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The Geology and the Oree of Rävlidenfältet, Västerbotten Sweden

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

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

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Thesis

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The eres described are the Sture and the A-, B-D, and C- eres of dividegram. The Sture and A eres are replacement eres constring in a limestone milicu, and are pyritic eres with Sp. Os and Fb. with minor "D. Ag and Au.

The 3-D and C ares are massive sphalerite rich displacement ores with Pb. Sb and Ag in the main.

The surrounding rocks are quarts schiets )with serieits, oblorite and biotite) limestones, and graphite phyllites. The wall rocks show the effects of obloritization and biotitization, feldspathization, and possibly carbonatization, the last only or 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.

Chloritio rocks at Sturemalmen are formed from lirestones by regional metamorphic processes associated with the period of folding closing with the formation of the Revsund granitus. The different quarts 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 Rävlidenfältet antioline, the plastic limestones and graphite phyllites having flowed into a sone of weakness in the axial plane, and the ores occurring at competent-incompetent rook contacte. The Sture ore has been localized by a drag fold in a limestone horison. A large shear sone through this drag fold apparently also accounts for the structure of the ore.

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# He. 1.

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

- 1. Rävlidsyran Sturesalsen ares.
- 2. Rävliden.
- 3. Mörkliden.
- 4. Eristineberg.

#### A. INTRODUCTION.

# This work discusses the orebodies of REvlidenfEltet.

Révildenfâltet liee in the well known Skellefte district of Northern Sweden and refere to the ores containing the ores of: (1) F-vremalmen (the Sture ore), (2) Râvlidnyran, called the A-, B-, C- and D- oree and (3) the Râvliden ore. Râvliden itself is no longer worked so that only the Sture and Râvlidnyran 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.	Tops.	An Elte	Mr. R. S.	212	2nd	<b>E</b>	SE
1953	16,151	1.5	54	1.15	3.81	0.62	22.3
1054	62 024	1.4	26	1.42	2.04	0.26	21.1
1374	111 870	1.0	33	1.47	2.31	0.28	22.0
1977	111,079	2.0	22	1.40	2.37	0.28	23.2
1950	171, 315	0.9	24	1.48	3.61	0.27	24.4
1957	184,771	0.9					
	546,140	1.0	33	1.43	2.47	0.28	23.0

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

H H H

The information and data for this description wore 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 Messre. 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

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These of most consequence are Du Riets's work on the regional aspects of the Kristineberg district, (DG RIETZ, 1953), and Gevelin's references to the area in his description of the Pre-Cembrian in the Västerbotten county. (GAVELIN and EULLING 1.955). Short reference has also been made by Gavelin as Efvlidayran in discussing the relationships of one deposition and structure in the Skellefte district (GAVELIN 1942). Of Mare greater importance have been several reports by Prof. Gevelin for the Boliden company which contair much unpublished data and which were very kindly passed on to this anthor for use.

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#### B. GEOLOGICAL SETTING.

- 3 -

In order to understand the local geology it is, as with most geological problems, essential to consider the gs. sral aspects of the regional geology. REvidenfältet merely constitutes a minor locality in a large metallogenic province, manely the sulphide mimeralisation province of the Skillefte district. Thus a brief summary of the regional geology, and particularly of the Szellefte district will follow.

In Sweden the Pre-Combrian division into three different orogenic cycles is accepted by most geologists. They are, beginning with the oldest: the Sylonian or Sveccofennian cycle, the Gothian cycle, and the Karelian cycle. Following these eycles is a series of unfolded rocks, plutonis, volcanie and sedimentary, which are referred to as sub-Jetnian and Jotzing. (GEIJER, MAGNUSSON 1944, MAGNUSSON, GRANLUND, LUNDOVIST 1957).

Gevelin (1955) assumes the rooks of the Västerbotten ecunty to be equivalent to those formed during Sveccofennian. Karelian, sub-Jetnian and Jotnian times. The following chronological table of the Pre-Cambrian of Västerbotten is eited 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 eruptivee.

Adak granite series. Sersele granite series.

K K K K K

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Karelian granites and gabbros (Sulphide ore formation in the N.W. part of Vasterbotten e.g. Adak, Linsköld.)

Targfors series. Sediments of varying types from conglomerate to shale. Intercalated basie volcanies.

Karalian s. dimente and voloanios.

#### HIATINS.

Revenued granite geries, Late or Later phase of folding with post eregenic Sveceefennian thrust faulting and palingengranites and gabbros.

esis. Sulphide ore formation. (Boliden, O. Hoghulla etc.)

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# and the Jorn graging.

The second second second A differentiated series granite-gabbre. Aplite and greensters dykes. Early erogenic granites and gabbres. Dominantly gentle folding. Weak sulphide invasion with the possibility of ore having consentrated.

The Arvidejmyr series. A differentiated volcanic series. Liparitie, kerntophyric, dacitie, andeeitic and basaltic lavas with subordinate tuffs.

The Phyllic series A th. sk endimentary series in general of fine grained sodiments containing graphite. Sandy, groywooks and conglomeratic codiments aloo developed. Intercalated basic effuelyce.

The Bralleffe volognite series, A differentiated suite of liperitio, haratophyric, daoitie, andeeltie and basaltic lavas and tuffe. Intercalated sediments. Dominant vulcanian in the Arvidejaur district; dominant sediment formation within the Skellefte district.

Vulcanism within the Skellefte district.

The above elassification is hot accepted by Lautsky whe has suggested certain medifications. (KAUTSKY 1957). Kautsky contenas that the Vargfors formation is younger than the Revound granite, and it should, in its lower parts, underlie the Phyllite series. Furthermore, the same author is of the opinion that the Mask granite is contemporaneous with the Revound 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 investign on oan throw no light on the above controversy. Both the above sathors agree to the fact that the min period of sulphide mineralisation in the Skeliefte district conurred in conjunction with the formation of the Revound gramite

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

Quaternary deposite 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 unite. Thus from other areas the following facts may be learnt (GAVELIN, GRIP 1946; GRIP 1946; GAVELIN 1955).

The key to the early Sveccofennian rooks 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 methode, e.g. electrical and magnetic methode. Graphite phyllitee are taken as the boundary separating the Skellefte volcanic series from the Phyllite series.

The Skellefte volcanic corprise meta-liparitie, meta-keratophyric, meta-andesitic and meta-baseltic lavas and tuffs. (Stratigraphically from the bottom to the top). Differences exist at different localities but at the Vindelagranecle-Kristineberg area (in which Rävlidenfältet is eituated) the series is dominantly moid or intermediate. In contradistinction to some other areasein the Skellefte district, the volcanic rocks of the Vindelegransele-Eristineberg area have their emphasis on potassium instead of sodium (GAVELIM 1955).

Sedimente 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.

Ŧ

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

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extent true elay eedimente. Sedimente eimilar to the graphite phyllites. but without carbon, aleo occur. Transitions to felsysthic sandetonce, arkease and greywackee are recorded. Conglemerates are likewise coccasionally encountered. True quartsites are rare, and in general the sediments show a poor degree of differentiation. They are, according to GAV_LIM (1955) a typical example of Pettijohne "greywacke series".

Finally the work of Da RIETE (1953) on the Kristineberg region has a direct bearing on the more local geology of REvlidenfältet. Appendix I shows the location of the Sture and Rävlidmyran ores in relation to the general geology. Outcrope are notably lacking. The geology consists in the main of a modific volcanic complex, originally of sodic quarts porphyry and albite porphyry (a sodic rhoylite with albite phencorysts). Decitic 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 volcanice, or was intruded simultaneously with the folding. Iscolinal folding with fold ares pitching towards the west dominate. The thickness of the volcanic series is estimated at somewhat less than 2 km.

These are cohiets differing in nature to the cericite quarts-schiets, which appear in the couthern part of the region. These contain much biotite, cordierite or andalusite in relation to the cericite quarte cohiete. Chlorite tende to be abcent or of minor importance. This alteration is associated with the formation of the Revsund granite, and a distinct metamorphic soning in relation to this granite has been cetablished.

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## <u>Pig. 2.</u>

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

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## C. THE STRUCTURAL GEOLOGY.

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#### 1. AUNTRAL ASPECTS.

The structural goology finds its main interpretation in the goophysical 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 ap' Fig. 1 illustrate the broad structural trends. Here it can be seen that the Rhvlidnyran and Sture ores are located in the antiolinal part of the Skellefte Volcanic series, very elose to the contact of the overlying Phyllite series. The whole of the volcanic series is in the shape of a huge antieline which plunges flatly towards the west. A division of the major antioline into three smaller antiolines is evident. The mineralisation of the area is clearly related to these smaller anticlinge, the Ravlidnyran and Sture ores having been located in the Northernmoet one, which plunges at about 25°

Looking closor 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 cons 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 borshole data. See appendix II.

Along the axial plane one has a coriec of rooks with low competences in comparison with the brittle altered volcanic rocks and quarts rick sedimente. The graphite phyllites consist constrainly of quarts and serioits and/or chlorite, and a variable graphite context, the graphite acting as a inbricant and thus allowing intergrammlar elip. Novement is also foreased along very definite planes along which graphite is concentrated giving the took its platy or foliste character. Linestones are also incompetency of these rooks one has to consider it in terms of flow. The linestones and graphite phyllites corupy a norm 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 Rävlidenfältet anticline and shows the general location of the ores and the graphite phyllite sons along the axial plane, as well as the general location of the graphite phyllite horison.

The some 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 horisons of the competent reak complex. One must remember that this effect is somewhat exaggerated in this horisontal plan view, this being due to fint plunge of the fold axie  $(25^{\circ}W)$ . In relation to the huge antioline displayed in Du Riots' map (Appendix I) one sees that this phenomenol, 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 sompression on the flanks of the fold, a lengthening in the direction of the axial plane might take place, and thme being under tension, openings in the different members of the stratigraphy, or at lithological contacts would form at the creat of the folds, i.e. saddle rests would result. The other type is fue to tension in the creats 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 Bivlidenfält anticline.

This gone of accumulation of incompetent rocks has been particularly favourable for the deposition of ore. It is clear that incompany favourable for the deposition of ore deposition to be easily replaced. However, even with this in the dominant feature at Hövlidmyran has been openings that existed at the contexts of the incompetent linestones and

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following description of the individual ores.

II. THE INDIVIDUAL ORES.

(a) <u>Bivlidezze</u>a

The A ore consists of a mamber of small massive sulphide lenses occurring in a larger minoralized zone. See Appendix II. The ore is of a metasometic 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

- 9 -

ore. It is particularly instructive in showing how there is a definite tendency for the ore lenses to occur at the margins of quarteits fragments, and the quarteite wall rook of the limestons. The effect is better appreciated if one can remember that generally tremolitic skarn forms from limestones, while the wall rook alteration of the quarteites is usually manifested by a small surcele of chlorite schist or chlorite rich rooks. Biotits may be formed in the latter case. Many ohEdritic boundaries are thus expected to give way to quarteite 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 sine plan (Appendix II) shows that the B and D ores are supersted, but this is only a local feature. From the bornhole data it appears that the B-D ore tends to follow the lineation of the Frem, 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-quarts-schist-graphite phyllite contact esthe 90 m level. It is made up of two distinct somes of minoralisetion one of which is relatively small. The ore also follows that insection of the area. Mylonitication, or a definite recorystallistic of the ore has been observed underground as well as in the boreholes. This appears to follow definite somes in the oraski indicates that movement was still in progress slightly after the introduction of the ore. These somes of recorystallistic on be emaximed more fully only when the ore is observed ever its full extremity. A general tendency for movement to have taken place in the direction of the fold axis is characteristic for this area so that these somes are expected to follow the B-W schistopity of the area.

There is little information about the Rävlidmyran ores, but the main trends show that the ores have basen localised in a definite sens, 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 ekarn 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 oan gain an idea of ite broad behaviour, while the detailed structure is highly confusing. Here again the replacement of a line stone herison is of importance and this second for the complexity of the ore a behaviour and shape. Regular well shaped boundaries, and the relationship of small second sector to each other, cannot be reckoned with in detail. On the other hand, while considering the broader some of mineralization one does find a structural influence on the ore.

A simplified and generalised block diagram of the Sture ore can be even in Appendix VII. The dominant feature is the thickening of the limestone which requires an explanation.

Another feature requiring an explanation is the antioline, 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 strate, i.e. there is no symmetry in the structure. It would seen then that the structure is a result of other causes than simple anticlinal folding, which would result in the linestones having flowed to, and collected in, the anticlinal create. Furthermore, he has been pointed as in the provious description that the axial plane of the

- 10 -

Reviidenfaltet antieline is found in the sons in which the Revlidayran ores are located. Unfortunately this eap 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.  $25^{\circ}W$ . East of the "centre" the ore dies out into two mineralised sones. The northernmost will be spoken of as the "tail" of the main ore-body and it follows the contact of the limestones and the metaquartmites obsciently. Again one sees the importance of the competent-incompetent rock type relationship. The conthern mineralized some constitutes the mouthern flank of the antiolized mineralized some constitutes the mouthern flank of the antiolized

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 sones 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 immeral trend still conforming to the fold axis.

A glance at the mineralized somes west of the "centre" shows how irregular they are from the one level to the next. (Compare the Aypendices II and IV; see Appendiz III). The individual massive sulphide lenses are extremely complex and hard to follow as they pinch out, swell, join new somes, etc. hard to follow as they pinch out, swell, join new somes, etc.

## Elde An

X

Stereographic projection of the pole of the schistonicity planes measured at Sturemelson and REviidayran. 50 observations and a maximum at a strike of 8 86 V and dip of 70°8. ere solutions. The main features, however, i.e. the anticline, and the "centre" have been controlled by come 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 horison which has in turn localized the Sture ore, fig. 2 is of use.

CHNKKKKKKKKK

The differential movement on the H limb or F half of the Revlidenfaltet anticline is such that H movem to the sent (or upwards in relation to the shape of the anticline) while the continues formation of the shape of the anticline) more to the for the formation of a drag fold in the incompetent rocks such as the limbtones. The more configuration of the limber output that it may have been thickened by a drag fold, and the configuration of the Revlidenfältet anticline tends to support this. See Appendices II and IV.

The anticline of the Stars ore, however, appears to be the result of a cheer some which cats over the general achiever of the area. The general schilstosity is shown in Fig. '. In spite of the limited number of observations in Fig. 4 a clear maximum is obtained at  $886^{\circ}$ W, the dip being  $70^{\circ}$ S. A shear in the direction of the S limb of the anticline and combining the northernmost aineralized some west of the "centre" strikes approximately \$75W and dips at about 50 -  $60^{\circ}$ S. See 140 m level mine plan (Appendix JV) 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 S and the dip flattens. This fact has been used in compling the block diagram.

Two pessibilities exist for the explanation of the shear plane. It should be realized that this is a plane of compression and not of tension into which the linestones have flowed. The linestone that one encounters in the Northernmest some of mineralization west of the "centre", and the linestone in the S linb of the antieline, are in the author's opinion caused by the over-rifing of the guartaitee by the linestone along the shear

Fig. 5. Principle ekstch showing the major structures which have localized the Sture ore body.



X

Showing drag fold effects in ore region west of the Sture ors "centre" on the 140 m level. S.W. face of the N.W. -D.E. cross drive. plane (See Appendix IV). The possibilities for the formati a of the shear plane are either that the shear has developed as a direct onnes 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 some found in the Ravlidenfaltet anticline itself cuts across the Nure limestone. (See Fig. 2). The latter possibility seems the more favourable in accounting for the shear some 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. Brotsen for having pointed out the feasibility of the existence of this fault from the geophysical survey maps.

The existence of the shear sons in the direction indicated above reveals itself again and again by small apophysal protrusions of the massive ore with essentially the same direction as the above discussed sons. See Appendix III where some such apophysics 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 southerr 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 recognisable 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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## 214. 7.

Linsetone inclusions in a chaloopyrite 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 interprotations given here thus lie in the reals 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-ere fractures are those which have given rise to the ere breecia or hard ore mineralisation found east of the Sture ores "centre". For an explanation of "hard ore" eee page 66. These fractures and shears follow definite systems, the most important being themmain echietosity of the area. Intersecting breaks make a shall angles with this direction and result in a network of sulphide impregnated veins, which, when the ore is abundant and the metasomaticm effective, forms impressive ore breecias with well rounded metaquartsitic inclusions.

The schietocity of the area strikes essentially E-W and dips approximately at  $70^{\circ}8$ . Ore brocois mineralisation also reveals systems dipping at  $75^{\circ}H$  and vertically. Strikes of H70 -75W and H70 - 57E have also been found as the main directions in the hard ore. The strikes can readily .e divided into three directions while the relationships for the dips are not so elemr.

Considering the Sture ore as a whole it is seen that the ere has been localized by limestones which due to their incompetency in the hard metaquarteitee have undregone a considerable thiskening eaused by a drag fold during the formation of the Rävlidenfältet anticline. A shear some 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.

/... 15 /...

D. THE ROCKS OF RAVIDENTALAR.

- 15 -

GEORRAL.

I.

The successful establishment of a systematic local stratigraphy at Exvlidenfältet is not entirely feasible. This is largely due to the highly unrecognisable nature of the primary rocks and to the unreliable position of the limestones (in detail) which have been testonically affected and now can occu y positions which are structurally controlled rather than true stratigraphic positions. In general the limestones cocupy positions of stress minime in the overall teotonic 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 rooks with the regional stratigraphy. The Rävlidenfältet rooks 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 rooks at Rävlidenfältet which may be given a sedimentary origin, and rocks representing modified acid to intermediate volcanic rooks, interbedded with each other and occurring below the graphite phyllite.

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

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 else also given by the biotite) in a suricitequarts-schist, are suggestive of a banded pelitic and passitie sediment.

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

#### of the antiolinal part of the Sture-ore.

The lengtomeretes appear to have been seattered pebble sengtomerate without any rich concentration of the pebbles or reak fragments. The pebbles are now 1 - 1.5 on in diameter, drawn out in the direction of the fold axis. In some cases the sengtomeratic nature is well preserved while in others the pebbles are testonically affected and highly metamorphosed, and the almost unrecognizable. The pebbles now consist of a fine grained graneblastic aggregate of quarts with very small, widely distributed, flakes of esticite and/or chlorite. Biotite may also essur. Between the pebbles the "matrix" shows a higher cerisite, chlorite or histite content (or a mixture of theso) in a graneblastic quarts mosain. A bright green chlorite has been observed in these conglomerates. Accessories are: spheme, ealsite, albitic plagicolase, spidote and salphides.

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Thus rooks of eedimentary origin are present in this area. Just what percentage of the sericits quarts echists are made up of eedimentary rocks, and what percentage is made up of volcanic rooks cannot be said.

That volcanio rocks have been among the original rock types is confirmed by blactoporphyritic quarts eyes (often opalescent) appearing occasionally in the soricite-quarts-schists. Under the microscope these quarts grains often show a wavy extinction indicating etrain. 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 Riots (op. cit.) e.g. quarts porphyrics. The altered phenocryste 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 scricite-quarts-echiste 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 rook shows a somewhat complex

/ ... 17 / ...

mineralogy due to articlastic alteration. Of greatest intirest, are the relatively largish foldspar grains (plagicelase) up to about 2 mm in eise. These grains are somewhat resorbed at their morgins and where they have been fractured, are intruded by the normal bietite and chlorite quarts groundmace of the rock, as well as by calcite which has been introduced into the rock. Judging by the stout ahape of the grains, which now have a modified embedral outline, these could represent relict feldspar grains of a lava. See Plate II.

Those feldspars that are undoubtedly of secondary . ... at Rivlidenfältet are commonly untwinned, though cometimes the different grains may penetrate each other. They also have a tendency to develop a crude sonary structure making universal stage determinations difficult. The feldspars occurring in the 8 part of the mine, however, are characteristically twinned and show the following twin laws and anothite contents:

Twin Lew.	<u>S An.</u>
Karlsbad	40
Ala	20
Albite	35
Nenebach	35

These feldspars often show excellent eaueseuritisation. Epidote is developed as inclusions in the feldspar grains. They also show numerous inclusions of quarts derived from the breakdown of the plagicolaces rather than representing polkioblastic feldspar grains. Gavelin, in discussive he Bjurtrack ores, says that the first trace of alteratio f the plagloolaces 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, ie subschitch with the ore simerals, fills errocks in the bloste organization of an extremely fine grained grounish emphibele mineral (tremolite - actinolite?).

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

1 ... 18 / ...

Another more momental rook type for this area was the appearance of a true leptito immediatoly N of the limestone in the B part of the Sture ore. (Room 16, 140 m level). The rook is almost entirely of xenoblastic quarts and feldepar (albitic plagicelass; microeline ?) in a fine grained equigranular mesaic. The feldepar constitutes abov 20% of the rock and the average grain diameter is 0.06 mm. Biotite, ohlorite, ephene, flourite (metacometic), and sulphides make up the accessory minerale.

Regarding the original nature of the rooks as a whole, very little can be established apart from the above details. Generalisations have to be made, and these, based on the regional etratigraphy, and the data observed underground, give a picture of a rock eequence of interbedded eediments and lavae, i.e. Gavelin's transitional sequence with lineetones. Finally irrespective whether the rocks were either eedimentary (apart from the graphite phyllites and lineetones) or volcanic they must have had a fairly eimilar chemical composition to give rise to the dominant rock type of the area - the sericite quarts schists. These rocks were then rich in silics and contained lesser and variable amounts  $Al_2O_3$ ,  $K_2O$ ,  $Na_2O$ , with minor quantities of FeO, Fe₂O₃ MgO.

The chlorite-bearing rooks, 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 quarts schlets, chlorite schlets, graphite bearing rocks and the limestone and ekarn rocks.

## II. THE ROCK TYPES.

The quarts-rich wall rocks have the local name of "quartaites" 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, schiste and represented by sericite-quarts-schists, chloritequarts-schists as biotite-quarts-schists. The classification is not strict, as the Auck types are for example, often seen to centain both soricite and chlorite, or chlorite and biotite. . Furthermore, the rock types grade into one another and various intermediate types are time possible. However, the classification

1 ... 19 / ....

is effective for practical reasons, as the chlorite- (and biotite)-

## IIs. EMERTER OFARTS BUILTING.

Quarts which is developed as a fine grained equigranular messic, usually dominates and characterises these rooks. The grain size is variable but is generally of the order 0.04-0.06 an in diameter. Fine flakes of sericite, which tend to have similar orientation, are fairly evenly spread in this momento when the amount of cericite is small. With increasing cericite 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-curfaces correspond to the fracture cleavage surfaces along which movement had taken place during the tight folding of the Révlidenfältet anticline formation. See Plate III. The variation in the emount of corricite in these rooks is brought out in Table 1.

Mineral composition of cericite quarts schists							
Specimen So.	21	207	227	249	301		
Quarts. Serieite. Sphsne. Flagioclase. Chlorite. Tourmalins. Epidote mins. Apatite. "Thlogopite". Caleite. Bietite.	34.6 59.8 2.0 0.8 1.3 - 0.1 - 0.3 - 1.2	74.4 24.2 0.1 - - - - tr - 1.2	40.5 52.9 1.5 - 4.3 tr tr tr tr 0.2 - 0.6	76.8 20.2 0.3 0.3 - 0.1 tr - 0.1 2.2	64.0 34.3 0.2 - tr tr 0.1 tr 1.3		

Chlorite is generally present though in small amounts. With the pressing chlorite someant the rook becomes a chlorite quarts mains (1.4. when the amount of chlorite dominates over serieite). /... 20 /...

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PLATE 1 I45 2 Micole.

Blastoporphyritic Quarts Grain in a Sericite Quarts Schist.

> PLATE II IAS 2 Micols.

K H H H H H H H H H H

Resorbed Plagioglass Phendocryst in a Biotite Quarts Schist.

## PLATE III 18 2 Ficels.

Differing Seriaite Orientations, prosumably para- and post-crystalline, in a Seriaite-Quarts Schist. It is characteristically developed as fibrous flakes though larger zenoblastic grains have been found. Biotite may occur, though generally only in subordinate amounte.

Minerals that occur in small but pereistent amounts are sphere and minerals of the spidote group. Amoung the latter scicite and elimo-sciste are the most frequent.

Another minoral that probably belongs to the epidete 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 plans is parallel to the elongation of the grain dividing it in two halves. The cross section of these prices is usually rhombic, the twinning plans 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 inte aggregates and porphyroblasts. The formation of sphene is spparently 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 serioite flakes of differing orientation. In other eases it completely disrespects the banding in the serioite and forces its way into this banding which is evidently due to its late orystallisation. Leucoxene may be developed, generally as fine aggregates. It is a rare constituent.

Tournalize is an important, though rarely encountered constituent of the cericite quarts schists. It is noted as extremely fine grains (0.05 mm) widely dispersed in some of these rooks. 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 needlelike grains with distinct pleochroism. Two varieties have been identified: - 34 * 0,003 Faint yellow 1,618 * 0,003 Colourleee. 1,643 * 0,003 Bluish green 1,621 * 0,003 Colourleee Other accessory minerale are rutile (exceptionally rare)

calcite, sulphides.

Sericite is not the only mice in these rocks. Larger, tending to polkioblastic grains of musocvite are found occasionally. Another mice 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 Malanãe district has described a musocvite 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 -  $j8^{\circ}$ ). The Rävlidenfaltet yellow mice 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 ? Ite occurrence is as larger porphyroblastic frame with poor crystal outlines. Inclusions of quarts are not uncommon.

Foldepar grains are to be found though only in very small amounts. They are generally porphyroblastic. However, in some cases small grains the same eise as the engranular quarts grains are encountered. The foldepare are typically somed, 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 eleavages. A list of more reliable foldspar determinations is presented in Table 2. These determinations, however, include foldspars found in chlorite-quarts-cohists. In general the composition of the foldspars is An 30 - 40%.

These feldspar grains pose the problem as to which were formed in conjunction with the ore forming proceeses and which are modified grains of the primary rock. No answer can be given. In errtain cases (see later) one can undo btedly relate feldspathisation to mineralisation 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 /... 22 /...
TADLY 2. Universal stage determination of secondary feldspars based on twin law or cleavage. Twinning Law. Anorthite Specimen No. Rock type. content 30% Serieite-quarts-cohiet Albite-20. Carlbad. 35% 22. Chlorite-querts-schist 35% Serieite-quarts-echiet Albite-Als. 106. 35% Chlorite-quarts-echiet 201. 35% Chlorite-quarts-schist 203. 05 Albite. Chlorite-quarts-echiet 311.

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

A chemical analysis of a serioite-quarts-sohist is given in Table 3. The analysis has been calculated in accordance with the method of Barth (BARTH 1948, 1955; ESKOLA 1954). The Epinorm 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 rooks has an olivene or pyroxene been found. This is hardly possible in the low grade of metamorphism encountered at Rivlidenfältet. Similarly, no anhydrous aluminius silicates have been observed. It is cautioned, however, that eordierite may be present. This mineral has not been observed in these rooks under the mioroscope, but could be a certain small percentage of the minerals interpreted as feldspars. Feldspar and serdierite as dispersed grains can be confused in such rocks. Consequently the author has tried to make universal stage determinations on all suitable grains einmlating 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 the perisive-marts-achieve than an analysis of a selected hand specimen. On the other hand there is a greater possibility of having more mimerals present which makes it more difficult to arrive at the mode. Secondly, in censidering such altered reeks as these one should not expect perfect equilibrium to have been attained. That one cannot form strictly stoichiom.tric mineral assemblages is thus not so surprising. Mg ++ can replace Al ++ in the ideal mesorvite formula and such substitution is highly probable in the corieite. 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. Y substitutes for OE so that one can reduce the EgO deficiency. It is interesting to record that ODMAR (1941) in calculating the model composition of sericitie schists from the Boliden deposit found poer agreement in one of the analyses; there was a deficit in the amount of Al203 and H20 in proportion to the alkalies.

1 ... 24 / ...

- 25 -

-							_
			541	12.4			
4		Car	tion percent o	f a seriei	to-quar	ts-schist.	
		<b>B.</b> 1	I. 630,0 ⁰ .190	n level.	3.45 -	5.12 m.	
			analys	t: H. Olei	?son.		
		Cation \$					
				Polynam.			
	101	81.81		Cettone.	H.O.		
		7.04	0	67.3	20		
	70	1.27	q	12.7			
	20	4.6y	Ab	2.4			
		2 32	Teel	6.7	3.4	Pyr is a mixture	20
		0.42	Se	1.2	0.1	pyrite TeS, and	
				2.5	1.0	pyrrhotite PeS,	
Ξ.				2.9	1.2	748, = 0.8	
		0.16		0.4	-	7.5 = 0.5	
ψ.	The local data	¥7	Gare	0.3	(0.3)		
1			Sph	0.1	(0.1)		
		0.02	Prr	1.3	(2.0)	2	
	Ō	0.18	Ht.	1.9			
	7	(0.44)	II	0.3		I I COrrespond	
	01	22	Ар	0.1	_	BUT BURE .	
	E.0-	(0.13)		100.1	5.7		<b>1</b>
5	X-02	(2,22)					
	Ca	0.15	Hode.	Cations.	H ₂ O		
	8m	0.12	Quarts	70.8			
	8	(2.42)	Orthoelase	1.2			
	Costing	100.00	Sericite.	16.1	2.3		
			Antigorite.	4.0	7.0		
	0	182.74	Albise.	0.5			
		0.44		0.6	C.1		
Dr.		2.42	Dolomite.	0.4			
F	And and a	190.04	Cha .copyrite	0.3	(0.3)		
		730104	Sphalerite.	0.1	(0.1)		
-			botite.	1.7	(2.0)		
10			Megnetite.	1.9			
			Apetite.	0.1	-		
				100.1	4.0		
			3				

- 11 1.4

1.1 .

 $T^{*}$ 

/... 25 /...

The corresponding amounts of water incorporated in the ideal minoral formulae for anesito, antigorite, and eericite mancovite) are shown in the table. It is clear that this amount is larger than that of the analysis, i.e.  $H_2O+$  plue 2.

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

"E 0 Ba_0 combined with Ng0 Ca0" "a very high SiO₂ centent (say greater than 80%, or more than 50% Q in the norm".) MASON 1958. The merioite-quarts-cohist contained 82.4 wt \$ SiO₂.

Though this data may suggest a rook of sedimentary origin, which is by no means surprising in the sequence at Rävlidenfältet, it should be borne in mind that quarts porphyries have a high 5102 content, e.g. the quarts porphyry E of Maurliden published by GAVELIE (1939) has 79.84 wt \$ S102. Also one of the characteristic features of the central Swedish Pre-Cambrian is a strong type of netasonation, magnesia metasonation, by which the foldspathic rooks such as leptites and helleflintes are altered to "quartsites" and mice schists. Minerals such as cordierite, almandine, andalusite and gerdrite are generally formed. One obtains an enrichment of Mg. Aland Fe while the alkalies are driven out of the rook. (OHIJER 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 sharn minorals in limestone rooks). Do Riets points out that the Kristineberg region is characterized by a strong metasometic alteration of the volcanic complex which was originally sodic. "The alteration of the whole region is characterized by a more or less complete ; enoval of sodium and partly also of lime and an addition of potassium, magnesium, sulpher and iron." DU RIETS 1953. Such conditions might easily account for E20 > Ma20 combined with Mg0 > On0.

folding of the Mivlidonfaltet antioline, i.e. they were well prepared by testenie agencies for alteration, and if necessary, influx of material. This metamorphism has effectively destroyed the primary foldspars with the formation of sericite which implies an introduction of Oh into the rooks. A recrystallisation has also cocurred.

## ITS CHLORINE QUARTE SCHIETS.

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

At certain apophysal portions of the ore, and often associated with the intrusion of chaloopyrite-rich fractions into the meetve cericite-quarts-cohiete, one has an unquestionable introduction of chlorite into the wall rock.

Decitie rooks may also give rise to a certain amount of ohlerite 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 rook. 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.

Quarts is developed identically with that found in the serieite-quarts-schiste, i.e. a fine grained equigranular messio. Ohlorite is developed as fibrous flakes widely distributed in the reak, 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 erigin) and one may then have all transitions to pure chlorite echiete. Table 4 illustrates the variation in chlorite content in some of these rooks.

1 ... 27 / ...

		vojam bes			
Specimen No.	22	105	141	147	239
Quarta.	39.7	38.4	68.2	41.6	69.1
Chlerite.	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
Serielte.	1.3	12	tr	tr	0.2
Boidete Mins.	0.5	0.1	tr	0.2	tr
Plastoplass	21.9	-	tr	-	
	0.2	-	-	-	-
Shiphides	0.3	-		-	0.:
Dubila	tr	-	-	-	-
		tr	-	tr	-

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

Feldspar grains, again showing typical soned etructures, are developed as rare porphyroblasts. In one ohlorite quarts sohiet (See table 4, No. 22) feldspar is present in unusually large amounts. This rock derives its feldspar from setaeomatic processes. The composition of feldspare in the oblorite-quartssohiete is the same as for the previous rock group; from this group, however, albits has been recorded.

Sericite can occur as fine flakes constince. Tale is also found as a minor constituent. Biotite is a rare constituent in these rocks. The accessories are spidots group minorals, sphere, apatite, calsite, leucoxene, rutile and sulphides.

II. . BIOTITE-TRADIES OUARTE SCHISTS.

The biotite isograd is useful in metamorphic petrology, this being particularly so when comparing the same or equivalent reck types undergoing metamorphism. At REVIIdenfältet, however, there has apparently been sufficient K associated with the ert forming colutions, for the partial, and in some cases conversion of all rite to bictite. In the pertinent sulphide oree them the matrix of the ore can be entirely of biotite. The ore forming processes have a direct influence on the distribution of bietite, eince the metamorphic grade is such as to allow ite formation. This type of blotite is specially related to the ores, generally within the adjacent wall rooks and the ore itself.

In actual fact biotite-bearing quarts-schiete are the previously described meta-quartsites, the main difference being the significant appearance of biotite.

Bietite may be formed as small flakes spread in the equigrammlar quarts mosaie. It may often be found together with serioite or chlorite. Larger xenoblastic grains, often poikeblastic, are not unneual in the mode of formation of the biotite. The blotite 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:

serioite + ohlorite ----- biotite K-feldspar + ohlorite ----- 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 colution.

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.

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The question arises whether biotite was formed during the regional metamorphism or was only formed in conjunction with the salphide invasion. The latter period would be the most feasible since if we look at the map of the Eristineberg reg'on (Appendix 1) is indicates that the main rocks in this area are esticite quarte schiete with chlorite. In general the metamorphic grade has been tes low for the complete biotite formation from chlorite and sericite. This is confirmed in the mine area by the dominance of sericite quarts schiets with chlorite in varying (A., 29 / a.) emounte, and the appearance of biotite in close vicinity of the ore bedies (See also page 83 ).

Considering the mote-quartaitee as a group they are seen to be rocks in which quarty, which is granoblastically developed and fine grained, dominatee. Two dominant types can be distinguished, the sericite-quarts-schists and the chlorite-quarts-schists. Of these two types the former is by far the most important quantitatively. There is also a third group of quartaites; it is a mell group and merely a variant of the previous types. The quartaites of this group are the biotite bearing quarts schists which together with the chlorite-quarts schiete may be formed either by metasomatism in association with the ors forming solutions, or also as metamorphic derivante of sedimente, invas, and tuffs.

## IIC CHLORITE SCHISTS.

These rooks, when typically developed, are almost monomineralio, comprised of virtually only fine grained chlorite. Macroecopically it is a dark green uniform rook sometimes containing more tale-rich echlier and bands. In general tale is subordinate to chlorite. Three purer chlorite schists have their mineral composition displayed in 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 Hins.	0.7	0.1		
Caloite.	0.5	5 <b>7</b>		
Tale.	-	2.5	4.7	
Sulphides.	•	6.6		

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

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

A consistent accessory is ephene. It has a habit of forming porphyroblastic grains which seldom attain good idioblastic outlines, and are often polkioblastic. 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 rook. 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 ephene. The mineral is possibly rutile.

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

The mineral thought to belong to the epidots group, which shows excellent twinning (see page 20 ) is a regular, almost characteristic mineral of the oblorite schist paragenesis. It is frequently idioblastic and very commonly has a burder of emother spidots mineral about it (solsite or elinesolsite). GAVELIN (1939-) describes a mineral which he considers is probably orthite, or an alteration production of orthite, which in the oblorite rocks of the Bjufors oree. It too is surrounded by a colourlees mimeral displaying the properties of soleite. This mimeral is, however, not the same as that found at Réviidenfâltet. The optical characteristics do not allow orthite.

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The chlorite schiste intimately accounted with the ores, however, i.e. the varieties that are derived from altered quartsites, and also in the chloritic matrix of the ore, contain a metamict mineral surrounded by a colourlees epidote mineral border (coicite ?) which could be an alteration production of orthite. Share (1957) in decoribing the sharn minerals if central Sweden has mentioned an orthitic mineral, which judging from the data and photographe presented, is similar to this metamiet mineral.

The role of talc has been discussed before. Tremolite is found in the ohlorite echiste and one can have gradations to pure skarn rooks. Tale is often present in such cases. Tremolite has also been noted to be directly related to the sulphides which have entered the rock. Carbonates, quarts, and sulphides are among the accessorice.

An analysis of a ohlorite echiet some (6 m of borehole core) is presented in Table 6. Here 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 end tale. Once again one can point out that anhydrous minerals such is pyrozene and olivens are not possible in the low facies assemblage at Rävlidenfältet. Cordierite has not been found in these rooks 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 ohlorite as derived from the norm is then Sheridani e (after TRÖGER, 1956). However with increasing hydration tale in the mode would be converted into the antigerities end member of the series thus lowering the Al:Mg ratio of the ohlorite. This implies that it would push the ohlorite composition to the olinochlere or penninite varieties.

Optical observations were unsuccessful in determining the

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

The analysic of a chloritic rock from the Krietineberg mine is included for comparison in Tabl. 5. The essential difference between the two analyses is the higher water content of the Krietineberg sample and a higher content of alkali metals combined with a comewhat lower quarte content. The amounts  $Al_2O_3 + Pe_2O_3$  and MgO + PeO + MnO are ess _lially comparable.

Three different chloritee 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 Guinler eamera with a camera radiue of 39.94 mm, using copper radiation and KCl as internal standard. This latter powder photogram was thus able to reveal the 14 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 determinetion 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 elimochlorite or close to it.

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X	Cation p.	642 0°.38.75	lorite schist - 44.75 E.	Te de
21       33.066         1       15.89         1       15.89         1       10.06         1       0.06         1       0.06         1       0.06         1       0.06         1       0.06         1       0.06         1       0.06         1       0.06         1       0.06         1       0.06         1       0.06         1       0.06         1       0.06         1       0.06         1       0.06         1       0.06         1       0.06         1       0.06         1       0.06         1       0.06         1       0.06         1       0.06         1       0.06         1       0.06         1       0.00         1       0.00         1       1.29         1       1.29         1       1.29         1       1.29         1       1.29         1       1.29	Chl. Chl. Chl. Chl. Chl. Chl. Chl. Chl.	E-0 E-0 IT-1 17.1 15.9 0.3 (tr) (tr) (tr) (2.6) ICL 33.3 INE 33.3 INE 33.3 INE 33.3 INE 33.3 INE 33.3 INE 33.3 INE 33.3 INE 33.3 INE 33.3 INE 33.3 INE 33.3 INE 33.3 INE 33.3 INE 33.3 INE 33.3 INE 33.3 INE 33.3 INE 33.3 INE 33.3 INE 33.3 INE 33.3 INE 33.3 INE 33.3 INE 33.3 INE 33.3 INE 33.3 INE 33.3 INE 33.3 INE 33.3 INE 33.3 INE 33.3 INE 33.3 INE 33.3 INE 33.3 INE 33.3 INE 33.3 INE 33.3 INE 33.3 INE 33.3 INE 33.3 INE 33.3 INE 30.1 100 100 100 100 100 100 100	$A^1$ $S10_2$ $35.1$ $A1_20_3$ $17.0$ $Pe_20_3$ $2.6$ $Pe_20_3$ $0.03$ $Pe_20_3$ $0.04$ $Pe_20_3$ $0.04$ $Pe_20_3$ $0.042$ $Pe_20_3$ $0.042$ $Pe_20_3$ $0.011$ $Pe_20_3$ $0.05$ $Pe_20_3$ $0.05$ $Pe_20_3$ $0.05$ $Pe_20_3$ $0.05$ $Pe_20_3$ </th <th>ARALIZURI F B² 30.32 17.67 2.69 2.49 33.41 tr 0.40 0.52 0.50 0.52 0.50 0.30 0.17 - 0.00 tr 0.00 tr 0.08 11.44 0.00 0.13 6.94 101.98</th>	ARALIZURI F B ² 30.32 17.67 2.69 2.49 33.41 tr 0.40 0.52 0.50 0.52 0.50 0.30 0.17 - 0.00 tr 0.00 tr 0.08 11.44 0.00 0.13 6.94 101.98

This sample.

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2.

Chloritie rock from Kristineberg mine. After Da Biets 1953

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	1000								4,604	X	
	(3,922)	2	4.16	1	4.16	1					
			3.57	5	3.55	5					
J	3.509	10					3.54	5	3,543	X	
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	2,828	7	2.84	3	2.83	3	2.81	2			
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	1,234	10	1.49	2	1.50	1.5	1.50	1	1,503	T.R.	
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4 values of 3 shist		time 7 10	correspondi- and Dabini	rg values	
CLINO-CHICRIFF"	P 15	80.107	10.24T	No.24	I
1,319       4         1,283       4         1,251       1         1,218       7         1,191       1         1,181       3         1,131       4         1,094       4	1.32 2 1.29 1 1,22 2	1.32 2.9 1.29 1		1,322	¥.¥.
1,04051,03051,01331,00130,9674					

- 1. Values of chlino-chlorite according to Hikkeev and Bubladian (1939)
- 2. Debye Scherer eamers.
- 3. Quinier camera.

2 and 3 are chloritos from Revisionfältet.

LINCOMPOSIT AND STATE SOUTH.

The linestones and skarn reaks are here considered as the and the same group as they are genetically related, the latter are gaugesly a variant derived from the former.

In the discussion on the structural goology it was seen that the limit one horizons have had a deciding influence on the subjects over at hivildentiator. The deministing feature is of over at the context of competent and incompetent reals the latter are the graphite phylices and limestence. (not do ) we shall discuss the formation of these limestence. (not do ) we shall discuss the formation of chlorite reals in it can already to method have that it is 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.

4.81

1.00

100

A. Wirstam who has logged most of the boreholes at Rivlidenfaltet is of the opinion that dolomite and caloite occur in approximately equal proportions at Sturemalmen while at Revlidayran dolomite is presumably rare. (personal communication). Table 8 shows analyses of MgO and CaO of limestones from the Sturemalmen area. The ratiosCaO:MgO has been calculated in each 'se on a molecular basis. The values are given in with and the values given in parenthesis are the nolecular propertions of the four molecules CaO, MgO, CO,, SiO2 calculated to 100%. In virtually each case there is an excess of Ca0 + MgO in relation to the molecular amount of CO2. The error in each case can be seen by comparing the molecular value of CO2 in parentheeie with the sum Ca0 + MgO ( which can simply be obtained by adding the two amounte given in parentheeie in the fourth column, i.e. CaO:MgO). These amounte have been arrived at after subtracting equivalent amounte of CaO and MgO to combine with SiO2 to form tremolite.

In a few cases the moleculer amount CO₂ is greater than CaO + NgO indicating yet other carbonates. In such cases SiO₂ is left as "free silica".

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

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Sample He.CaOHgOS102CO2CaO i HgOB.H.603 0 ^B 39.60-41.40 m24.816.717.621.81.6i1.0(25.4) (25.2) (17.8) (30.1)(22.4:14.1)41.40-45.47 m26.919.78.034.51.1i1.0(25.4) (25.2) (24.9) (22.3) (28.7)(18.6i1.0)(23.6i21.5)45.47-47.65 m22.616.722.321.01.7i1.0(24.2) (24.9) (22.3) (28.7)(18.6i11.0)58.10-61.60 m28.216.811.827.21.5i1.0(24.0) (24.0) (24.0) (11.3) (35.6) (26.2i17.0)B.H. 604 0 ⁰ 12.10-15.75 m27.912.69.433.62.1i1.0(26.8) (18.1) (9.0) (444.1) (26.5i12.5)15.75-19.98 m26.414.46.137.01.3i1.0(26.6) (20.2) (5.7) ^X (47.5) (26.6i20.2)19.98-24.50 m25.110.79.834.71.7i1.0(26.9) (15.9) (9.8) ^X (47.4) (26.9i15.9)24.50-28.52 m25.214.58.234.31.3i1.0(26.1) (20.8) (7.9) (45.2) (25.6i19.6)(6.0) ^X (25.6i19.6)(23.8i18.7)28.52-33.55 m22.715.17.928.71.3i1.0(25.9) (24.0) (8.4) (41.7) (23.8i18.7)(23.8i18.7)28.52-33.55 m25.219.48.231.71.1i1.0(25.9) (24.0) (8.4) (41.7) (23.8i18.7)(23.8i18.7)28.52-33.55 m25.219.48.231.71.1i1.0(25.1) (25.9) (24.0) (8.4) (41.7) (23.8i18.7)(23.8i18.7	Approximate as	locular ratio	of CaO : Ng	of some	Sture ore limester	DO
<b>5. H</b> . <b>601</b> 0 ^{<b>8</b>} 39.60-41.40 <b>24.8</b> ( <b>166.9</b> ) (25.2) <b>17.6</b> (17.8) (30.1) <b>1.61.0</b> (22.4114.1) <b>41.40-45.47 a</b> (25.4) (25.4) (25.4) (25.4) (25.9) <b>19.7</b> (20.1) <b>8.0</b> 34.5 (21.6) (22.3) (28.7) <b>1.11.0</b> (23.6121.5) 1.71.0 (18.6111.0) <b>45.47-47.65 a</b> (24.2) (24.2) (24.2) (24.2) (24.9) (24.0) <b>12.3</b> (22.3) (22.3) (28.7) <b>1.6611.0</b> (18.6111.0) (18.6111.0) <b>58.10-61.60 a</b> (29.0) (24.0) (24.0) <b>26.2</b> (11.3) (35.6) <b>26.2</b> (26.217.0) <b>B.H. 604</b> 0 ^{<b>0</b>} (22.0) (24.0) (24.0) <b>11.8</b> (27.2) (27.9) <b>27.9</b> (26.6) (26.217.0) <b>B.H. 604</b> 0 ^{<b>0</b>} (22.8) (22.8) (18.1) (26.6) (26.2) (26.6) (26.2) (5.7) ^T (44.1) (26.5) (26.6) (26.2) (26.7) (26.9) (26.9) (26.9) (26.9) (26.9) (26.9) (26.9) (26.9) (26.9) (26.9) (26.9) (26.1) (26.6) (26.2) (26.1) (26.8) (26.1) (26.8) (26.1) (26.9) (26.0) (26.1) (26.9) (26.0) (26.0) (26.1) (26.1) (26.1) (26.8) (26.1) (26.9) (26.0) (26.0) (26.1) (26.1) (26.1) (26.1) (26.2) (26.0) (26.1) (26.1) (26.2) (26.1) (26.2) (26.1) (26.2) (26.1) (26.3) (26.1) (26.1) (26.3) (26.1) (26.4) (26.1) (26.6) (26.1) (26.9) (26.0) (26.1) (26.9) (26.0) (26.1) (26.9) (26.1) (26.9) (26.0) (26.1) (26.9) (26.1) (26.9) (26.0) (26.1) (26.1) (26.9) (26.1) (26.1) (26.9) (26.1) (26.1) (26.9) (26.1) (26.1) (26.1) (26.9) (26.1) (26.2) (26.1) (26.2) (27.9) (26.	Sample No. Co	io NgO	\$10 ₂	c0 ₂	Ca0 : Mg0	
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<b>B.H. 604 0°</b> 12.10-15.75 <b>a</b> 27.9 (28.8)12.6 (18.1)9.4 (9.0)33.6 (44.1)2.11.0 (26.512.5)15.75-19.98 <b>a</b> 26.4 (26.6)14.4 (20.2)6.1 (5.7) <b>x</b> 37.0 (47.5)1.311.0 (26.6120.2)19.98-24.50 <b>a</b> 25.1 (26.9)10.7 (15.9)9.8 (9.8) <b>x</b> 34.7 (47.4)1.711.0 (26.9115.9)24.50-28.52 <b>a</b> 25.2 (26.1)14.5 (20.8)8.2 (47.4)33.1 (26.9115.9)1.311.0 (26.9115.9)24.50-28.55 <b>a</b> 22.7 (25.1)15.1 (20.8)7.9 (45.2)(45.2) (25.6119.6)28.52-33.55 <b>a</b> 22.7 (25.9)15.1 (24.0)7.9 (8.4)28.7 (41.7)28.52-33.55 <b>a</b> 22.7 (25.9)15.1 (24.0)7.9 (8.4)28.7 (41.7)28.52-33.55 <b>a</b> 25.2 (25.9)14.5 (25.9)33.1 (25.9)11.2 (25.9)33.1 (25.9)11.2 (26.9)6.4 (41.7)32.6 (23.6118.7) <b>b</b> .84. 605 0° (25.1)25.2 (26.9)19.4 (6.2)32.7 (43.3)5.05-8.05 <b>b</b> 25.2 (25.1)19.4 (26.9)31.7 (1.6)6.05-12.07 <b>b</b> 24.0 (23.8) (27.5)11.3) (37.3)(21.0120.4) (21.0120.4)12.07-15.45 <b>b</b> (28.2 (33.2)13.2 (20.3)(11.3) (37.3)(27.413.2)	(29	9.0) (24.0)	(11.3)	(35.6)	(26.2:17.0)	
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$\begin{array}{cccccccccccccccccccccccccccccccccccc$	12,10-15,75 = 27	1.9 12.6	9.4	33.6	2.1:1.0	
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$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	15.75-19.98 m 20	5.4 14.4	6.1	37.0	1.3:1.0	
19.98-24.5025.110.79.8 $34.7$ 1.7:1.0(26.9)(15.9)(9.8) ^T (47.4)(26.9:15.9)24.50-28.5225.214.58.234.31.3:1.0(26.1)(20.8)(7.9)(45.2)(25.6:19.8)(26.1)(20.8)(7.9)(45.2)(25.6:19.8)(28.52-33.5522.715.17.928.71.3:1.0(25.9)(24.0)(8.4)(41.7)(23.8:18.7) <b>B.B.</b> 605 0°1.28-5.0533.111.26.432.72.3:1.0(34.4)(16.2)(6.2)(43.3)(32.8:14.3)5.05-8.0525.219.48.231.71.1:1.08.05-12.0724.019.912.229.5<0:1.0	(2)	6.6) (20.2)	(5.7) ^x	(47.5)	(26.6:20.2)	
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$\begin{array}{cccccccccccccccccccccccccccccccccccc$	121	5.9) (15.9)	(9.8) ^X	(47.4)	(26.9:15.9)	
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	24 50 28 52 5 21	14.5	8.2	34.3	1.3:1.0	
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$		(20.8)	(7.9)	(45.2)	(25.6:19.6)	
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$\begin{array}{cccccccccccccccccccccccccccccccccccc$	09 50 33 55 5 2	27 15.1	7.9	28.7	1.3:1.0	
<b>B.H.</b> $605 0^{\circ}$ 33.111.26.432.72.3:1.0 <b>1.28-5.05 m</b> 33.111.26.432.72.3:1.0(34.4)(16.2)(6.2)(43.3)(32.8:14.3) <b>5.05-8.05 m</b> 25.219.48.231.71.1:1.0(25.1)(26.9)(7.6)(40.3)(23.2:22.1)(25.1)(26.9)19.912.229.5 $\therefore$ 0:1.08.05-12.07 m24.019.912.229.5 $\therefore$ 0:1.0(23.8)(27.5)(11.3)(37.3)(21.0:20.4)12.07-15.45 m28.213.210.926.5 $१.11.0$ (31.2)(20.3)(11.3)(37.3)(27.4:13.2)	20.72-33.77 = 20		(8.4)	(41.7)	(23.8:18.7)	
<b>B.H.</b> 605 0° 1.28-5.05 <b>a</b> 33.111.26.432.72.3:1.0 (32.8:14.3) $(34.4)$ $(16.2)$ $(6.2)$ $(43.3)$ $(32.8:14.3)$ $5.05-8.05$ <b>b</b> 25.219.48.231.71.1:1.0 $(25.1)$ $(26.9)$ $(7.6)$ $(40.3)$ $(23.2:22.1)$ $8.05-12.07$ <b>b</b> 24.019.912.229.5 $1.0:1.0$ $(23.8)$ $(27.5)$ $(11.3)$ $(37.3)$ $(21.0:20.4)$ $12.07-15.45$ <b>b</b> 28.213.210.926.5 $2.1:1.0$ $(31.2)$ $(20.3)$ $(11.3)$ $(37.3)$ $(27.4:13.2)$			(0.47			
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5.05-8.05 = $25.2$ $19.4$ $8.2$ $31.7$ $1.1:1.0$ $(25.1)$ $(26.9)$ $(7.6)$ $(40.3)$ $(23.2:22.1)$ $8.05-12.07 =$ $24.0$ $19.9$ $12.2$ $29.5$ $1.0:1.0$ $(23.8)$ $(27.5)$ $(11.3)$ $(37.3)$ $(21.0:20.4)$ $12.07-15.45 =$ $28.2$ $13.2$ $10.9$ $26.5$ $3.1:1.0$ $(31.2)$ $(20.3)$ $(11.3)$ $(37.3)$ $(27.4:13.2)$	(34	4.4) (16.2)	(6.2)	(43.3)	(32.8:14.3)	
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	5.05-8.05 m 2	5.2 19.4	8.2	31.7	1.1:1.0	
8.05-12.07 =       24.0       19.9       12.2       29.5       3.0:1.0         (23.8)       (27.5)       (11.3)       (37.3)       (21.0:20.4)         12.07-15.45 =       28.2       13.2       10.9       26.5       2.1:1.0         (31.2)       (20.3)       (11.3)       (37.3)       (27.4:13.2)	(2)	5.1) (26.9)	(7.6)	(40.3)	(23.2:22.1)	
$12.07-15.45 = \begin{pmatrix} (23.8) & (27.5) & (11.3) & (37.3) & (21.0;20.4) \\ 28.2 & 13.2 & 10.9 & 26.5 & 2.1;1.0 \\ (31.2) & (20.3) & (11.3) & (37.3) & (27.4;13.2) \end{pmatrix}$	8-05-12.07 E 2	4.0 19.9	12.2	29.5	1.0:1.0	
$12.07-15.45 = \begin{array}{ccccccccccccccccccccccccccccccccccc$	(2	3.8) (27.5)	(11.3)	(37.3)	(21.0:20.4)	
(31.2) (20.3) (11.3) (37.3) (27.4:13.2)	12.07-15.45 = 2	8.2 13.2	10.9	26.5	2.1:1.0	
	(3)	1.2) (20.3)	(11.3)	(37.3)	(27.4:13.2)	
				1		

CHRHHHHHHHHHHHH

Approximate value of "free quarts". This is SlO₂ that will be incorporated in other eilicates if they are present and will form free quarts if it cannot combine with other molecules in the absence of such.

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

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

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

Sphene again is present in one r ok 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 leucozene.

Skarn rocks are developed at both REvlidayran and at the Sture orebody. The skarn mineral developed 1/3 tremoliteactinolite.

One such amphibole gave the following obsractoristics with sodium light:

 $\begin{array}{r} \mathbf{x} = 1.613 \stackrel{+}{\to} 0.001. \\ \mathbf{x} = 1.626 \stackrel{+}{\to} 0.001. \\ \mathbf{x} = 1.637 \stackrel{+}{\to} 07001. \end{array}$ 

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

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1... 39 /...

In general, the sharn needles formed as greenish grains macroscopically, but are colourless under the microscope. One has transitions of limestones with exattered sharn needles to massive translitic 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 + caloite + quarts -- tremolite + CO2. Talo - caloite + quarts -- tremolite + CO2.

The large amount of limestone and the highly acid mature of the wall rook 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 skarr 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 doer not have minerals such as cummingtonite, garnet, cordiorite and antnophyllite, such as have been formed at the Adak mine and which have been described by GAVELIM (1948 and 1952).

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

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

(a) differences in composition (dclomite and calc.te),
 (b) differences in grain eise and texture,

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(e)

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concentration of extremely fine inclusions in the carbonates into somes which are poorly defined under the microscope, but well defined to the maked eye. These bands of inclusions conform with the general outline of the limestone inclusion but age quits 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 soning thus would seen 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 sones represent mixtures of the carbonates of the already crystallised sons and carbonates of the new gone. Re-solution and -precipitation of the already crystallised sons may explain this.

## IIT. BRAPHITE PHYLLITES AND GRAPHITE BRARING ROOMS.

These rocks have their most pronounced development at Rävlidmyran where a huge wedge of graphitic rocks appears in the quartsitee. 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 rook under the microscope essentially of equigramular quarts, and flakes of coricite (or chlorite) with graphite which is scattered throughout the rock as extremely small grains, i.e. they resemble coricite quarts schists simply chouded by finely disceminated graphite. The graphite can also be concentrated along definite bands. Sulphides are typ.cally present in varying amounts usually as fine streaks or even discontizmous broader veinlete. The sulphides are mainly of pyrrhotite and pyrite. Accessory minerals are sphend, epidote minerals, (including the twinned variety) tale, and calsite. Highly altered feldspar grains have been rarely found, and are meet likely altered plagicelase grains. Another variety of feldspar has been found but is evidently related to the sulphide /... 41 /...

### mineralisation; it is microoline.

A grain of ophone 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 echietosity.

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Another variety of graphite rook consisting mainly of chlorite and graphite is present in the Ravlidnyran area. Tale, ealsite, sphene and sulphides were the main accessories found. These rocks might represent metasomatised equivalents of the type of graphite phyllite described above.

#### IIG. QUARTS VEINS.

Quarts voine of varying types are found in the whole area. Broadly one may divide them into two main types; the barren quarts voins containing laggely quarts and, less commonly, with other silicates such as chlorite, tale, and amphodelite; the mineralised quarts veins generally with subordinate chalcopyrite and pyrrhotite, and on the 240 m level, with sphalerite, galena and terrurides, and ecveral 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 orystals) cut across the schistcsity, and are in turn traversed by the mineralisation of the ore brecois which proceeds right across them. Some quarts veins are intimately associated with the ore and are derived from the uncommolidated fractions of the ore which were equeceed out of the main ore. These are the copper bearing veins with chalcepyrits and pyrrhotite. Finally a huge quarts vein on the 240 m level appears to be late- or poet-ore in age.

The cilicate bearing quarts veins are of interest in that the mineral amphodelite has been observed in some of then. This mineral has been found in veins in the hanging wall of Sturemalmen, and also in smaller veinlets near the A orebody at Ravlidnyran. It was best studied at Sturemalmen where it eccurred in large amounts. Amphodelite is easily characterised /... 42 /... by its red vielet 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, tale and of course, quarts. Sphene had obviouely crystallised before the quarts; quarts has forced the sphene grains apart that formerly fitted together (See Plate VI). Veinluts of quarts and calcite are seen to cut across the amphodelite grains. The order of crystallisation is thus: Sphene, amphodelite, quarts 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 plagioclass. It has been found in two differing parageneses, one with veins of quarts 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 mineralisation, 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.

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At Rivlidenfältet, amphodelite is alec ...and in the lime silicate parageneeie. The reek as observed in this area was a meta-quartaite with quarts, caloite, 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 rook occurred some 11 m away from the quarts vein described above. One then wonders if amphodelite has not been mobilised and enriched in these quarts veins from the adjacent well rocks? Gavelin's examples show, however, that in many of the amphodelite specimens he has examined, amphedelite is a mineral that has often formed in situ from previous feldmar grains. The Rivlidenfältet amphodelite shows a rather arbitary distribution. The small veinlets at Ravlidmyram suggest a secretion origin for both quarts and amphodelite.



PLATE IV.

Crustified Limestone Inclusion in the Sture Ore.



PLATE V. X45. 1 Nicol.

Sphene Grain with an In-clusion of Rutile at the Apex of the Grain. Graphite Phyllite.



PLATE VI. X8. 1 Nicol.

Sphene (black) and ampho-delite (grey) which have crystallized sarlier than quarts (light grey). Quarts veinlets often con-tain 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 arbonate 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 thue be derived from there.

The galena bearing late- or post-ore quarts vain of the 240 m level shows an interesting mine al assemblage. Quarts and cordierite dominate among the silicates. Chlorite is generally found associated with the sulphide minerals often as pourly radiating aggregates. Colcite occurs as independent grains, and also as amall irregular veinlets at quartz-cordierite contacts. The quarts is often riddle 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, eltaite and heesite.

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 (137) as VENKATESH (1954) has described. See Flate VII. Pseudo-hexagonal outlines are often developed. The optic angle is surprising in that 2Vx is only 20 -  $20^{\circ}$ . 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 RIGEY (1949).

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

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## S. TALL DOOR ALTERATION AND PERCLOSICAL PRATINESS ACCOULATED VIEW THE SULFLUE INVASION.

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Foatures associated with the sulphide invasion ere best considered under the following sub-titles:

I. Carbonatisation.

II. Chloritisation and biotisation.

III. Peldspathisation

IV. Association of other ellicates with the ore formation.

Many of these features san be studied only under the microscope wherers others have been complemented by underground of servations. Those rooks where alteration can be studied best are the immediate wall rocks of the pyritic veinlets of the ore breecia. Transitions from ore to unaltered wall rook can often be : "served in one and the same thin section.

A common form of wall rock alteration described from other sulphide ores is serioitisation. See GAVELIN 1939, ODMAN 1941 (particularly well developed at Boliden) SCHWARTE 1955. Looking at Du Riets' 1953 map of the Kristineberg region it becomes evident that cericitisation is to be reckuned 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 sons of serioits formation to the individual ore-bodies. What one can study, however, is the alteration of the sericite quarts cohiete and limestones, by the ore forming solutions, which is important, as it gives an idea of the composition of the ore solutions.

#### I. Carbonatisation.

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This type of carbonatisation is not a usual form of wall reck 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 k penetrated the signeent wall rocks the were strongly abcared. On a microscopic scale, however, it has been observed that small sulphide bearing veinlets that have out across the meta-quartaites, have had carbonates with them, and precipiented them as calcite together with the sulphides. Smaller mecrok epic

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# Pid. J. Scale 1 : 50.

Sture 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 some of mineralisation west of the ore "centre".	
1. Linestone with pyrite imprognations.	
2. Pyritie ore with protrucions into the wall which	
locally costain quarts and caleite.	
3. Serieite guarts echist with rare opalescent quart	
"eyes" (Altered quarts porphyry?)	
4. Chalcopyrite with tremolitic skars.	
5. Irregular some with intonse tremolite formation often	
as radiating aggregates. Chaloopyrite is enriched	
here. Sphalerite and chlorite also present.	
6. Pyritic ore in dominantly carbonate matrix.	
Chaloopyrite enriched irregularly at base.	
7. Folded limestone.	
8. Massive tremolite ekarn rock.	
9. Pyritic ore.	
10. Chaluopyrite enrichment.	
11. Pyritie ore in dominantly carbonate matrix with	
tremolite and chaloopyrite irregularly and locally	
enriched at margins.	
12. Limestone.	



## The. 4. Bot to scale.

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Generalised sketch of the anticline on the 140 m level at Sturemalmen. Chlorite tende to develop from the wall reak alteration of the meta-quartaitee while tremolitic skarn tends to form the same alteration of the limestence. veinlets generally with galene aimeralisation and earbonatee reveal the sem) feature.

In general thus, the carbonitisation one observes at Ravlidenfiltet in the wall rock: adjacent to the ores,(i.e. banded and mixed linestons and quartisitic rocks often with tremslite having developed) should not, in the author's opinion, be confused with important carbonitisation associated with mineralization, as it is mainly a teotonic feature.

## II. Chleritiantica.

In the discussion of chloritisation here only the chloritisation related to the sulphide invasion will be considered. The mass of chlorite rooks at Rävlidenfaltet are thought to be formed from two closely linked, but sufficiently different, processes: (2) Their formation from limestone; a presses supposedly pressding the ore formation and most likely related to the metemorphism and folding of the whele area, and (2) obloritisation 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 obaractor to the former type in that alkali metals are usually also associated (feldspar and biotite). This form of alteration to the quartsites 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 herder of massive tremolite ekars rook. (See Figs. 8 and 9.)

Local chloritisation of this nature is particularly neticeable in those regions where apophysal portions of the ore project into the quartaites and are generally rich in chalcopyrite and pyrchotite. The same applies to the under side of the anticlinal part of the Stars-orebody more much of the copper rich fraction has forced its way into the self will recks in the form of numerous veinlets, giving rise again to chloritisation of this rock.

The ore breecis exemplifies this principle. Here the pyriis veinlets have sharp contacts with the quartaites, while the chalcopyrite rich veinlets corrode and chloritize the quartaites remitting in more irregular contacts. This use con frequently observe is exponences of less than 1 m² in size in frequently observe is exponences of less than 1 m² in size in the ore breecia. Similar phenomena in other parts of the Skellefte district have led Gavelin to suggest that chalcopyrite and pyrrhetite rich orse give rise to the origin of altered rocks rich in iron and magnesium while the pure pyritic ores coour together with the serioite quartsitee. GAVELUE 1939.

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

Before proceeding further with obloritisation, biotisation should be mentioned. Often the significance of blotite is marred visually by the dominance of oblorite. Biotite is frequently associated with this type of wall rock alteration. It is particularly well developed in the massive orestal part of the Sture orebody, i.e. in the massive sulphide ore immediately above the contact of ore and quartalte 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 oblorite.

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

Details of this elteration are seen in the ore breccis. Here the adjacent wall rooks are fairly normal looking quartaitee, but they frequently contain biotite together with chlorite. In such cases serioits a probably responsible for the E contained in the biotite. (In other cases where the ore lies in a biotite atrix an influx of potassium together with EgO is required). In the more metacomatized parts of the rooks, where chlorite in biotite are enriched, feldspar is often encountered. It is polkicblastic containing about 35% An.

The ore bands of the ore brecois may show abrupt or / ... 47 / ...

transitional boundaries with the que trites. A general feature is the coarsening of the quarts grain else. Quarts 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. Tale may also be present. Plagioclase is often developed with good albite twins. The composition is generally 35% An. Spidote 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.

Microscopio investigation of the other chloritio ores confirm the above features found in the hard ore region. Biotite, however, is less important and frequently absent. Tale is usually present though in small amounts. Sphene and epido*s are always present though only as subordinate constituents. Feldspar, caloite and tremolite have been found in these ores and their wall rock and on one occasion a Na rich seapolite was found. The aspenblages 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, Na₂O, K₂O and OH into the surrounding rocks. The quartsites have been altered to oblorite and biotite bearing echiete while at the limestone contacts a thin border of tremolitio skarn reveals the fixation of MgO,  $Al_2O_3$ , SlO₂, and OH (these are essentially similar to the elements which are listed above, showing one and the same process). The simili metale where a preference of being incorporated in the obloritio milieu where biotite can then be formed.

That such an alteration does not proceed far in the quartaitee is not so surprising in that it requires great amounts of MgO, FeO, Al₂O₃ and OH. C. VITALIANO (1957) has made a detailed study of the wall rook alteration of the rhyolite porphyrry wall rock along a vertical fissure at the Broken Hills Range in Nevada. Here distinct soning has produced sericite-talc-chlorite. Chemical analyses showed /... 48/...



## <u>Pia. 10.</u>

NEX KXXXXXXXX

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

a enrichment of MgO and a corresponding impoverialment of  $810_2$ ,  $A1_20_3$ ,  $E_20$ , and  $Na_20$ . 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 stained.

## III. Peldspathisation.

Foldspathisation in the country rock is of two types and these are difficult to distinguish. During the regional metamorphism and corricite-quarts-cohiet formation, porphyroblastic foldspars may cortainly have developed. Another stage of foldspar formation is related to the ore forming proceeses as well and the evidence for this follows below. This latter stage of foldspar formation is not easy to define in its distribution largely due to the fact that it is quartitatively small.

However, critical examination has revealed that feldepathisation closely related with the sulphide mineralisation has existed, as is clear from the accociation of albitic rich plagicelace often accociated with the chloritisation, described above. On a microscopic coale, 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 feldepathisation is provided by fig. 10. Here a quartaitic rook tapers out into the chloritic schist. Related to the shape of the original metaquarteite is a sone of feldepathic spotting in the chlorite schist. The meta-quartaite is a typical chlorite-quarta-echiet made up almost entirely of granoblastic quarts and small flakes of chlorite which are evenly dispersed throughout the rook and which make up a very small fraction. Sericite and ephene are accessories.

The chlorite schist is almost entirely of fine grained chlorite flakes of similar orientation. Calcite, ephene, and epidote minerals make up the accessories. The feldspathised schist then, is morely the latter with rounded feldspar aggregates frequently showing interpenetrated types, /... 49 /... While not representing interpenetration twins in the majority of cases examined. The feldspar is highly modified being altered and replaced by corisite, tale and oblorite. Quarts is cometimes found as granoblastic aggregates. The composition of the feldspar is shown below.

The question arises as + whether the feldepathised chlorite echlets is a transiti al stage in the ohloritisation of the coricite quarts schists: a deteiled front of metasomaticm? This, if so, should always be found associated with the ohloritisation of the meta-quartaites, which is not a general rule or feature. Secondly, these quartaitle 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 ohlorite schists and/or larger banks that have been drawn out.

It seems more probable thus that feldepathising solutions have entered into the ohlorite rock at a site that was controlled by openings due to the relative competency of chlorite schists and the brittle quartsitee. This example is described from an occurrence in the hanging wall rocks of the Sture orebody. Spotted ohlorite schists of a similar nature have also been found in the A ore area. The anorthite content of these plagicolasses 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	Perioline Aoline	JON (aligned)

Refractive index determinations indicate an An content of 35%.

Other microscopic features have testified to the existence of this feldepathisation. In sericite-quarts-schimte feldspars have been developed along, and in the sericite bands. These are shear planes, and in detail, would be where solutions sculd enter the reak. They would not flow through the granoblastic quarts bands. When sulphides and chlorite appear /... 50 /...

- 49 -

tegether with the feldspar then a metacomatic origin of the foldspar also cooms highly feasible.

Indisyutable evidence of feldepathisation is supplied by a quartaite lying in the anticlinal part of the Sture ore-body, where veinlets of foldepar out diagonally acrose the schietoeity of the resk. In this same locality one has observed the chloritisation of the quarteites adjacent to the massive ore; chalcopyrite rich quarts veinlete which have been equeesed out of the ore; and now even further away from the ore - feldepar veinlete, (30% in)

Feldspar formation as a whole then is complex as we have differing origine for this mineral. What can be established is, however, that there has been a small though noticeable formation of feldepar in conjunction with sulphide formation. In general the feldepar is a soned, often altered, plagioclass and having an average composition of 30 - 40% An. Simple albitic twinning is not uncommon. Microoline has also been observed. The limits of this process appear to be close to the altered rooks of the sulphide ores and in some cases there is etrong evidence to suggest that they (the feldepare) are very late in the paragenes of the different rock types found. possibly due to a equessing out of a residual solution from a eemi-concolidated ore.

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#### IV. Accountion of other Silicatee with Ore Formation.

Amphiboles are often found in the ores where lineetone has been present. It is generally a tremolitic variety and thue indicates that MgO, A1201, SiO2 and OH were introduced into the rook. 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 aseociated 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 soisite - a soisite fele in other words. Under the /... 51 /...

microscope the rock revealed the following constituents; soisite, chlorite, mecovite  $(2V = 40^{\circ})$ , tremolitic ekarn, emicite, a highly altered feldepar and sulphidee. Zoweite and mecoc.ite had a poikioblactic form.

Here then, is an example of a previous rock of unknown composition, ohanged to soleite and muscovite by the action of the ore colutions. Zoleite, asweloptd as such, is a ekarn mineral, its mode of formation being similar to tremolite.

Sphene is found together with the sulphides in the more unaltered rocks. This association of ephene 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 parageneeis, 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 relatione of the accesseory minerals are difficult to establish and the conclusions one draws are possibly far reaching.

Concluding the wall rook 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 feldepars indicate that a small but certain amount of alkali (Ka, Na) metals were also brought along with the mineralizing solutions. CaO and CO₂ 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 soning and clear out wall rock alteration. At Rävlidenfältet certain trends may only be brought out and left on a qualitative basis.

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## 7. THE ORDE OF RAVIDLENFILTER.

## I. ORE ELEPATORI.

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

### ABSTROPURITE.

In general this mineral is rarely encountered. It appears to be more frequent in the Ravlidsyran ores than in the Sture ere where it is very rarely encountered. The minoral occurs as subsdral grains so that paragenetic relationships are difficult to establish. The data setablished shows that it is both sarlier and later than pyrite. In the Sture .e, arsenopyrite was noted to contain rounded inclusions of pyrite similar to those found in the contripctal replacement of pyrite by later minerals. In the A ore remnants of a mineral which might be arcenopyrite 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 arcencyrite was in fact later than pyrite and corroded it.

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

It can thue be established that areenopyrite is one of the first minorale to orystallies, possibly being elightly later than pyrite.

#### PYRIE.

Pyrits is widely spread and coours in all the erebodies, though it is of greater importance in the A cre and Sture ore. In the sine rich 3-D and C cree pyritic bands are senstimes developed, and often diffuse, being well co. ded by the sphalerite. This mineral is also one of the first to

## 24. 12.

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Fig. 11.

PT	-	Pyrite.
gal	-	Galona.
opr	-	Chalcopyrite
op	-	Sphalerite.
G	-	Gangue.

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

Fig. 12 x 55. Carles texture of pyrite.


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118. 13.

N.L.L.Y

py = Pyrite. opr = Chalcopyrite. G = Gangue.

## 71g. 13 x 55.

Pyrite attacked by ehalcopyrite giving rise to isolated rounded grains.

## 71g. 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 minurals it is generally crystalline displaying cubic forms. The ore breesia of Sturemalmen provides a good example of this feature. Pyrite cocurs as independent scattered grains, invariably subsdual, with a grain size which varies  $0.00 \times 0.07$ cm² to  $0.005 \times 0.005$  cm². Under similar conditions pyrite may occur as massive rather irregular clusters of grains, the individual grains still pertaining to their cubic habit.

When accoriated with other sulphidee 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. contripetal 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 sulphidee, the pyrite may fust occur as small (0.01 - 0.1 mm) rounded, isolated remnants, scattered throughout the surrounding sulphidee. (Figs. 1.4 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 individuale in the A ore reveal a rather peculiar feature. These individuale have a definite soned 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 anisotropian has been found in both conce. The anisotropian is strong and suggests that the mineral might be arsenopyrite or elec 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 245 2 Micole.

Cordierite. Interpenetration Twins and fine Polysynthetie Twine.



## PLATE VIII X200 1 Nicol.

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



## MATE IX I O 1 Nicol.

Bozlike framework of Pyrite which has been replaced by phalerite.





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Ebowing sened pyrite shapes from the A-ore.

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

Anisotropic effecte, sometimes rather strong, varying from a buffish yellow colour to a bluich 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 anisotropicm and the temperature of deposition. It is an interesting fact that the anieotropism could be obliterated by harch 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 Rävlidenfaltet.

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 quartaitee, 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 account of chalcopyrite. In all those epcoimens /... 55 /...



## PLATE X. X180 2 Nicols.

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

## PLATE XI. X215 1 N1001.

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

> PLATE XII. X175 1 Nicol.

Exectved 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 ephalerite 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 ephalerite lattice a certain amount of pyrrhotite is driven out of the orystal 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 ephalerite 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 lummelae are developed. These are identical to those described by GAVELIN (1939).

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

#### SPHALERITE.

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Sphalerite is encountwred in all the ores but has its most important development in the B-D and C ores. It is not a true ephalerite, and due to a certain amount of iron eulphide mixing is really a marmetite. The amount of iron in one specimen of ephalerite was 8.5 wt \$. (BIZOUARD 1958). It was originally intended to use Kullerud's (KULLERUD 1953) method of iron content of ephalerite 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 Bisouard op.cit. )

Above we saw that pyrrhotite is exsolved from ephalerite developing characteristic forms. (Plate XI.) As regards the exsolution of chaloopyrite however no general tendency has been observed. One may observe chalcopyrite /... 56 /... grains in sphalerite which show a certain alignment. Closer examination shows that if one follows the trands 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 quarts vein (ore pegnatite) gave evidence of ohaloopyrite having exsolved from sphalerite. This however, is more of a curiosity than a general feature of the whole area. SUGAKI and YUMLE (1952) were able to show experimentally that lattice shaped and globular ohaloopyrite diffuse into the schalerite lattice at a temperature of  $350^{\circ}$  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. HENGER in 1934.

It seems thus, that exsolution of ohaloopyrite 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.

#### CHALCOPYPITE.

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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 excolution structures. Vallerite is nearly always found as excolved in obaloopyrite, 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 /... 57 /... <u>Fig. 16. z 600.</u> Vellerite exectved from chalcopyrite (opr).

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solved vallerite according to orystallographic directions in the chalcopyrite. (See Fig. 16). According to EDWARDS vallerite included in chalcopyrite is converted to pyrrhotite and chalcopyrite if heated above 225°C. This temperature is the temperature at which chalcopyrrhotite becomes unstable and transforms to vallerite.

Cubanite is also exsolved from chalcopyrite in the chalcepyrite from the whole area. It generally cocurs 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).

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

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

In a banded ephalerite and pyrite ore an interesting feature was noted and this was that the chalcopyrite tended to /... 58 /...



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## PLATE XIII X300 1 Micol.

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



## PLATE XIV X200 2 Nicols.

Large Grain of Cubanits (cub) excolved from Chaloopyrite (Opr) G = Gangue. PY = Pyrite.

## PLATE IV X175 1 Micol.

Poorly developed Sphalerite Stars (Blae) and a Cubanite Excolution Lath in Chaleopyrite. confine itself to the pyritic bands. It did attack, or permot the sphalerite band to some degree, but microscopical investigation showed that this was only confined to the marginal some,

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Pyrite-ore with chalcopyrite.

Pyrite-ore with chalcopyrite.

Chalcopyrits invaded some in sphalerite band.

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

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

Some unusual occurrences of Chalcopyrite are also encountered - unusual in that it is closely related with galena. Opper rich ores are generally differentiated from the sine rich ores which nontain 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 fellows galena explicitly. A reaction between tetrahedrite and remant 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, galean and a little tetrahedrite may occur tegether. " see paragemetic relations have also bers recorded from other parts of the Skellefte district, e.g. See GAVELIN 1936.

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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 mineralization.

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

Galena is intimately associated with the sine ores. This trend is shown in fig. 21. GAVELIN has shown very of arly 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 cormon site of deposition, in the complex ores, is at the pyrite grain contacts.

#### TETRAHEDRITE,

BALLER.

This mineral always tends to coour together with galens. Hymekitic 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 thems two minerals. Plate XVIII. Such intergrowthe have been observed in chalcopyrite, pyrrhotite, sphalerite and alee in the ganges. In general, however, tetrahedrite coccure as small rare grains tucked away in the corners of larger galena masses. On other occasion it coccure with other sulphides in complex intergrowths as have been described above. Tetrahedrite is probably one of the chief carriers of silver, pyrargyriite also being important as regards silver.

#### GUDHUNDITE.

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 pre.

/... 60 /...

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### PLATE IVI I300 1 Nicol

Exactved Sphalerit in Ol cloopyrite. Note the well developed ephalerite star or the left.



PLATE XVII X200 2 Nicole

Twinning in Chalcopyrite.

> PLATE XVIII X150 1 Nicel

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





FIG 18



FIG 19

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

## PLG. 17. x 375.

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

Pig. 18. z 625.

Galena later than boulangerite which it corrodes.

## Pic. 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 remotion 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 anieotronism 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 ave been discussed in other ores from the Skellefte district by GAVELIN 1936 and ODMAN 1941. In the REvlidenfältet 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.

シスエー

The author has drilled holes in purs tetrahedrite crystals and filled these with powdered pyrrhotite and then heated them in order to eimilate the above reaction in the solid pyrrhotite phase. Gubes of tetrahedrite and pyrrhotite were clamped together and also heated. Cupper apparently moves very quickly as chaloopyritic and chaloopyrrhotitic looking minerals are obvained 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 chaloopyrrhotite 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 eimilating cubanite +<br/>whitish material.That not only tetrahedrite is responsible for the<br/>formation of gudmundite is revealed by figs. 17, 18 and 19.

Nets that after the antimony has been used up in the gudmandite, a reaction rim of galena forms, the lead having been releved from the altered boulangerite. Gudmundite has also formen as a reaction product of bournonite and pyrrhotite. It is of interest to note that the texture is apparently dependent on the realtents. A ramification texture is developed (with bourmonite), and this has only been observed when gudmandite forms from this mineral. Plate XX. The same feature le 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 ie replacing the bournonite or is a reaction product caused by the breakdown of bournenite (the antimony being incorporated in gudmundite, the remaining Cu and Pb and Sb and S forming tetrahedrite and galena) is not possible.

#### BOULANGERITE.

X

I

Boulangerite has been found in all the ores though it is rare in the Sture orebody. It has been found in all the Rävlidmyran ores in fairly important amounts in the galena phase of mineralisation. Amounts as high as 6 volume \$ have been recwrded 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 mineralisation 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 meetion 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 en one other occasion in the sine rich B-D ore. Here it gave rise to the gudmundite ramification texture described above.

In the calcite vein bournonite occurs intimately inter-

# 714. 20 x 600.

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



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

#### PYRARGERITE.

Pyrargerite had been observed in several instances in the O erebody 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 cocurs 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 proustits.

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

#### BISEUTH.

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 /... 63 /... softer than sphalerite. The mineral was isotropic and is thus probably gold.

## 

Occasionally, bright white, extremely small, generally rounded grains can be observed under high power mernification 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.

#### ALSAISE.

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

#### HESSITE.

Heceite has been observed in the same quarts vein deceribed above. It is faintly brownich grey in colour, with a weak but observable reflection pleochroism, and is strongly anisetropic. It is cofter than galens and altaits, and frequently shows twinning. It may be found together with altaite and boulangerite as deceribed above; these minerals worely 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 4 ore. Its mode of occurrence was as irregularly shaped ,rains often with a bad polish.

## MARCASITE.

Marcasito was one of the first supergene minerals to form, forming commonly from pyrrhotite. Plate XIII. It /... 54 /...



tends to cocur 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:

MULTER REAL MAN WANTER

This is a supergene mineral derived from chalcopyrite in the main. It occurs as veinlets brecointing other sulphides and frequently as challs or ceatings around other sulphide grains. In the breakdown of chalcopyrite into chalcocite, geothite (or a similar Fe mineral) is frequently found in the came veinlete.

As regards the supergene minerals the above two sulphides are the only two that have been mentioned. Other supergene minerals are geethite, malachite, eiderite, 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 ere specimens. As was pointed out before far better statistical data on another Skellefte district ere 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 normalized, i.e. they have been divided by some number so that, in this ease, the quotient for the highest percentage for any one mineral occurring in the different samples has the value twe.

The specimens are plotted along the abscissa according to decreasing sphalerite content. Along the ordinate the normalised values are plotted. The object of using normalized 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 cach 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 (er ores)

/... 65 /...

- 64 -

divide tinnesives into the types: one is sphalerite ore with shoer amounts of pyrite, chalcopyrite and pyrhotite, and a second type where these latter minerals reach maximum 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 eine peer oree there is a striking correlation between pyrite and chaloopyrite.

This diagram has many weaknesses. The main weakness lice 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 sinc rich types which contain the galena phase of miner-lisetion (which usually contains antimony sulphides and silver and also bismuth), and the pyritic oree with varying amounts chalcopyrite and pyrrhotite. Another ore type is the copper rich ere 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 Revlidmyran 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 sinc. 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 fellewing 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 ere types is the group of copper rich fractions, or segregations.

(1) Dominantly massive pyritie ores. In this group are included those pyritie ores with appreciable visible quantities /... 66 /... ophalerite minu alization, usually developed as pyrite and ophalerite banded . . (distinguished on the mine plans) and these without or with very little eine mineralization. The latter eften earry chalcopyrity.

(ii) Ore breecia ("hard ore" on mape). Hard ore is a direct translation of the Swedich word "hårdmala" a layman's term originally need at Falu mine (Central Sweden) to describe chalcepyrite concentrations in meta-quartaites. This term has subsequently been adopted into mine terminology for even other types of ore in meta-quarteitee and mich-schiete. At the Sture ore "hard ere" refers to what is essentially an ore breecia cocurring in the meta-quarteitee. The ore mineralization is largely of pyrite and losser copyrite. See plate XXI.

(111) Copper rich fractions: they are usually small and lectted 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 haphasard. The eino bearing pyritic ore does not represent any separate independent ore which was introduced earlier or later in relation to the pyritic ore without eine; the whole ore coincides with one ore forming period and not with different well defined periods as at Bolider in particular, and even at Krietineberg which has a late sphelerite ore phase. See 0.2MAN 1949 and DU BIETS 1953. As a general trend, but by no rigid, is the occurrence of more sinc 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 fmirly rich ere of copper, but unfortunately, is rather narrow (* 2% Cu and about 20% S, with sine).

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

The sphelerite banding le interesting. It may vary /... 57 /...

## PLATE XIX X1000 1 Micol.

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

## PLATE IX 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.



Mas - Ginerite with miner tale.

from several mas. to several one in thickness. Where inclusions (linestone as described on page 39. Plate IE) coour these sphalerite bands wind their way smoothly around them and centime as before. The sphalerite bands and lenses may take on surious shapes (locally folded, arounte, pinch out and swell, convex swellings etc.,) and are not continuoue. See Plate IXII. 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.

Linestone, oblorite and tale, biotite and tremoliteactinolite 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 obloritic ore types in general are confined to the area where the unceive ore lies in centect with quartsitee. A general tendency noted in the pyritic ores is that sine mineralisation becomes noticeable in the limestone rooks while the obloritic ores are dominantly pyritic with miner chaleopyrite and sphalerite.

Fig. 22 is a section taken through the ere te demonstrate the behaviour of the ore and the nature of the wall reeks in the dominantly linestone regions of the ore. In general the contacts with the wall rook are abrupt. However, the ore is also seen to brecoiste the linestone 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 rooks are dominantly of carbonate, but in epite of this, the ore is confined to definite sonse; the ere even follows fractures in the limestone. The more massive ores have probably been localized, by definite sones of more intense shearing and/or fracturing.

To illustrate the importance of J'mcetone in localising the ore, fig. 8 serves well. Here the ores follow the limestone horisons obediently and no ore is found in the skarn recks or the altered quarts porphyry. Here again the centacts are sharp. These contasts are, in nest cases, bordered by a thin and persistent band of massive tremelitic skarn (10 - 20 cm thick) which frequently contains pyrrhotite and shaleopyrite mineralizetion. Ore contacts may also be of a different nature to these eases above. But infrequently does one objerve veinlets of quarts will chalcopyrite and pyrrhotite which out across the contact of the massive ore and the enveloping wall reck. 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.

- 60 -

The minoralegy 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 m² to 0.6 x 0.6 m². Larger grains up to 5 mm have been found. When the pyrite occurs in a gangue matrix it has a relatively well developed subsdral 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 ohaleopyrite give rise to the most effective corrosion of pyrite.

Areenopyrite is an unusual constituent of these ores, being sparingly and widely scattered. The grain eise is similar te pyrite but it is invariably subsdrally 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, mads complex by the appearance of pyrrhotite, sphalerite and occasionally galens. Intricate intergrowths may thus be found.

The sine bearing pyritic ores can be similar to the eepper bearing types in that sphalerite dominates after pyrite. Chalcopyrite and pyrrhotite may be present in subordinate amounts, while galena, though making up a miner constituent, is frequently associated with sphalerite. The sphalerite invariably reveals blobs, lathe and broader staves, of excelved pyrrhotite of the same eise that are recorded in the Raviidmyran eres.

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

- #3 -

Although galena tends to follow the sphalerite phase of mineralisation, its concentration in the sine 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 mineralisation of the Sture ore and the Rävlidmyran ores. The latter are decidedly richer in antimony minerals (e.g. Tetrahedrite, boulangerite, gudmundite) which are occasionally intergrewn in approximately equal amounts in the galena phase.

The important Ag mineral at Sturemalmen is Pyrargyrite. Minute intergrowths of galena, tetrahedrite, pyrargyrite, shalcopyrite 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.

#### 11. THE ONE BRECCIA.

The ere breecia is of a totally different character to that described above. The ore is made up of numerous sulphide veinlete, generally only several ens thick, following a definite system of fractures in the brittle meta-quartaites. The resulting ore is thus a type of breecia.

The veinlete can be noted to give the following characteristice. The pyritic veinlete have extremely sharp contacts with the meta-quartaitos. The amount of alteration is negligible to the maked we. The contacts between the oulphide veinlete end the meta-quartaites tend to be fairly straight and continuous. One also has a transition from the above type of veinlete inte a wider mineralised or sulphide impregnated somes up to about 30 cm in thickness, and them into massive ures. This larger mineralised some still has sharp contasts with the quarteites and is variable from disseminated types to /... 70 /... denser types, the matrix being essentially of biotite and oblerite. This is not a case of vein filling but rather a sheared sons in the quartaites, metasomatized and replaced by the ore and the constituents of its transporting medium. The final transition is then, to massive pyritic ores which esser in a similar matrix and represent an intensification of the latter example, i.e. a larger shear sons in the meta-quartaites.

- 70 -

A greater part of the ore east of the ore "centre", and sections of the 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 eres in general at Sturemalmen. (The same applies to Rävlidmyran), i.e. somes of shear, (even in the limestones) and opening at the contact of the limestones and competent quartzite.

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

The mineralogy of the ore breccia is relatively simple, consisting mainly of pyrite. In the more copper rich veinlete, obaloopyrite and pyrrhotite dominate. Pyrite may vary in eise, often being coarse, several mus in eise. An average eise is 0.2 - 0.5 m. The pyrite grains are subsdral when they coour alone and attacked rather severely when obaloopyrite appears. Beautiful breecistion textures of pyrite by chaloopyrite have been recorded from these ores.

Arsonopyrite has best noted in these ores but is rare. Sphelerite is generally not a common constituent of these ores. A thin continuous band of sphelerite, however, lies in the foetwall 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 veinlete rich in sphalerite have been observed in the ore brecois. The sphalerite attacks the pyrite and is relatively free from excelved pyrrhotite. As a rule sphalerite

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Cu	6.3/	0,82	294	1.00	123	167	2.30	0 ef	1.82	165	aH		234	107	-		3.00			
Zn	0.05	0.10	0.55	022		03/	044	44	0.95	010	0/3	0.29	051	an	6.00	1.00	027	189	14	
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## FIG. 23.

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

Yellow	-	Nota-Quartisic Wallrock. Pyritic Ore.
Red. Bright Red Dark Green	-	Quartz Veins. Chalcopyritic Mineralization.

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

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

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

Concerning the chalcopyrite mineralisation several features are worthy of menion. Sphalerite excolution stars have been found which indicate relatively high temperature. Cubanite and vallerite are also excelved 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 ee 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 preved 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 ere are assay limits rather than true geological boundaries.

# 111. COPPER RICH SEBREGATIONS.

As was pointed out in the beginning these ores do not represent any real secondais 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 crea as repards genesic.

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 apophysel protrusions equeezed out of the main ore. Another feature associated with these copper rich segregations is the local chloritization of the mete-quartaites (A. 72 / ... where they lie in contact with such. At this stage some of these features can be better illustrated with diagrams.

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Fig. 8 shows some o these features well. Chaloopyrite and pyrrhotite are enriched along the marginal portions of these sulphide lepses and at the same time an intense sons of tremolite is developed.

The 140 m levelshows the same feature combined with an intense chloritisation (a quartsitic milicu) e.g. on this level, in the region west of the ore "centre" the northenmost lense has a small offshoot from the main ore which projects into sericite-quarts-schists. This apophysy is firstly rich in chaloopyrits and pyrrhotits. Secondly a local sons of obloritisation around the copper ore is obvious.

The footwall contact on the 190 m level again illustrates this feature. Here the massive ore contacts sericite-quartzschiste. A chloritic sons some 1 m wide with chaloopyrite 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 else of the individual minerals may vary between wide limits. Usually visibly large pure chalcopyrite grains, are contaminated by other minerals when viewed under the microecope. 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 oree. 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 squeess d out with the unconsolidated obaloopyrite. Galena is one of the last minerals to orystalize in the Sture ore paragenseis and thus would also be unconsolidated when the chaloopyrite had not yet crystallized, and thus be forced out /... 73/... with chaloopyrite. The fact that this feature is not so commonly found lies in its small concentration in the ere, and ite sporadie distribution.

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## IIb. THE A ODE.

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Data on this ore has been obtained from underground boreholes, and from the stopes that were being prepared. Considering the whole ere it can be seen that it is in fact a mineralised some 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 ors with a small content of copper and sinc. The since mineralisation in particular, appears to be highly erratic. In general the massive lenses pinch out and give way to disceminations on strike. The matrix of the ore is mainly limestons and tremolitic skarn, while chlorite and tale are also encountered. Often a chloritic border is found at the massive cre contacts, particularly when the wall rook is a quarteite.

The most interesting feature with this ore is the manner in which the meesive ores are in general, located at the limestone-quartaite contacts. Quarteitic fragments and lences often lie in the limestone, probably as a result of the folding, the limestones having been forced into a sone of tension in the Ravlidmyran anticlins, by virtue of their ability to flow under stress. A look at fig. 3 shows how the meeive ores lie very often just at these sites where quarteites 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 colutions which have subsequently metacomatically veplr.ed 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 pyrits in a mangue matrix. In virtually all the cases the ores have a more or less well developed subsdral pyrite grains in varying eises and concentrations. A characteristic feature is that the mains tend to be independent of one another. Grain eises vary mently: from shout 0.12 mm to several mms in diameter. An size is of the order 0.012 x 0.012 mm to 0.15 x 0.15 mm. When other sulphides occur they have a tendency to lie /... 74 /... 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 letter mineral not being frequent. Where these sulphides increase in quantity and are in excess of pyrite, the pyrite grains may be severely corroded. Fyrite 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 soned in this ore type (p Arconopyrite is rare appearing as cuhedral grains of approximately the same cise as the pyrite grains.

The copper rich fractions of the ore are dominated by obaloopyrite (exsolved cubanite and vallerite often included) and pyrrhotite. Chaloopyrite grains can be relatively large, 3 - 4 mm's in diameter. Closer examination of much 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, ohaloopyrite, galena and areenopyrite. Pyrrhotite is most commonly developed as exsolved blobs and lathe and even larger aggregates. Replacement of sphalerite by chaloopyrite happens when the latter is sufficiently dominant. Galena is not of great importance quantitatively and shows preference to be formed at pyritesphalerite contacts.

Pyrrhotitie variants of the A ore generally have pyrrhotite and sphalerite as their main constituents. Pyrite, /... 75 /... however, is sometimes intermixed. Certain amounts of galena and chalcopyrite are also included thus giving fairly complex mineral paragenesses.

As regards the whole some it is of interest to record that the galena phase of mineralisation is extremely eporedic 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 rether unusual as the galena mineralisation is invariably related with sphalerite i.e., this arsociation with sphalerite, which is rigid in the other ores at Rävlidenfältet, is not so important in the A ore.

Antimony minerale obsractories the galena phase of mineralization. Tetrahedrite is the most important of these. Boulangerits 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 be-a 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 ... as been studied in the B-tre 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 untities 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 bards in various stages of replacement. The contacts with the wall rock tend to be sharp. At those contacts veinlets of pyrthotite, chalcopyrite and quarts havebeen observed to project into the adjacent wall rocks. //... 76 /...

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

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

Hintralogically the ores consist mainly of sphalerite which in some cases is almost entirely free from impurities. More commonly one has "toolved pyrrhotite in the form of small laths and blobs which are widely and evenly dispersed throughout the sphalerite. The grain cise of such pyrrhotite graine 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 graine in various stages of replacement. Pyrrhotite masses 0.36 x 0.6 m² are found but even larger grains and bands have been observed.

Pyrite, which is generally enriched into bands, tends to develop subschal grains which in general resist correction by the other sulphides fairly well. The mean grain else is 0.1 x 0.1 mm to 1.3 mm x 1.3 mm. Areenopyrite may also be found tegether with the pyrite. These two minerals can be rather intricately mixed. Areenopyrite is nearly always found as subschal, grains when scourring 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. Areenopyrite elusters of theelse 0.2 mm x 0.15 mm containing small individuals of the else 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 conscious only. It may occur as small rounded grains in the sphalerite, 0.072 mm x 0.048 mm to 0.18 im x 0.07 mm .m elee. Chalcopyrite is also found under different conditions as was described above (vainlets). It is then the dominant minoral with inclusions of areenopyrite (substrul), sphalerite, pyrthetite given in increasing The latter two minorals are as a rule well /... 77 /...

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corroded. Vallerite has been excelved from this chalcepyrite.

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

Boulangerite and tetrahedrite dominate among the antimony minerals. One polished section B.H. 504 N, 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 tlement. Tetrahedrite can take a cortain amount of Ag into its crystal structure, so that one is led to the conclusion that tetrahedrite is the important Ag mineral. A cortain amount of silver may even occur in the galena, and possibly even in the boulangerite.

Bismuth is also associated with the galena stege of mineralisation in this ere. Finally, marcacite has been found as a supergene alteration product of pyrrhotite.

# TIG THE COPE.

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

The fine grained massive mours of the sre is attributed as a crushing and recrystallination of the sre. As it cannot be continued, but this "mylenitization" probably fullows on B-2 direction which has been characteristic for Revlidenfaltet as a whole. Judging from the borcholee this mylemitization is not necessarily applieable to the entire crebedy. In fact normal sphalerite are portions are located in the bercholes. These facts will become clearer once mining of the ere-bedy economese.

However, a direct roult of this mylenitisation is the highly complex intergrowth of the minerale. This complex ere is prodominantly of sphalerite intrisately mixed with galexa and pyrrhotite. Grain elses are small. Sphalerite can appear as small 0.012 mm x 0.008 mm graits 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 minorals are characteristic and represented by tetrahedrite and grimmndite. Gudmundite grains are of the else erder 0.024 mm x 0.024 mm. Boulangerite has been observed but is uncommon in this ere.

Pyride and arsonopyrite are found occasionally. Pyrite can be fairly smal. in the sylonitic ore types, e.g. 0.008 me to 0.012  $m^2$ . Areonopyrite, though rare, appears as subcaral grains. It is of interest to recard that elongate areonopyrite grains are oriented with their long axes parallel to the lineation of the sylonite ore.

Pyrrhotite is invariably present and is developed as extremely small rounded bloks in both ephalerite and galens.

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 cylonitised, sphalerite has exacted pyrrhotite laths and staves in it. Chaleopyrite, and this applies to the whole ore, is uncommon. Gudm.adite is formed together with galena, indicating a consistent enrichment of antimony. This is furthermore confirmed by the presence of tetrahedrite. Bismath has been for ad associated with the galena phase of mineralization.

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

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Arconopyrite and galena have been observed to a minor constituente under such conditions. This (as with the B Ore) suggests an enrichment of chalcopyrite vogether with pyrrhetite at and outside of the maccive sphalerite ore.

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

TABLE 9.				
	A-Ore.	B-D Ore.	C-Ore.	Sture Ore.
Arsenopyrite. Pyrite. Pyrrhetite. Sphalerite. Chaleopyrite. Galena. Tetrahedrite. Gudmundite. Boulangerite. Bournomite. Pyrargerite. Haroacite. Electrum.	X XXX XX XXX XXX XXX X X X X X X X	X XX XXX XXX X XX XX XX XX XX XX XX XX	X X XXX XXXX X XXX XX XX XX XX XX XX XX	• 27223 272 272 272 272 272 272 2
Biamth.	I	X	2	Z

TERE Very common.

xxx Rather common.

- IX Comon.
- z Uneomon.
- Rare.

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# DISCUSSION.

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After having described the general and detailed geology of the Mavliden 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 Ravlidenfältet 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 quartaites 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 rooks at Sturemalmen which is apparently not related to the sulphide invasion which itself only gives rise to local chloritisation.

(3) the nat. e 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 chloritie rocks intimately associated with carbonate rocks and skarn mineralisetion. 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 ligestones 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

chlorite schists at related to the sulphide ores? The symmetry of the chlorite recks in relation to the ore-body does not bespeak a direct opecial relationship. We also have evidence of the existence of chlorite recks prior to the ore formation as illustrated by ekarn veinlets with sulphides having formed in the chlorite schiete, the ere presumably having been introduced tegether with a certain amount of CaCO₂. Feldspathisation intimately associated with the ore forming processes, has been observed in chlorite schiete that must have existed before the

introduction of the sulphides. (Page 48).

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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 RIETS (1953) of the Kristinsborg mine shows that these rocks are found only adjacent to, and in, the sulphide ores, illustrating thme local chloritisation. The sone of massive chloritic rocks at Kristinsberg, is by no means comparable to the large area of chlorite schists at Rävlidenfaltet. See also page §6.

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

development of much serpentine. These two latter types are, however, confined to the phyllits series, GAVELIN 1955. DU RIFTS' map of the Krietineberg region gives no indication of basic effusives (See Appendix I). The hornblende dasites from Hernberget are the most basic types described by the latter enthor, and these would require large amounts of magnesis for the formation of a chlorite sohiet. According to Du Rietz these rooks are strongly chloritised and contain 7.38 wt% and 4.22 wt% MgO:

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The chlorite schiets then are of particular interest at REvlidenfältet, 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 expansions available in this area to study the more unaltered nature of the limestones. Were they rich in dolomite so that magnesia metasomatian played very little part? DU RIETZ (1953) speake of a removal of Na and Ca and an addition of K, Ng, S and Fe for the Kristineberg region in general. See page 25.

The alteration of dolomite or dolomitic limestone to ohlorite schist (i.e. if it contained MgO in sufficient quantities) would imply a removal of Ca and CO2 and an introduction of H20, Al, Si and Fe. Some of the Ca might be fixed in the new existing carbonate rocks. Where these latter elements same from capact be said with certainty. A certain amount of them could quite assured'y have occurred in the primary stratigraphie 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 Co₂ balanced by an introduction of H20 which would be added during the main period of folding. The analyses of the linestones 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 nets somation. 1 .... 10 / ....

It is unlikely that magnesis notasonation associated with the fermation of the Revsund granites in the 5 of the Kristineberg region would be affective as far N as Sturemalmon (See Appendix I). Cordierite is found in the quartalte soning afound the Revsund granite mass and this occurrence is some 2 hm 5 of Sturemalmen.

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It would seen to be more likely that the large amounts of Mg required for the relatively wast 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 ceale magneeis 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 nome previous skarn mineral (e.g. amphiboles, indicating a higher metamorphic grade) by the hydrothermal alteration eaused by the introduction of the sulphides?

Returning to DU RIETZ' map of the Krietineberg region again one see that Rävlidenfältet lies in rook types obaracterised as "Sericite quarts schiste often with oblorite" which would indicate rooks of the greenschiet facies, i.e. the reaction:

eericite + ohlorite ----- biotite has not yet started. Biotitic rooks do in fact coour in a sons related to the Revsund granite some 2 to 3 km south of Sturemalmen. These rocks are labelled as "cordierite biotite eericite quarts echiete" and the biotite isograd probably lies in the N of this some.

The formation of ohlorite in preference to amphibolee would thus be more suitable for Sturemalmen.

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

It is realised that these views are strictly hypo-

thetical dans to the impossibility of obtaining concise evidence to prove of disprove them (e.g. the original composition of the earbonate recks).

However, a deal of deduced information obtained from other parts of the Skellefte field and the observations at Divlidenfiltet de 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 othere may exist.

# The Mature of the Ors Forning Selution.

Sturemalmen provides the best area for a discussion of the nature of the ore forming colution, 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 miliou, while the B-D and C-ores are dominantly displacement eres 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 rooks are sharp, and we'l rock fragments are also found in the ore, i.e. the observed character of the ores is similar to that displayed by intrusive igneous rooks. The general intrusive character of these ores suggests that they were intruded in rather a consentrated state.

The Sture ere on the other hand, is highly complex in its nature. Undoubtedly the ohemical 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 quarteite contact. In this many region are eclutions have also forced their way along fiftures in fractures in the quarteites to give the ore breecia 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 breeciate the rock. /... CB /...

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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.

factor can still be established, Fig. 3.

As we have seen before, the ore has been introduced along definite chear sense at Sturemalmen (Lie Tig. 22). The drag fold iteelf 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 rooks (or rooks of a shear sons) are represented by chlorite, biotite, tale or tremolite rich bands (streaks, lenses, schlier) in the ore. Banding thus caused by original shear sons slivers, and lenses, have sometimes been folded and moved together with the ore before complete crystallisation, and locally take on textures similating flow structures in ignous 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 cree as explained before. Such banding cannot be due to rythmic precipitation filling veine or openings.

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

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

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Mal und

PLAIE XXII

Locally folded Pyritic Cre Bands in Massive Sture Oie.



PLATE XXIII 1 Nicol. 245

Pyrive Ore Breccia. Pyrite White High Relief. some where movement after part of the ore had erystallised has been established (see above) eculd also be explained by pressure acting da a comi-consolidated mass or a mace which has crystallised to a greater part.

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The question whether the sphalerite ore bands are due to a celective replacement or due to a cogregation of the sphelerite and galena phase from a larger dominantly pyritie sulphide ore solution remains open.

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

One asks then why should not this feature which operates on a large scale (e.g. the L-D and C cres me. t surely represent good examples of a segregated sphalerite cres from a previous ore source) also operate on a detailed scale in a pyritle ore, the in 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 mineralization 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 chalcepyrite 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 erystallisation of the eres.

1 ... 07 / ...

This crystallisation order can hardly explain the accountion symplerite - galena, when considering a mechanism of the segregation into 2n and Cu rich ores. It does however explain the enrichment of chalcopyrite at the ore margins which has teen found together with galene (page 72), the cause of the enrichments thus being a type of filter press action on a semiorystallised org. 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 reliability.

As yet, however, we know too little soout the nature of sulphife bearing colutions, 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 univescal 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 is the understanding of the Revlidenfaltet ores is given by the study of wall rock alteration and a study of the matrix of the ore itself. A definite order of orystallisation of the sulphides can be established and coincident with this is the formation of eilicatee. 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 brecciste the previous silicate grains, e.g. quarts and feldspar in the ores thesselves, and in general occupy positions filling the interstices of the silicate grains. The order of orystallisation of the phyllosilioatee in relation to the sulphides is hard to establish but they appear to be contemporaneous, and in some enses (biotite and oblorite) even later than the sulphides.

It was outlined in a previous section (page 44) that the following features could be associated with the sulphide /... 88 /...

# invasion:-

Carbonitisation: apparently of no greater importance is impossible to establish the significance of this is a limestone milion,) but certainly some low temperature sulphide veinlets s.g. In, Pb, Sb, Ag are found in close secociation with carbonates.

Dar Tord 200.

- (11)-

Other manerals: fregolitic ekarn is frequently formed in limestone rocks.

Foifote minerals have formed by the same precesses but ore quantitatively of minor importance. Other minerals that have been identified in the ores and wall rocks on rare occasions of tournalins, flourits, and apatite which indicate the presence of J., 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 coours in a quarteitic milion oblorite and biotite are generally developed. Feldspar and epidote minerals are also formed. These minerals occur in the wall rooks and the process becomes intensified in the ore.

This feature is illustrated by the occurrence of biotite and ohlorite 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 tremplitic sharn may be developed although tale 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 quarteites while Si Al  $H_2O$  have been introduced into the carbonate rocks.

The two features seem to balance each other; a desilification of thequarteites occurs when the quartaitee are chloritised and biotized. Silica must, however, be added to the limestones for tremclite fermation. Mg for the chlorite sould thue also partly be derived from the limestones themselves which are replaced by the sulphides and sharn zinerals. Fo of course is to be inherent to the ore judging by the vast amounts of biotitic and chloritic ores in the "hard wre", antioling& and "teil" reaches of the ore.

Al likewise found both in the chloritie alteration products and in the tremolite group, is an enrichment compared with coricite quarts sohist and limectonce respectively. The same applies to  $H_0O_0$ .

By such reasoning it can be seen that some of the elements of the ore colution 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, OB2, and MgO.

Mg apparently remains a long time in solution as is evidenced by the common association of chlorite with the late stage chaloopyrite mineralization which is squeesed out from a partly crystallised ore. CaO and CO₂ 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 spe 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 tremolitie rooks 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 granits. The sulphide ores are thus slightly hter 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 poet orogenic granites.

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APPENDICES I - V.











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









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