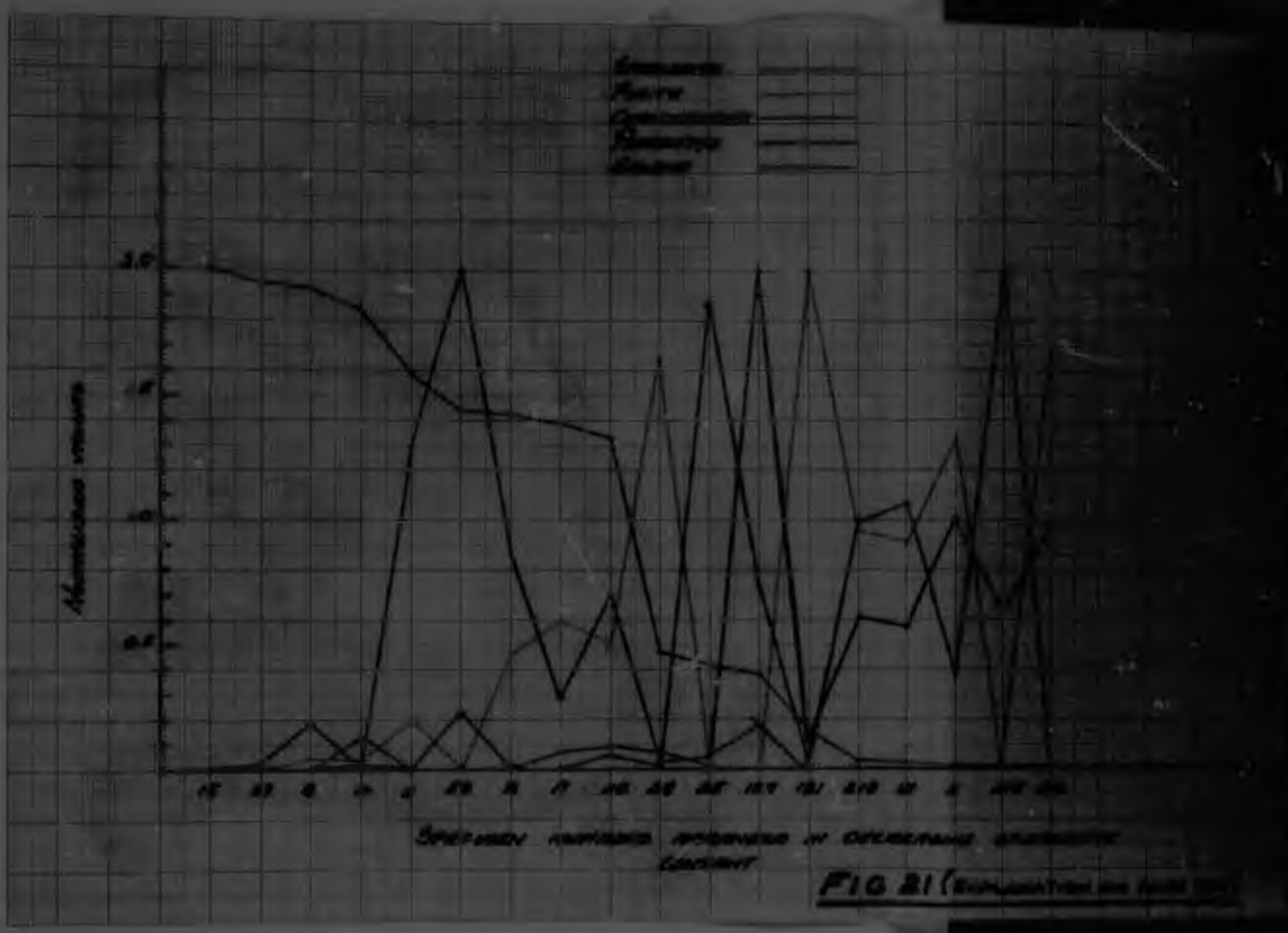

FIG 21 (EXPLANATION ON [illegible]

FIG 21

tends to occur as long elongate lenses and more irregular bodies in the pyrrhotite. An alignment of these lenses in the same direction has also been found.

CHALCOCITE:

This is a supergene mineral derived from chalcopyrite in the main. It occurs as veinlets brecciating other sulphides and frequently as shells or coatings around other sulphide grains. In the breakdown of chalcopyrite into chalcocite, goethite (or a similar Fe mineral) is frequently found in the same veinlets.

As regards the supergene minerals the above two sulphides are the only two that have been mentioned. Other supergene minerals are goethite, malachite, siderite, smithsonite and several clay minerals which have not been identified.

Fig. 21 has been constructed to see if there is any correlation between the amounts of the sulphides occurring in some differing ore specimens. As was pointed out before far better statistical data on another Skellefte district ore is to be found in Gavelin's description of Ravliden. (GAVELIN 1943).

In fig. 21 the volume percentages of the various sulphides have been recalculated to 100% sulphides. After this all the percentages for one mineral have been normalised, i.e. they have been divided by some number so that, in this case, the quotient for the highest percentage for any one mineral occurring in the different samples has the value two.

The specimens are plotted along the abscissa according to decreasing sphalerite content. Along the ordinate the normalised values are plotted. The object of using normalised values is that the curve so produced shows the variation of one mineral in one specimen to the next irrespective of the quantitative values. By plotting such values or curves for each mineral one can then compare the various curves of the different minerals considered and see if there is any correlation, i.e. if one mineral follows another.

Considering the graph then, the specimens (or ores)

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divide themselves into two types: one is sphalerite ore with minor amounts of pyrite, chalcopyrite and pyrrhotite, and a second type where these latter minerals reach maxima and sphalerite is unimportant.

Galena reaches its maximum percentage in the sphalerite ores, and is of no importance when sphalerite is a minor constituent.

In some of the zinc poor ores there is a striking correlation between pyrite and chalcopyrite.

This diagram has many weaknesses. The main weakness lies in the fact that it is compiled from so little data. It also does not bring out the correlation between chalcopyrite and pyrrhotite. However, it does serve adequately to bring out those features that one already knows from observation. The main feature is that there is a definite segregation of the ore into zinc rich types which contain the galena phase of mineralisation (which usually contains antimony sulphides and silver and also bismuth), and the pyritic ores with varying amounts chalcopyrite and pyrrhotite. Another ore type is the copper rich ore largely of chalcopyrite, pyrrhotite and varying pyrite.

II. CHARACTERISTICS OF THE INDIVIDUAL ORES.

IIa. THE STURE ORE.

The knowledge of this ore is better than that of the Råvlidmyran ores as it has been prospected and worked to a greater extent than the others.

The Sture ore is essentially a pyritic ore with a certain amount of copper and zinc. See Page 1. The precious metals won from the ore are gold and silver which are present in small amounts. Due to the varied and complex nature of the ore it is necessary to consider separately the various entities constituting the ore. For this reason the ore has been divided into the following types which are those that have been found most suitable and practical for underground mapping. A small, but nevertheless interesting group, which has been added to these ore types is the group of copper rich fractions, or segregations.

(1) Dominantly massive pyritic ores. In this group are included those pyritic ores with appreciable visible quantities

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of sphalerite mineralisation, usually developed as pyrite and sphalerite banded ... (distinguished on the mine plans) and those without or with very little zinc mineralisation. The latter often carry chalcopyrite.

(ii) Ore breccia ("hard ore" on maps). Hard ore is a direct translation of the Swedish word "hårdmalm" a layman's term originally used at Falu mine (Central Sweden) to describe chalcopyrite concentrations in meta-quartzites. This term has subsequently been adopted into mine terminology for even other types of ore in meta-quartzites and mich-schists. At the Sture ore "hard ore" refers to what is essentially an ore breccia occurring in the meta-quartzites. The ore mineralisation is largely of pyrite and lesser copyrite. See plate XXI.

(iii) Copper rich fractions: they are usually small and located at the marginal portions of the massive pyritic orebody. They may also appear as small apophysal protrusions.

1. PYRITIC ORES.

The distribution of the two different ore types is rather haphazard. The zinc bearing pyritic ore does not represent any separate independent ore which was introduced earlier or later in relation to the pyritic ore without zinc; the whole ore coincides with one ore forming period and not with different well defined periods as at Bolider in particular, and even at Kristineberg which has a late sphalerite ore phase. See ÖDMAN 1949 and DU RIETZ 1953. As a general trend, but by no means rigid, is the occurrence of more zinc ore on the southern and western regions of the Sture ore. On the 240 m level the "tail" of the ore, i.e. the eastern part develops into a fairly rich ore of copper, but unfortunately, is rather narrow (± 2% Cu and about 20% S, with zinc).

Where the ores are massively developed, they generally show a marked banding. This may be due to chlorite and talc schlier, or to pronounced sphalerite banding. In all cases the banding tends to follow the contacts of the individual lenses or follows the local schistosity. In these pyrite ores small schlier of copper rich mineralisation (chalcopyrite) are also found.

The sphalerite banding is interesting. It may vary

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PLATE XIX
X1000 1 Nicol.

Gudmundite (white) with inclusions of Pyrrhotite. Other sulphide minerals are Tetrahedrite, Chalcopyrite and Galena. Black is Gangue.



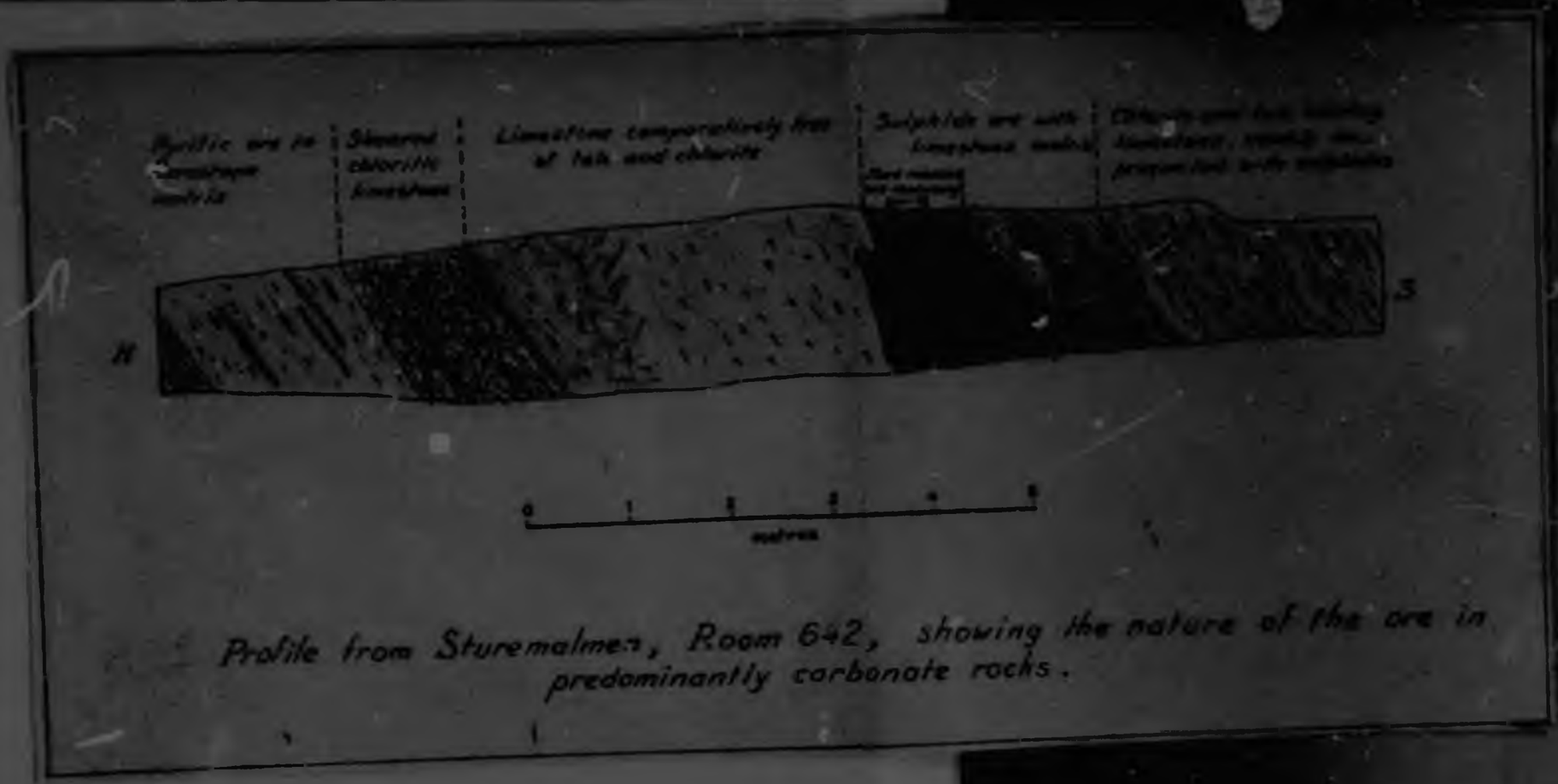
PLATE XX
X670 1 Nicol.

Ramification Texture of Galena (white) in Galena (light grey). Medium grey grains are pyrrhotite.



PLATE XXI

Ore Breccia or "Hard-ore" Mineralisation. Sturemalmen.



Profile from Sturemalmen, Room 642, showing the nature of the ore in predominantly carbonate rocks.

Fig. 22.

Section of the ore from the dominantly limestone region of the Stura ore. Due to obvious reasons in scale transfer the breccia effect is exaggerated in size on this diagram.

Yellow = dominantly pyritic ore.
Brown = sphalerite ore. Increased massiveness of this type indicated by darkening of colour.
Dark green = Chalcopyrite mineralisation.
Blue = Limestone.
Pale green = Chlorite with minor talc.

from several mms. to several cms in thickness. Where inclusions (limestone as described on page 39. Plate IX) occur these sphalerite bands wind their way smoothly around them and continue as before. The sphalerite bands and lenses may take on curious shapes (locally folded, arcuate, pinch out and swell, convex swellings etc.,) and are not continuous. See Plate XXII. In comparison to the pyritic bands the sphalerite bands appear to have been more plastic or mobile as is revealed by the above shapes. In fact this banding cannot be explained by rythmic precipitation or selective replacement.

Limestone, chlorite and talc, biotite and tremolite-actinolite skarn are found in the matrix of the ore. The skarn is relatively unimportant as compared with the other types; limestone is shown in Appendix V. The chloritic ore types in general are confined to the area where the massive ore lies in contact with quartzites. A general tendency noted in the pyritic ores is that zinc mineralisation becomes noticeable in the limestone rocks while the chloritic ores are dominantly pyritic with minor chalcopyrite and sphalerite.

Fig. 22 is a section taken through the ore to demonstrate the behaviour of the ore and the nature of the wall rocks in the dominantly limestone regions of the ore. In general the contacts with the wall rock are abrupt. However, the ore is also seen to brecciate the limestone resulting in a more transitional type of contact. This has been observed at other localities as well. Here one sees the importance of structure, in detail, as regards ore deposition. The surrounding rocks are dominantly of carbonate, but in spite of this, the ore is confined to definite zones; the ore even follows fractures in the limestone. The more massive ores have probably been localised by definite zones of more intense shearing and/or fracturing.

To illustrate the importance of limestone in localising the ore, fig. 8 serves well. Here the ores follow the limestone horizons obediently and no ore is found in the skarn rocks or the altered quartz porphyry. Here again the contacts are sharp. These contacts are, in most cases, bordered by a thin and persistent band of massive tremolitic skarn (10 - 20 cm thick) which frequently contains pyrrhotite and chalcopyrite mineralisation.

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Ore contacts may also be of a different nature to these cases above. Not infrequently does one observe veinlets of quarts with chalcopyrite and pyrrhotite which cut across the contact of the massive ore and the enveloping wall rock. These represent the unconsolidated copper rich fractions of the massive ore which have been squeesed out. A general enrichment of copper mineralization is evident at the marginal parts of the ore.

The mineralogy of the pyritic ores is rather complex. Pyrite is a major constituent in both variants of this ore. In general it is developed as fairly small grains 0.15 x 0.15 mm^2 to 0.6 x 0.6 mm^2. Larger grains up to 5 mm have been found. When the pyrite occurs in a gangue matrix it has a relatively well developed euhedral character. With the appearance of other sulphides the alteration becomes apparent, and severe, and thus reveals the usual features of occurring as small rounded grains in other sulphides, caries textures, cut by numerous veinlets of other sulphides, etc. Sphalerite and chalcopyrite give rise to the most effective corrosion of pyrite.

Arsenopyrite is an unusual constituent of these ores, being sparingly and widely scattered. The grain size is similar to pyrite but it is invariably euhedrally developed irrespective of the surrounding minerals.

The copper bearing pyritic ores have chalcopyrite as the next most important mineral. Cubanite and vallerite may be exsolved. As a rule the chalcopyrite occurs in between the pyrite grains, i.e. it has replaced the gangue. The ores are, however, made complex by the appearance of pyrrhotite, sphalerite and occasionally galena. Intricate intergrowths may thus be found.

The zinc bearing pyritic ores can be similar to the copper bearing types in that sphalerite dominates after pyrite. Chalcopyrite and pyrrhotite may be present in subordinate amounts, while galena, though making up a minor constituent, is frequently associated with sphalerite. The sphalerite invariably reveals blebs, lathe and broader staves, of exsolved pyrrhotite of the same size that are recorded in the Ravlidmyran ores.

In the banded zinc ores the sphalerite bands contain varying amounts of pyrite sometimes well corroded. The pyritic

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bands may be virtually only of pyrite and gangue. Otherwise, the banding can be due to pyrite rich bands in a more or less uniform sphalerite and gangue matrix (2 - 5 mm in size). Pure sphalerite bands with a little gangue and exsolved pyrrhotite as the only impurities are also found. The individual ore types are thus numerous.

Although galena tends to follow the sphalerite phase of mineralisation, its concentration in the zinc ores is erratic. This phase of mineralisation is important as not only is lead present, but also one has a strict association of Sb and Ag minerals.

There is a distinct difference between the galena phase of mineralization of the Sture ore and the Råvlidmyran ores. The latter are decidedly richer in antimony minerals (e.g. Tetrahedrite, boulangerite, gudmundite) which are occasionally intergrown in approximately equal amounts in the galena phase.

The important Ag mineral at Sturemalmen is Pyrargyrite. Minute intergrowths of galena, tetrahedrite, pyrargyrite, chalcopyrite bismuth occur in some galena grains. Bi also follows the galena phase rigidly. Native Ag (electrum?) is probably present in the galena as rare minute specks. Bismuth is also developed in the same manner.

ii. THE ORE BRECCIA.

The ore breccia is of a totally different character to that described above. The ore is made up of numerous sulphide veinlets, generally only several cms thick, following a definite system of fractures in the brittle meta-quartzites. The resulting ore is thus a type of breccia.

The veinlets can be noted to give the following characteristics. The pyritic veinlets have extremely sharp contacts with the meta-quartzites. The amount of alteration is negligible to the naked eye. The contacts between the sulphide veinlets and the meta-quartzites tend to be fairly straight and continuous. One also has a transition from the above type of veinlets into a wider mineralised or sulphide impregnated zones up to about 30 cm in thickness, and then into massive ores. This larger mineralised zone still has sharp contacts with the quartzites and is variable from disseminated types to

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denser types, the matrix being essentially of biotite and chlorite. This is not a case of vein filling but rather a sheared zone in the quartzites, metasomatised and replaced by the ore and the constituents of its transporting medium. The final transition is then, to massive pyritic ores which occur in a similar matrix and represent an intensification of the latter example, i.e. a larger shear zone in the meta-quartzites.

A greater part of the ore east of the ore "centre", and sections of the more massive parts of the "tail" of the ore, are of this nature. However, a distinct differentiation between this type and that localised by limestone becomes impossible at times in the massive parts of the ore. It is felt though, that the structural factor has had the greatest influence on the deposition of the ores in general at Sturemalmen. (The same applies to Rävlidmyran), i.e. zones of shear, (even in the limestones) and opening at the contact of the limestones and competent quartzite.

The copper rich veinlets of the ore breccia (chalcopyrite and pyrrhotite bearing) show a rather irregular contact with the meta-quartzites, in comparison with the pyritic veinlets. These are thus far more reactive with the wall rock which is evidenced by the local chloritization of the adjacent rocks.

The mineralogy of the ore breccia is relatively simple, consisting mainly of pyrite. In the more copper rich veinlets, chalcopyrite and pyrrhotite dominate. Pyrite may vary in size, often being coarse, several mms in size. An average size is 0.2 - 0.5 mm. The pyrite grains are euhedral when they occur alone and attacked rather severely when chalcopyrite appears. Beautiful brecciation textures of pyrite by chalcopyrite have been recorded from these ores.

Arsenopyrite has been noted in these ores but is rare. Sphalerite is generally not a common constituent of these ores. A thin continuous band of sphalerite, however, lies in the footwall side (N. side) of the "tail" of the Sture ore which in its eastern limits is essentially a pyritic ore. Close to this band thin veinlets rich in sphalerite have been observed in the ore breccia. The sphalerite attacks the pyrite and is relatively free from exsolved pyrrhotite. As a rule sphalerite

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Sample values

m.	18.5-17	17-19	19-18	18-16	16-14	14-13	13-12	12-11	11-10	10-9	9-8	8-7	7-6	6-5	5-4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Au gr/t.	trace	trace	0.8	0.1	0.3	0.6	0.2	0.1	0.2	2.1	1.3	0.2	0.3	0.2	[illegible]	[illegible]	7.1	[illegible]	[illegible]
Ag gr/t.	4	6	13	6	9	10	12	4	10	13	8	8	17	12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Cu %	0.31	0.92	2.94	1.06	1.73	1.67	2.30	0.48	1.37	1.65	0.88	0.60	2.24	1.67	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Zn %	0.05	0.10	0.38	0.22	0.27	0.31	0.44	0.8	0.55	0.20	0.13	0.24	0.51	[illegible]	[illegible]	[illegible]	0.27	[illegible]	[illegible]
Pb %	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
S %	6.9	5.8	15.8	2.3	4.7	7.6	18.2	4.6	9.8	6.4	7.8	5.7	7.1	6.2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]



Profile of ore breccia mineralization, also showing sample values, Sturemalmen, Room 14.

FIG. 23.

Narrow section of the Ore Breccia Mineralization showing the structure and the sample values.

Yellow	-	Meta-Quartzic Wallrock.
Red.	-	Pyritic Ore.
Bright Red	-	Quartz Veins.
Dark Green	-	Chalcopyritic Mineralization.

is present when the ore assumes a more massive nature. Galena has not been observed in the hard ore, though it may be present.

Pyrite cubes may also occur in the meta-quartzites adjacent to the mineralized veinlets. It is then widely disseminated.

A mine plan showing a section through the ore breccia, with analyses, which gives a fairly good idea of the metal content, and of the structural pattern, is shown in fig. 23.

Concerning the chalcopyrite mineralisation several features are worthy of mention. Sphalerite exsolution stars have been found which indicate relatively high temperature. Cubanite and valleriite are also exsolved from this mineral. In this regard one specimen from the deepest level of this mine (at the time of this investigation) 240 m level had chalcopyrite that was extremely rich in cubanite. Cubanite was so rich that it was almost developed as independent grains of approximately the same size as the chalcopyrite grains. This could indicate a higher formation temperature of the chalcopyrite in depth which would then be able to take a lot more cubanite into solid solution. Such a feature, however, can only be proved on a statistical basis.

The distribution of the hard ore can be seen best on the block diagram of the Sture ore (Appendix III). It should be remembered that the limits of this ore are assay limits rather than true geological boundaries.

iii. COPPER RICH SEGREGATIONS.

As was pointed out in the beginning these ores do not represent any real economic quantities, as in relation to the whole Sture ore they make up a very small percent. They do, however, represent a rather interesting group of ores as regards genesis.

As a rule these copper enrichments may occur as veinlets (page 68), massive segregations, or minor impregnations, always located at the margins of the main pyritic ores. They have also been found as apophysal protrusions squeezed out of the main ore. Another feature associated with these copper rich segregations is the local chloritisation of the meta-quartzites

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where they lie in contact with such. At this stage some of these features can be better illustrated with diagrams.

Fig. 8 shows some of these features well. Chalcopyrite and pyrrhotite are enriched along the marginal portions of these sulphide lenses and at the same time an intense zone of tremolite is developed.

The 140 m levelshows the same feature combined with an intense chloritisation (a quartzitic milieu) e.g. on this level, in the region west of the ore "centre" the northernmost lense has a small offshoot from the main ore which projects into sericite-quartz-schists. This apophysy is firstly rich in chalcopyrite and pyrrhotite. Secondly a local zone of chloritisation around the copper ore is obvious.

The footwall contact on the 190 m level again illustrates this feature. Here the massive ore contacts sericite-quartz-schists. A chloritic zone some 1 m wide with chalcopyrite impregnations is present. Many other examples can be cited.

The mineralogy of these ores is also illuminating. The two major minerals have been repeatedly mentioned above. Pyrrhotite is frequently corroded by chalcopyrite giving rise to small irregular bodies of pyrrhotite. Cubanite and vallerite usually accompany the chalcopyrite though in sparse amounts. Sphalerite and galena have also been found in these ores, sphalerite usually being attacked by the genetically later mineral to crystallise, chalcopyrite. The grain size of the individual minerals may vary between wide limits. Usually visibly large pure chalcopyrite grains, are contaminated by other minerals when viewed under the microscope. Pyrite and arsenopyrite may also appear in these ores.

Of interest is the sometimes unusual association of galena with these ores. It generally has its home in the sphalerite ores. Sphalerite admittedly accompanies these though in subordinate amounts. The unusual occurrence of galena in these ores is thought to lie in the explanation that it has also been squeezed out with the unconsolidated chalcopyrite. Galena is one of the last minerals to crystalise in the Sture ore paragenesis and thus would also be unconsolidated when the chalcopyrite had not yet crystallised, and thus be forced out

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with chalcopyrite. The fact that this feature is not so commonly found lies in its small concentration in the ore, and its sporadic distribution.

IIb. THE A ORE.

Data on this ore has been obtained from underground boreholes, and from the stopes that were being prepared. Considering the whole ore it can be seen that it is in fact a mineralised zone consisting of numerous smallish fairly massive sulphide lenses lying mainly in a limestone which shows varying degrees of impregnation by the sulphides. The ore is essentially a pyritic ore with a small content of copper and zinc. The zinc mineralisation in particular, appears to be highly erratic. In general the massive lenses pinch out and give way to disseminations on strike. The matrix of the ore is mainly limestone and tremolitic skarn, while chlorite and talc are also encountered. Often a chloritic border is found at the massive ore contacts, particularly when the wall rock is a quartzite.

The most interesting feature with this ore is the manner in which the massive ores are in general, located at the limestone-quartzite contacts. Quartzitic fragments and lenses often lie in the limestone, probably as a result of the folding, the limestones having been forced into a zone of tension in the Hävlidmyran anticline, by virtue of their ability to flow under stress. A look at fig. 3 shows how the massive ores lie very often just at those sites where quartzites are present, and in contact with the limestone. Openings made by the difference in competence of the two rocks have formed paths of egress for the ore forming solutions which have subsequently metasomatically replaced the limestone. The tectonic control of the ores is thus of the greatest importance as regards this ore.

The pyritic ore types consist mainly of pyrite in a gangue matrix. In virtually all the cases the ores have a more or less well developed euhedral pyrite grains in varying sizes and concentrations. A characteristic feature is that the grains tend to be independent of one another. Grain sizes vary greatly; from about 0.12 mm to several mms in diameter. An average size is of the order 0.012 x 0.012 mm^2 to 0.15 x 0.15 mm^2.

When other sulphides occur they have a tendency to lie

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in the gangue as fairly independent grains or else fill the open spaces between the pyrite grains. These sulphides are generally chalcopyrite, sphalerite, pyrrhotite and galena, the latter mineral not being frequent. Where these sulphides increase in quantity and are in excess of pyrite, the pyrite grains may be severely corroded. Pyrite then may have rounded inclusions of one or more of the genetically later sulphides, or else is traversed by small veinlets of these sulphides. With mixing of more and more of the component sulphides the ore becomes highly complex and intricately mixed.

Pyrite is often zoned in this ore type (p
Arsenopyrite is rare appearing as euhedral grains of approximately the same size as the pyrite grains.

The copper rich fractions of the ore are dominated by chalcopyrite (exsolved cubanite and vallerite often included) and pyrrhotite. Chalcopyrite grains can be relatively large, 3 - 4 mm's in diameter. Closer examination of such grains reveal that they not infrequently have inclusions of other minerals, e.g. pyrrhotite and/or sphalerite. Such inclusions may be as small as 0.005 mm to 0.02 mm in diameter. Pyrite may be present while arsenopyrite and galena are rarely observed.

Sphaleritic variants of the A ore can vary from almost pure sphalerite (with no associated pyrrhotite) plus gangue, to more complex types contaminated with other sulphides. In the latter case the most important mineral giving rise to such a dilution is pyrite. Pyrite, as usual, resists corrosion fairly effectively. Only occasionally does one find really complex associations between sphalerite and pyrite.

Other sulphides also give rise to the complexity of these sphaleritic ore types, e.g. pyrrhotite, chalcopyrite, galena and arsenopyrite. Pyrrhotite is most commonly developed as exsolved blebs and lathe and even larger aggregates. Replacement of sphalerite by chalcopyrite happens when the latter is sufficiently dominant. Galena is not of great importance quantitatively and shows preference to be formed at pyrite-sphalerite contacts.

Pyrrhotitic variants of the A ore generally have pyrrhotite and sphalerite as their main constituents. Pyrite,

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however, is sometimes intermixed. Certain amounts of galena and chalcopyrite are also included thus giving fairly complex mineral paragenesees.

As regards the whole some it is of interest to record that the galena phase of mineralisation is extremely sporadic in its distribution. Tetrahedrite and galena are often intergrown in approximately equal amounts; such intergrowths have been recorded as inclusions in both pyrrhotite and chalcopyrite which is rather unusual as the galena mineralisation is invariably related with sphalerite i.e., this association with sphalerite, which is rigid in the other ores at Rävlidenfältet, is not so important in the A ore.

Antimony minerals characterise the galena phase of mineralisation. Tetrahedrite is the most important of these. Boulangerite is present and gudmundite has also been found. Bismuth has been recorded, frequently and almost only, as extremely small grains in galena-tetrahedrite intergrowths.

Other minerals which have been recorded but which are relatively unimportant are rutile and marcasite. The latter has developed as a result of supergene processes.

IIc. THE B-D ORE.

This ore has been studied in the B-ore stops which was situated at a level of 51 m below surface. It can also be studied in the underground development tunnels on the 90 m level. A great deal of data (all the data on the D ore) has been obtained from borehole cores. Originally these two ores were considered as separate entities but due to their structural relations, as well as the fact that their mineralogy is almost the same, it is just as well to treat them here as one and the same.

The B-D ore is an exceptionally pure sphalerite ore with occasional pyrite bands which are definitely of minor importance. These pyrite bands are well mixed with sphalerite and in places one has ghost like remnants, or faint streaks, of more well developed pyrite bands in various stages of replacement. The contacts with the wall rock tend to be sharp. At these contacts veinlets of pyrrhotite, chalcopyrite and quarts havebeen observed to project into the adjacent wall rocks.

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The veinlets are, however, small and do not extend very far from the ore body. A general impression is that they are more common on the hangingwall side of the ore body, i.e. the southern side.

Inclusions of the surrounding wall rock (graphite phyllite) are to be found in the ore, and show severe signs of deformation in that they can be intricately folded (microfolded).

Mineralogically the ores consist mainly of sphalerite which in some cases is almost entirely free from impurities. More commonly one has dissolved pyrrhotite in the form of small laths and blebs which are widely and evenly dispersed throughout the sphalerite. The grain size of such pyrrhotite grains is of the order 0.008 mm x 0.15 mm to 0.03 mm x 0.4 mm. Small laths are as small as 0.002 mm x 0.04 mm. Pyrrhotite is not only confined to this mode of occurrence, but can also be found as larger grains in various stages of replacement. Pyrrhotite masses 0.36 x 0.6 mm^2 are found but even larger grains and bands have been observed.

Pyrite, which is generally enriched into bands, tends to develop euhedral grains which in general resist corrosion by the other sulphides fairly well. The mean grain size is 0.1 x 0.1 mm^2 to 1.3 mm x 1.3 mm. Arsenopyrite may also be found together with the pyrite. These two minerals can be rather intricately mixed. Arsenopyrite is nearly always found as subedral grains when occurring in minerals other than pyrite. It may be widely scattered in the ore and is noted in relatively larger grains, i.e. 0.04 mm x 0.04 mm and 0.24 mm x 0.09 mm. Arsenopyrite clusters of theeize 0.2 mm x 0.15 mm containing small individuals of the size 0.003 mm x 0.003 mm to 0.007 mm x 0.007 mm, usually in a sphalerite matrix are sometimes found in the ore.

Chalcopyrite is of minor importance as it has been observed on rare occasions only. It may occur as small rounded grains in the sphalerite, 0.072 mm x 0.048 mm to 0.18 mm x 0.07 mm in size. Chalcopyrite is also found under different conditions as was described above (veinlets). It is then the dominant mineral with inclusions of arsenopyrite (subedral), sphalerite, pyrrhotite given in increasing importance. The latter two minerals are as a rule well

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corroded. Vallerite has been exsolved from this chalcopyrite.

The most interesting feature of this ore is the galena stage of mineralisation. It appears to be fairly irregularly distributed but is consistently rich in antimony minerals. These are boulangerite, tetrahedrite (sometimes myrmekitically intergrown with galena) and gudmundite. The individual grain sizes vary greatly; from small specks several microns in diameter to grains 1 mm in diameter, and possibly larger. These minerals can occur as small independent grains in the galena or else as highly complex intergrowths with galena; all these antimony minerals can be developed together as complex aggregates in the sphalerite. Bournonite has been noted on one occasion in this ore.

Boulangerite and tetrahedrite dominate among the antimony minerals. One polished section B.H. 504 E, 40.20 m, gave as high as 6.7% by volume boulangerite. Galena constituted 1.6% and tetrahedrite 0.6%.

As regards this ore no silver minerals have been found in important quantities. Pyrargyrite has been recorded from one specimen only. Silver must lie in some other mineral since this ore is important as regards this element. Tetrahedrite can take a certain amount of Ag into its crystal structure, so that one is led to the conclusion that tetrahedrite is the important Ag mineral. A certain amount of silver may even occur in the galena, and possibly even in the boulangerite.

Bismuth is also associated with the galena stage of mineralisation in this ore. Finally, marcasite has been found as a supergene alteration product of pyrrhotite.

IId THE C ORE.

This ore has been examined on the 90 m level and from borehole cores. The mineralogy is essentially similar to the B-D ore. It is nevertheless characterised by an extremely fine grained massive nature. An inclusion of wallrock in this ore was found to be highly modified and consist virtually only of scisite and talc. The C ore is a sphalerite ore with a fairly high Ag content.

The fine grained massive nature of the ore is attributed to a crushing and recrystallisation of the ore. As

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yet it cannot be confirmed, but this "mylonitisation" probably follows an E-W direction which has been characteristic for Revlidenfaltet as a whole. Judging from the boreholes this mylonitisation is not necessarily applicable to the entire ore-body. In fact normal sphalerite ore portions are located in the boreholes. These facts will become clearer once mining of the ore-body commences.

However, a direct result of this mylonitisation is the highly complex intergrowth of the minerals. This complex ore is predominantly of sphalerite intricately mixed with galena and pyrrhotite. Grain sizes are small. Sphalerite can appear as small 0.012 mm x 0.008 mm grains in a galena matrix. Galena on the other hand can occur as small 0.004 mm x 0.004 mm to larger grains in sphalerite.

Antimony minerals are characteristic and represented by tetrahedrite and gudmundite. Gudmundite grains are of the size order 0.024 mm x 0.024 mm. Boulangerite has been observed but is uncommon in this ore.

Pyrite and arsenopyrite are found occasionally. Pyrite can be fairly small in the mylonitic ore types, e.g. 0.008 mm^2 to 0.012 mm^2. Arsenopyrite, though rare, appears as euhedral grains. It is of interest to record that elongate arsenopyrite grains are oriented with their long axes parallel to the lineation of the mylonite ore.

Pyrrhotite is invariably present and is developed as extremely small rounded blebs in both sphalerite and galena.

An important mineral of this ore is pyrargyrite. It is frequently observed though in small amounts.

In the normal types of ore, i.e. not mylonitised, sphalerite has exsolved pyrrhotite laths and staves in it. Chalcopyrite, and this applies to the whole ore, is uncommon. Gudmundite is formed together with galena, indicating a consistent enrichment of antimony. This is furthermore confirmed by the presence of tetrahedrite. Bismuth has been found associated with the galena phase of mineralisation.

Veinlets and disseminations in the ore zone have chalcopyrite and pyrrhotite in them, as well as sphalerite.

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Arsenopyrite and galena have been observed to ... minor constituents under such conditions. This (as with the B Ore) suggests an enrichment of chalcopyrite together with pyrrhotite at and outside of the massive sphalerite ore.

Table 9 has been constructed to show the mineralogical relationships of the different ores and summarises the above.

TABLE 9.

Mineral frequencies of the different Ores.

	A-Ore.	B-D Ore.	C-Ore.	Sture Ore.
Arsenopyrite.	x	x	x	.
Pyrite.	xxxx	xx	x	xxxx
Pyrrhetite.	xx	xxx	xxx	xx
Sphalerite.	xxx	xxxx	xxxx	xxx
Chalcopyrite.	xxx	x	x	xxx
Galena.	xx	xxx	xxx	xx
Tetrahedrite.	x	xx	xx	x
Gudmundite.	x	xx	xx	.
Boulangerite.	x	xx	x	.
Bournonite.		.		
Pyrargyrite.		x	xx	xx
Marcasite.	x	x	x	x
Electrum.	.	.	.	.
Bismuth.	x	x	x	x

xxxx Very common.
xxx Rather common.
xx Common.
x Uncommon.
. Rare.

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DISCUSSION.

After having described the general and detailed geology of the Rävliden field certain unanswered problems have arisen and in the following these will be discussed. In many cases no definite solution to the problems can be given because our present knowledge of certain geological processes is still insufficient.

The main problems at Rävlidenfältet are:-

(1) The influence of structure on deposition, which has been discussed in the chapter on "The Structural Geology", and where the competent-incompetent relationship of the quartsites as opposed to the limestones and graphite phyllites was shown to have a deciding influence on the location of the ores. A large drag fold pitching flatly to the W seems to be responsible for the location of the Sture ore-body.

(2) the problem of the huge mass of chloritic rocks at Sturemalmen which is apparently not related to the sulphide invasion which itself only gives rise to local chloritisation.

(3) the nature of the ore forming solution which includes a discussion of wall rock alteration and the nature of the ore itself.

The latter two problems then will be discussed under the headings of "The chlorite problem" and "The nature of the ore forming solution".

The Chlorite Problem.

Sturemalmen reveals large masses of chloritic rocks intimately associated with carbonate rocks and skarn mineralisation. The author considers that there are two major periods of chloritic formation; one during the more regional metamorphism when the large areas of sericite and chlorite quarts schists were formed in the Kristineberg region, and when the limestones at Sturemalmen were transformed into chlorite rocks of essentially the greenschist facies; and a second period of chlorite formation closely related with the sulphide invasion, frequently with biotite, indicating higher facies conditions and, of course, the introduction of K.

The first question one might ask is: Why are the

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chlorite schists not related to the sulphide ores? The symmetry of the chlorite rocks in relation to the ore-body does not bespeak a direct special relationship. We also have evidence of the existence of chlorite rocks prior to the ore formation as is illustrated by skarn veinlets with sulphides having formed in the chlorite schists, the ore presumably having been introduced together with a certain amount of $CaCO_3$. Feldspathisation intimately associated with the ore forming processes, has been observed in chlorite schists that must have existed before the introduction of the sulphides. (Page 48).

From other ore bodies in the Skellefte district we learn that the ores generally only give rise to local chloritisation of the wall rocks, e.g. the chloritic rocks displayed in the map published by DU RIETZ (1953) of the Kristinaberg mine shows that these rocks are found only adjacent to, and in, the sulphide ores, illustrating thus local chloritisation. The zone of massive chloritic rocks at Kristineberg, is by no means comparable to the large area of chlorite schists at Rävlidenfältet. See also page 46 .

It seems most likely then, that the chloritic rocks at Sturemalmen are not all related to the sulphide invasion. The theme followed in this paper is that they were derived fr m the alteration of limestones shown by the frequent and common association of the limestones.

However, we have to consider an alternative explanation, namely, what were the possibilities of having had fairly basis rocks, e.g. basic lavas and tuffs in the succession which would then have given rise to the large areas of chlorite schist. No such evidence is attainable at Rävlidenfältet to suggest this, while there is evidence to suggest their formation from limestone (page 38). No definite data can be arrived at in the literature on the regional geology concerning the presence of basis effusives in the Kristineberg region. In the Vindelsgransele - Kristineberg region the Skellefte Volcanic series is dominated by acid or intermediate effusives, GAVELIN 1955. Also at Vindelsgransele which lies about 8 km to the west of Rävlidenfältet, there has been a strong development of talc at certain localities. E. of Vindelsgransele there has been the

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development of much serpentine. These two latter types are, however, confined to the phyllite series, GAVELIN 1955. DU RIETZ' map of the Kristineberg region gives no indication of basic effusives (See Appendix I). The hornblende dacites from Hornberget are the most basic types described by the latter author, and these would require large amounts of magnesia for the formation of a chlorite schist. According to Du Rietz these rocks are strongly chloritised and contain 7.38 wt% and 4.22 wt% MgO!

The chlorite schists then are of particular interest at Rävlidenfältet, and appear to have formed in conjunction with the main period of folding and preceded the ore solutions.

As regards a more detailed knowledge of their formation nothing can be said with certainty as there are no expasures available in this area to study the more unaltered nature of the limestones. Were they rich in dolomite so that magnesia metasomatism played very little part? DU RIETZ (1953) speaks of a removal of Na and Ca and an addition of K, Mg, S and Fe for the Kristineberg region in general. See page 25.

The alteration of dolomite or dolomitic limestone to chlorite schist (i.e. if it contained MgO in sufficient quantities) would imply a removal of Ca and CO_2 and an introduction of H_2O, Al, Si and Fe. Some of the Ca might be fixed in the new existing carbonate rocks. Where these latter elements came from cannot be said with certainty. A certain amount of them could quite assuredly have occurred in the primary stratigraphic column if the limestones were of a hetrogeneous nature. Mg would be incorporated in the chlorite while the Ca would be enriched in the carbonate phase, the main exchange of the system thus being essentially the lose of Co_2 balanced by an introduction of H_2O which would be added during the main period of folding. The analyses of the limestones in the Sture ore which are shown in table 8 are not reliable in discussing the possibility of the enrichment of Ca in the carbonate phase, as these have been greatly influenced by the sulphide invasion which results in the introduction of elements into the wall rocks. The entire process could thus proceed without large scale metasomatism.

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It is unlikely that magnesia metasomatism associated with the formation of the Revsund granites in the S of the Kr'etineberg region would be effective as far N as Sturemalmen (See Appendix I). Cordierite is found in the quartzite zoning around the Revsund granite mass and this occurrence is some 2 km S of Sturemalmen.

It would seem to be more likely that the large amounts of Mg required for the relatively vast amounts of chlorite schist occurring locally at Sturemalmen were derived from an indigenous source and were not introduced. We do not have examples of large scale magnesia metasomatism at this or corresponding distances from the Revsund granite mass.

Another question which arises is whether the chlorite as it is observed now was formed directly from this process of limestone (dolomite)transformation, or, whether it was formed from some previous skarn mineral (e.g. amphiboles, indicating a higher metamorphic grade) by the hydrothermal alteration caused by the introduction of the sulphides?

Returning to DU RIETZ' map of the Kretineberg region again one sees that Rävlidenfältet lies in rock types characterised as "Sericite quartz schists often with chlorite" which would indicate rocks of the greenschist facies, i.e. the reaction:

sericite + chlorite ⟶ biotite

has not yet started. Biotitic rocks do in fact occur in a zone related to the Revsund granite some 2 to 3 km south of Sturemalmen. These rocks are labelled as "cordierite biotite sericite quartz schists" and the biotite isograd probably lies in the N of this zone.

The formation of chlorite in preference to amphiboles would thus be more suitable for Sturemalmen.

Superimposed on this stage of chloritisation is a later phase related to the ore deposition which complicates the genesis. The characteristics of this type are discussed above, (page 45). The time difference between these two processes is probably small, the introduction of the ores following closely after the regional metamorphism.

It is realised that these views are strictly hypo-

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thetical due to the impossibility of obtaining concise evidence to prove of disprove them (e.g. the original composition of the carbonate rocks).

However, a deal of deduced information obtained from other parts of the Skellefte field and the observations at Kvlidenfältet do point towards two separate but closely related periods of chloritisation. The mechanism of the actual process is more uncertain and only one possibility is given here though others may exist.

The Nature of the Ore Forming Solution.

Sturemalmen provides the best area for a discussion of the nature of the ore forming solution, but the other ores will also be mentioned in this regard.

The first point is the fact that the Sture and A ores are dominantly replacement ores in a carbonate milieu, while the B-D and C-ores are dominantly displacement ores as defined by Gavelin. GAVELIN 1939.

What this has meant is that the B-D and C-ores have been intruded under high pressure and have forced the walls of their initial openings apart and came to rest. The contacts of the ore and the wall rocks are sharp, and wall rock fragments are also found in the ore, i.e. the observed character of the ores is similar to that displayed by intrusive igneous rocks. The general intrusive character of these ores suggests that they were intruded in rather a concentrated state.

The Sture ore on the other hand, is highly complex in its nature. Undoubtedly the chemical nature of the limestones, has led to its formation, but, even here, we find that the structural element has been a dominant feature in its emplacement.

An example of this is the "tail" of the ore which is located at the limestone quartsite contact. In this same region ore solutions have also forced their way along fissures and fractures in the quartsites to give the ore breccia on the S side of the "tail", while immediately to the N of this limestones exist. Even in certain regions of the limestones themselves, the ore has been seen to brecciate the rock.

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Thus one might state that structure, even in detail, has a dominant influence, and therefore that displacement was also initially a main feature but due to the reactive nature of the carbonate rocks, replacement has subsequently become dominant.

The same applies to the A ore, where the structural factor can still be established. Fig. 3.

As we have seen before, the ore has been introduced along definite shear zones at Sturemalmen (see Fig. 22). The drag fold itself must have led to a great deal of shearing and left many openings for the development of the massive parts of the ore.

It is not surprising then that highly modified remnants of the adjacent wall rocks (or rocks of a shear zone) are represented by chlorite, biotite, talc or tremolite rich bands (streaks, lenses, schlier) in the ore. Banding thus caused by original shear zone slivers, and lenses, have sometimes been folded and moved together with the ore before complete crystallization, and locally take on textures similating flow structures in igneous rocks. The whole mass was then in a semiconsolidated state.

That such movement has taken place can be confirmed by a pyrite ore breccia found W of the ore "centre". Plate XXIII. Recrystallised sphalerite ore from the same region also suggests movement of an ore which has crystallised in part. Whether this movement is a major tectonic phenomenon associated with the region, or whether it is caused by the inherent pressure of the ore bearing solutions as they moved into their site of deposition remains unsolved.

Sphalerite banding is often developed in the ores as explained before. Such banding cannot be due to rythmic precipitation filling veins or openings.

The banding of these ores is irregular. They are irregular in their distribution; they are discontinuous, locally independent lenses schlier and enrichments of sphalerite. Such irregularity can hardly be accounted for by rythmic precipitation.

Folded structures in such banded ore types (e.g. Plate XXII) and which have also been observed in stopes close to the

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PLATE XXII

Locally folded Pyritic Ore
Bands in Massive Sture Ore.

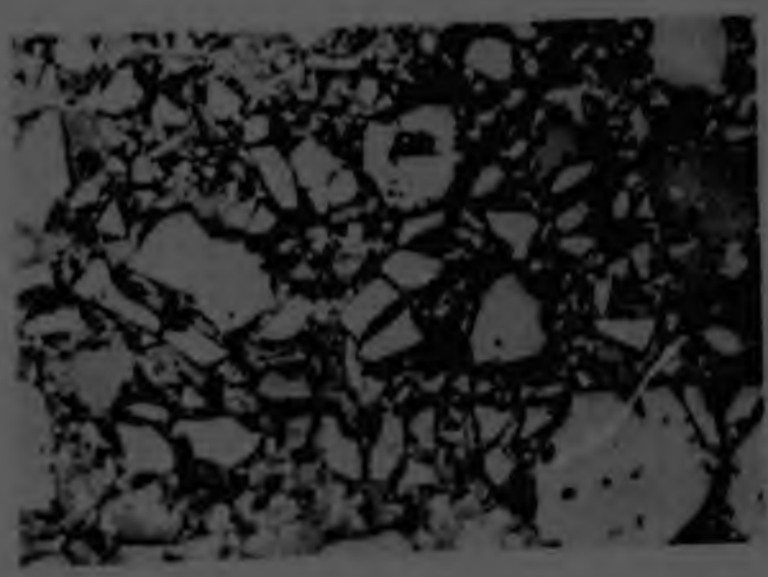

PLATE XXIII
1 Nicol. X45

Pyrite Ore Breccia. Pyrite
White High Relief.

some where movement after part of the ore had crystallised has been established (see above) could also be explained by pressure acting on a semi-consolidated mass or a mass which has crystallised to a greater part.

The question whether the sphalerite ore bands are due to a selective replacement or due to a segregation of the sphalerite and galena phase from a larger dominantly pyritic sulphide ore solution remains open.

The author feels, however, that these sphalerite and galena rich bands might be formed from a segregation mechanism. On a more regional basis, and as a more or less established trend for the Skellefte area, is a tendency of the sulphides to divide themselves into Zn ores with Pb, Sb, Ag poor in Cu, and on the other side Cu rich ores poor in the previous list of elements. The pyritic ores contain both Zn or Cu mineralisation. This has been proved by statistical analyses in the Rävliden Mine (See GAVELIN 1943) and the same trends also established in the Malånäs district, GAVELIN 1939. The mechanism is not known but the segregation established.

One asks then why should not this feature which operates on a large scale (e.g. the I-D and C ores are surely representative good examples of a segregated sphalerite ores from a previous ore source) also operate on a detailed scale in a pyritic ore, the Zn phase and Pb phase segregating into bands? Such a segregation might account for banding described on page 58

With these ores one is not able to think in the ideal way of fairly dilute solutions bringing first a pyrite stage of mineralisation followed by a sphalerite stage, a chalcopyrite stage and a galena stage.

These ores were introduced as a complex ore of all the different sulphides almost at once as is evidenced by the irregular and erratic distribution of the different sulphides when one considers the changes in mineralogy over a section of the ore.

It should be realised in this respect that the chalcopyrite rich ores at the ore margins at Sturemalmen are not a result of this major segregation of ore types but is a result of the order of crystallisation of the ores.

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The normal order is:- Pyrite (and arsenopyrite) —▶ pyrrhotite —▶ sphalerite —▶ chalcopyrite —▶ galena.

This crystallisation order can hardly explain the association sphalerite - galena, when considering a mechanism of the segregation into Zn and Cu rich ores. It does however explain the enrichment of chalcopyrite at the ore margins which has been found together with galena (page 72), the cause of the enrichments thus being a type of filter press action on a semi-crystallised ore. The fact that sphalerite and pyrrhotite can also occur in these enrichments is that there is an overlap in the duration of crystallisation of each of the sulphides.

As yet, however, we know too little about the nature of sulphide bearing solutions, or other feasible means of transporting the elements of sulphide ores, and how and why the ore precipitated as sulphides, always has a definite almost universal order of crystallisation. Laboratory information will certainly help to solve many of these problems. Until, then, these unsolved problems will have to be left open to discussion. However, it seems unlikely that a universal hypothesis or theory will be found for hydrothermal sulphide ores. Each district has its own characteristics and due respect must be given to each ore type and paragenesis.

A further indication in the understanding of the Ravlidenfaltet ores is given by the study of wall rock alteration and a study of the matrix of the ore itself. A definite order of crystallisation of the sulphides can be established and coincident with this is the formation of silicates. The sulphides apart from pyrite are extremely late in their time of crystallisation. This can be seen in the microscopic study of the ores where the sulphides brecciate the previous silicate grains, e.g. quartz and feldspar in the ores themselves, and in general occupy positions filling the interstices of the silicate grains. The order of crystallisation of the phyllosilicates in relation to the sulphides is hard to establish but they appear to be contemporaneous, and in some cases (biotite and chlorite) even later than the sulphides.

It was outlined in a previous section (page 44) that the following features could be associated with the sulphide

/... 83 /...

invasion:-

Carbonitisation: apparently of no greater importance (As is impossible to establish the significance of this in a limestone milieu,) but certainly some low temperature sulphide veinlets e.g. Zn, Pb, Sb, Ag are found in close association with carbonates.

Chloritisation and biotitisation: of great importance.

Other minerals: Tremolitic skarn is frequently formed in limestone rocks.

Epidote minerals have formed by the same processes but are quantitatively of minor importance. Other minerals that have been identified in the ores and wall rocks on rare occasions of tourmalins, flourits, and apatite which indicate the presence of B, F and P which are related to these processes.

At Sturemalmen a general idea of the distribution of these differing alterations has been established and as a general rule one may say that where the ore occurs in a quartsitic milieu chlorite and biotite are generally developed. Feldspar and epidote minerals are also formed. These minerals occur in the wall rocks and the process becomes intensified in the ore.

This feature is illustrated by the occurrence of biotite and chlorite in the "hard ore" regions, this becomes intensified in the tail of the ore and the underside of the antiolinal parts of the ore.

Where the ore contacts limestone tremolitic skarn may be developed although talc and chlorite have also been found.

The significance of these features is that an introduction of Mg, Fe, H_2O, Al and K has occurred in the quartsites while Si Al H_2O have been introduced into the carbonate rocks.

The two features seem to balance each other; a desilification of thequartsites occurs when the quartsites are chloritised and biotised. Silica must, however, be added to the limestones for tremolite formation. Mg for the chlorite could thus also partly be derived from the limestones themselves which are replaced by the sulphides and skarn minerals. Fe of course is

/... Mg /...

derived from the ore (pyrite in abundance) while K also seems to be inherent to the ore judging by the vast amounts of biotitic and chloritic ores in the "hard ore", antiolinal and "tail" reaches of the ore.

Al likewise found both in the chloritic alteration products and in the tremolite group, is an enrichment compared with sericite quarts schist and limestones respectively. The same applies to H_2O.

By such reasoning it can be seen that some of the elements of the ore solution can be derived locally and need not necessarily be characteristic of the solution. Local readjustments can account for some of the elements found in these associations.

Concerning the whole ore which is characteristically a replacement ore, something has to be pushed out to allow for the sulphides, and in the main this would be CaO, CO_2, and MgO. Mg apparently remains a long time in solution as is evidenced by the common association of chlorite with the late stage chalcopyrite mineralization which is squeesed out from a partly crystallised ore. CaO and CO_2 would thus appear to be the main elements driven off.

It is realised that these points lack any quantitative backing, but the general disposition of the ore and wall rock suggest the above trends. Also, our present knowledge of ore bearing solutions is so small that it would be to no avail to suggest any uncertain hypotheses on the ore forming solution and this would only confuse geological thought.

It is interesting to record that biotite and tremolitic rocks are stable under conditions of the ore deposition. This implies a higher metamorphic grade than the surrounding serioits quarts schists (which frequently contain chlorite) and which were formed in conjunction with the Revsund granite. The sulphide ores are thus slightly later than the regional metamorphism which closes with the formation of the Revsund granite, and therefore there is good reason to relate these ores to the emplacement of these late or post orogenic granites.

/... 90 /...

ACKNOWLEDGEMENTS.

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APPENDICES I - V.

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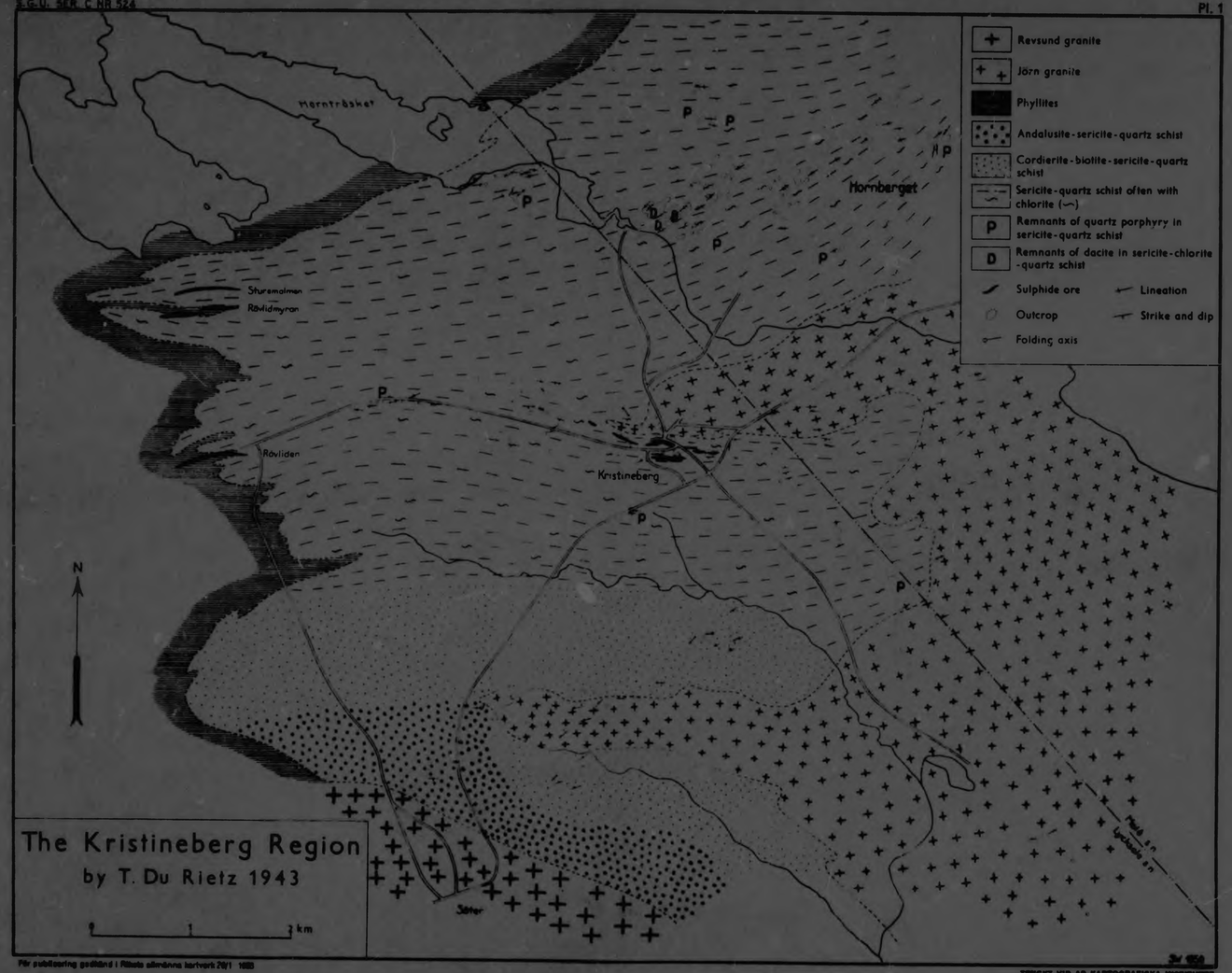

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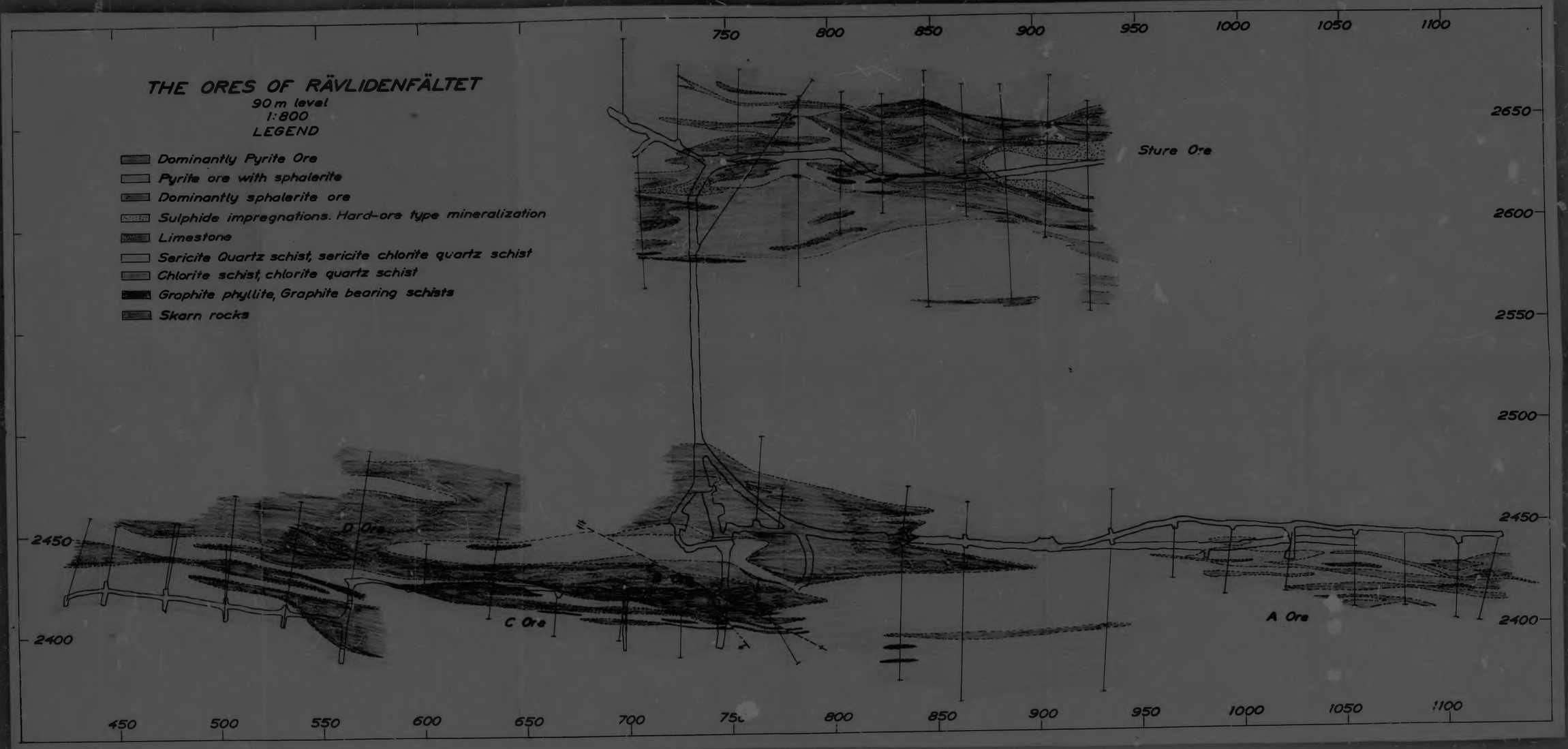
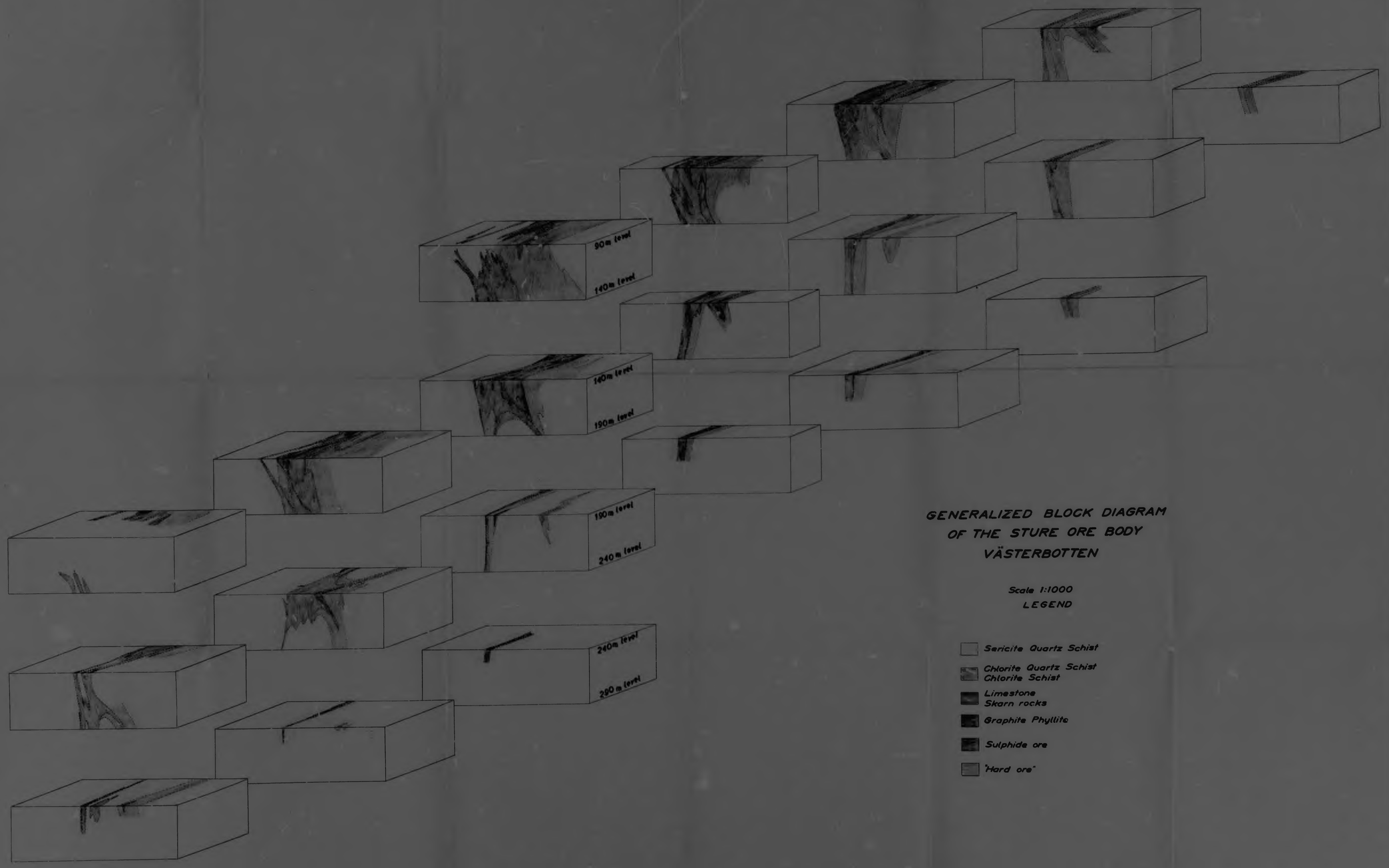
THE ORES OF RÄVLIDENFÄLTET

90 m level
1:800

LEGEND

- Dominantly Pyrite Ore
- Pyrite ore with sphalerite
- Dominantly sphalerite ore
- Sulphide impregnations. Hard-ore type mineralization
- Limestone
- Sericite Quartz schist, sericite chlorite quartz schist
- Chlorite schist, chlorite quartz schist
- Graphite phyllite, Graphite bearing schists
- Skarn rocks



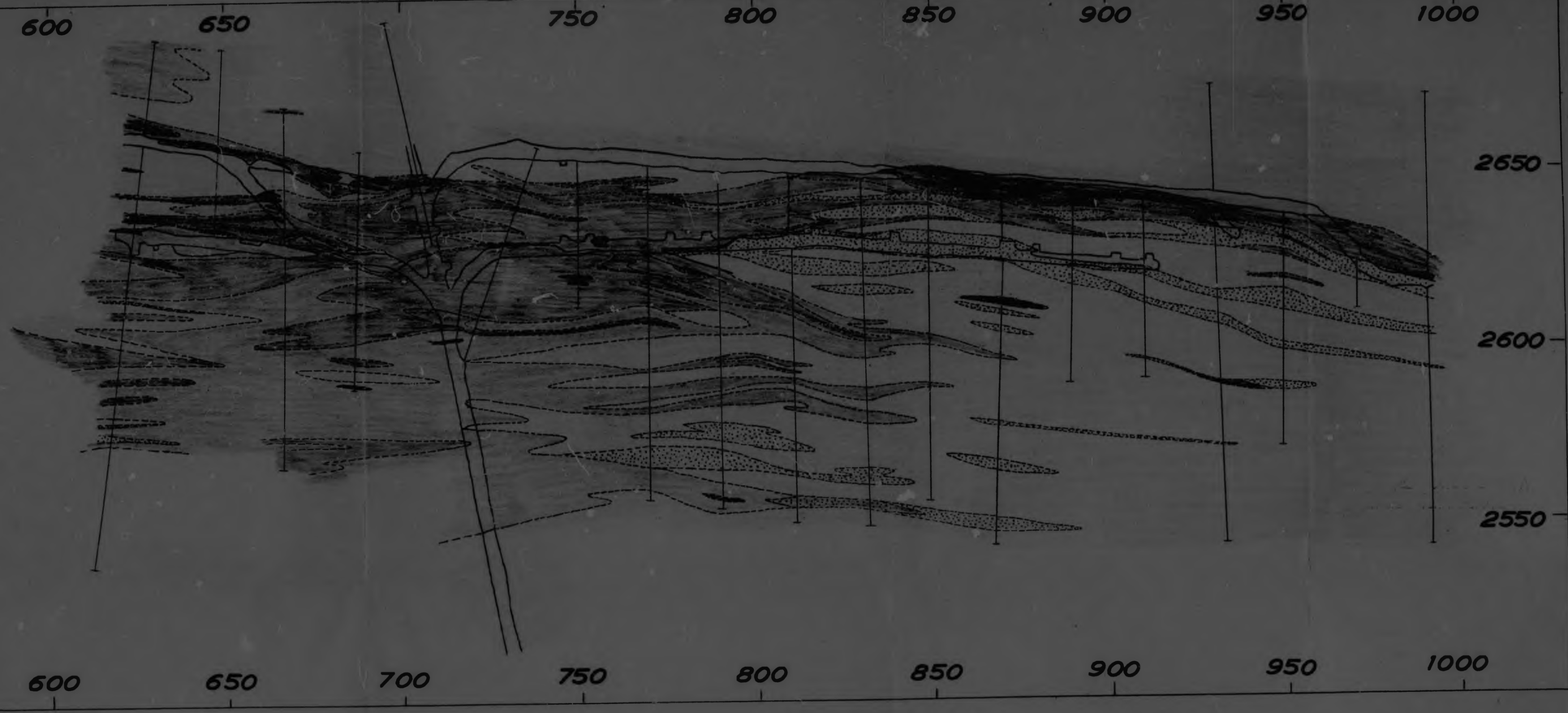


GENERALIZED BLOCK DIAGRAM OF THE STURE ORE BODY VÄSTERBOTTEN

Scale 1:1000

LEGEND

- Sericite Quartz Schist
- Chlorite Quartz Schist
  Chlorite Schist
- Limestone
  Skarn rocks
- Graphite Phyllite
- Sulphide ore
- "Hard ore"



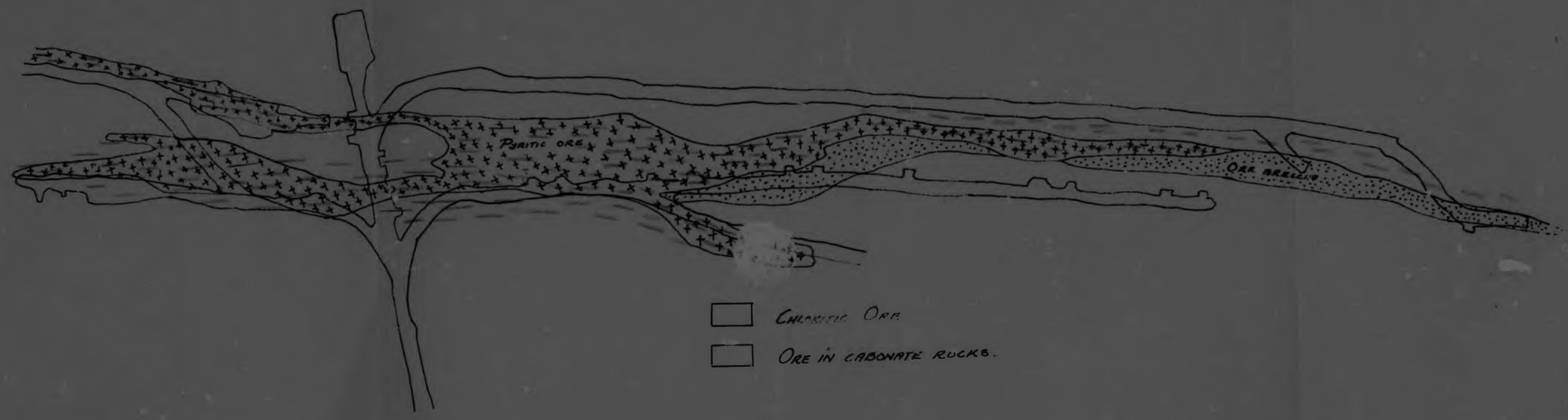
STURE ORE BODY

140 m level

1:800

LEGEND

- Dominantly Pyrite ore
- Pyrite Ore with sphalerite
- Sulphide impregnations. Hard ore type mineralization
- Limestone
- Sericite Quartz schist , sericite chlorite quartz schist
- Chlorite schist, chlorite quartz schist
- Graphite phyllite, Graphite bearing schists
- Skarn rocks



CHLORITIC ORE

ORE IN CARBONATE ROCKS.

140 M LEVEL SCALE 1:800

SHOWING THE GENERAL DISTRIBUTION OF THE CHLORITIC AND LIMESTONE ORE TYPES AT STUREMALMEN

Author Roering C
Name of thesis The Geology and the ores of Ravlidenfaltet, Vasterbotten Sweden 1959

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