Petrology. — *Metamorphic differentiation in hartschiefer of Northern Sweden.* By Prof. H. A. BROUWER.

(Communicated at the meeting of January 27, 1940.)

In crushed granites or felspathic sandstones sericitic zones, along which slipping took place, are found between the broken minerals and the more freely soluble quartz may be entirely recrystallized while the felspar crystals have partly resisted recrystallization. The unequal distribution of stress has a selective effect and different minerals are found in contiguous lenticles or bands. Elevation of temperature relaxes rigidity, but at those temperatures where biotite is formed the effects of fracture may still be clearly shown.

A more or less pronounced alternation of bands and lenticles which differ in the relative proportion of muscovite and biotite in their mineral associations is well developed in some of the so-called hartschiefer near Abisko in northern Sweden. These metamorphosed rocks show a large amount of recrystallization and also the mechanical effects of dynamic metamorphism [1, 2]. The pressure and temperature necessary for the intense mylonitization and for the generation of new minerals prove a considerable depth of cover. They alternate with dolomites and the varying mineralogical composition also points to an original stratification but the original differences between the alternating layers have often been greatly obscured and many of the rocks now show banding and not stratification as their most striking feature.

Along the banks of the Abiskojokk and along the lower slopes of Mt Nuolja the metamorphosed rocks mostly were felspathic sandstones with a varying felspar content. In some rocks on the lower slope of Mt Nuolja garnet, titanite, epidote, apatite and other minerals are found, which prove that the detritus was derived from various kinds of crystalline rocks. Felspar eyes (potash felspar and acid plagioclase, mostly albite) are common in these rocks. Along the banks of the Abiskojokk intercalations, which are rich in large crystals of broken potash felspar, are locally found in rocks of a somewhat different type in which tourmaline is a common constituent.

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1) P. J. HOLMQUIST, Die Hochgebirgsbildungen am Torne Träsk in Lappland. Exkursionsführer no. 6. Congrès Géol. Intern. Stockholm 1910.

2) H. A. BROUWER, Ueber metamorphe Gesteine am Torne Träsk (Lappland). Proc. Kon. Akad. v. Wetensch., Amsterdam, **40**, 414—421 (1937).

Cataclastic displacements in the felspathic intercalations.

The felspathic intercalations in the Abiskojokk consist of broken felspars and blastic quartz with biotite, carbonate and iron ore.

The felspar fragments are sometimes strongly torn apart, the other minerals have crystallized in the spaces between them. More or less continuous surfaces of discontinuity along which slipping took place mainly

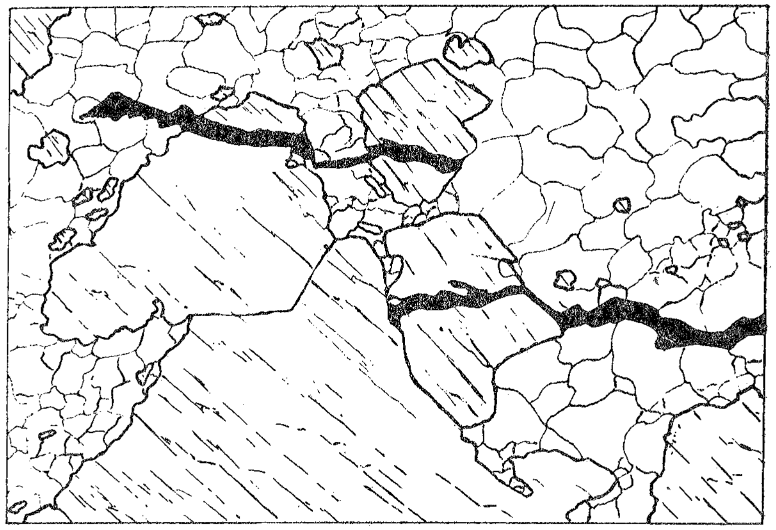

Fig. 1. Felspathic intercalation in the hartschiefer of Abiskojokk (Swedish Lappland). Successive stages in the cataclastic process: fragmentation of the felspars, crystallization of blastic quartz, formation of cracks (in the figure with iron ore) and finally faulting movements. Enlargement $\times$ 174 [1]).

consist of muscovite [2]). Different stages of breaking-down and recrystallization are shown in fig. 1. During and after the fragmentation of the felspars, the soluble quartz is redeposited between the felspar fragments. A crack with iron ore is of younger formation and was faulted in a later stage. The faulting movements are oblique to the plane of the figure.

Biotite in places of relative relief from stress.

In strongly folded micaschists, which are found below an intercalation of dolomite in the hartschiefer on the lower eastern slope of Mt Nuolja, biotite is found near the bends of the folds, whilst the limbs consist of muscovite (fig. 2).

Some biotite is also found in the limbs with blastic quartz at places of local relief of pressure. The folding is clearly later than the crystallization

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1) The drawings of fig. 1—5 have been made by Mr. W. F. M. KIMPE.

2) The colourless and light-coloured greenish or brownish micas are taken together as muscovite.

of the muscovite because the crystals are bended. During the deformation there has been adjustment by differential movements in the limbs of the folds.

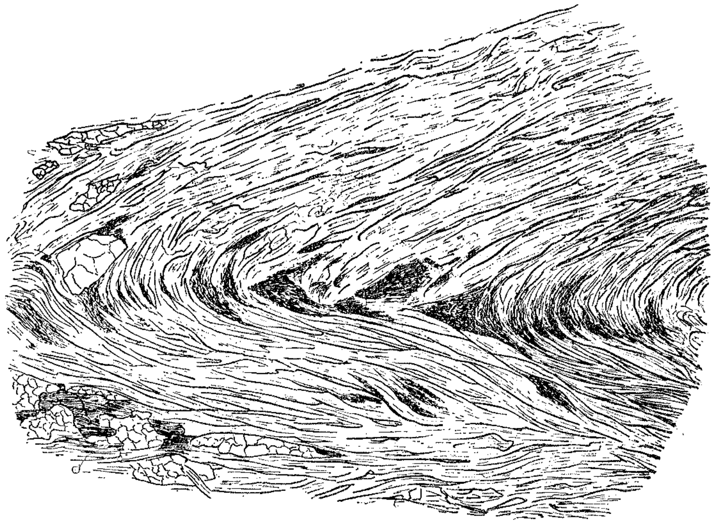

Fig. 2. Folded micaschist on the lower eastern slope of Mt Nuolja (Swedish Lappland). The biotite is found near the bends, the muscovite in the limbs of the folds. Enlargement × 86.

The appearance of biotite at places of relief from stress is shown in a different way in rocks which are found higher up the eastern slope of Mt Nuolja below the lowest intercalations of limestone. These rocks are as a rule somewhat coarser grained than the normal hartschiefer and they contain numerous felspar eyes (potash felspar and acid plagioclase, mostly albite) up to more than 2 cm in length. Some of the rocks are

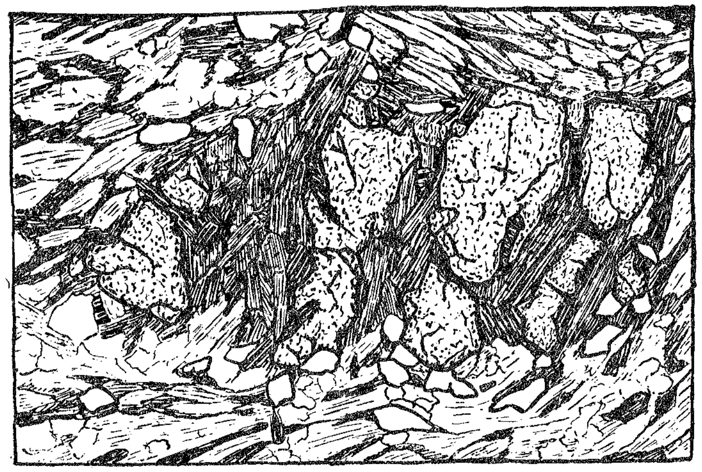

Fig. 3. Broken garnet in a hartschiefer with muscovite, biotite and felspar eyes on the eastern slope of Mt Nuolja. Large and thick crystals of biotite have accumulated in the fractures. Enlargement × 174.

characterized by the occurrence of large crystals of muscovite. The larger felspar eyes are sometimes broken and then resemble the broken felspars of the intercalations in the hartschiefer in the Abiskojokk. Their twinning lamellae and cleavage cracks sometimes show strong bending. There are also cracked titanites, garnets and minerals of the epidote group. The garnet has more or less rounded forms and when it is cracked the pieces are sometimes strongly torn apart with fractures which are more or less normal to the schistosity (Fig. 3). The cracks afforded protection from shearing and here larger and thicker crystals of biotite could develop. The biotite is also found in thinner crystals outside the garnets but here muscovite, which does not enter into the cracks, is by far the principal mica.

In other broken garnets of which the pieces have not been torn apart biotite is also found in the cracks and moreover it is accumulated on both sides of the garnet crystal where this afforded protection from the lateral pressure as is seen in figure 4 in the left upper and the right lower part of the figure. On the other sides of the garnet crystal the schistosity is shown by the more or less parallel orientation of the muscovite.

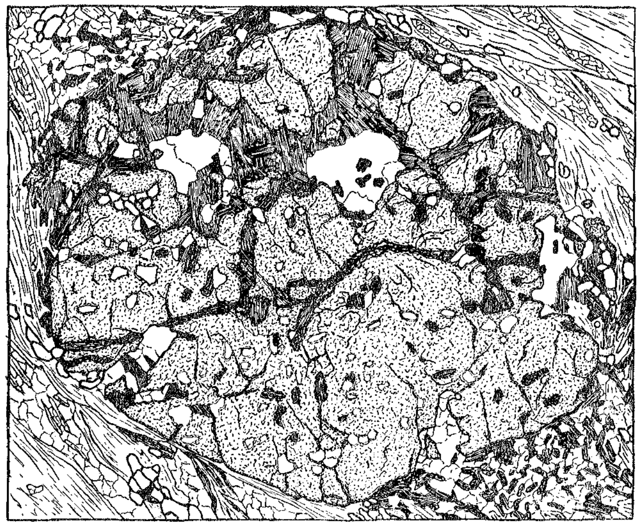

Fig. 4. Garnet, which has more or less preserved its original form. Same rock as fig. 3. Biotite (dark) with quartz in the cracks and in the protected parts outside. Enlargement × 90.

Clear examples of differentiation of the micas are found in the felspathic intercalations in the hartschiefer of the Abiskojokk. The fractures in the felspars are often more or less normal to the schistosity, the felspar fragments have been torn apart and in the spaces between them biotite is found with much blastic quartz. There is also some recrystallization of felspar near the borders of the fragments. The muscovite bands of the hartschiefer along the borders of the felspathic intercalations bend into the open spaces between the felspar fragments but do not enter into the narrower parts of the fractures, which in the example shown in figure 5 (between the two larger felspar fragments in the upper part of the figure) are filled with blastic quartz and biotite. This shows the movement of the muscovite bands. The deformation and the movement in the muscovite bands is further illustrated by the crystallization of biotite and quartz at places which were protected from lateral pressure, whereas at the places of greatest pressure the muscovite bands border directly upon the felspar. In the upper part of figure 5 there is no crystallization of biotite between the muscovite band and the left border of the felspar fragments, but biotite crystallized on the "leeward" side. In the muscovite bands there are streaks of local relief from stress, in which biotite was stable; they illustrate the deformation and movement in the muscovite bands themselves.

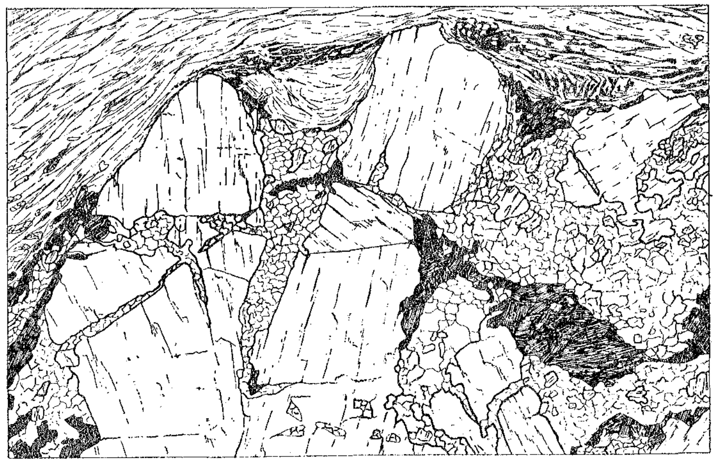

Fig. 5. Border between banded hartschiefer and felspathic intercalation in the Abiskojokk (Swedish Lappland). Muscovite band of the hartschiefer in the upper part of the figure. Biotite (dark) in streaks in the muscovite band and on the "leeward" side of the felspar border. In the open spaces between the felspar fragments of the felspathic intercalation blastic quartz and biotite have crystallized. Enlargement × 26.

The biotite crystals reach their largest dimensions in the open cracks between the felspar fragments proving that there existed the most favourable conditions for their formation. In the neighbourhood of felspar fragments the biotite is mostly found directly on their border, the quartz filling up the rest of the open spaces. This shows that the biotite crystallized first in the fractures.

Distribution of mica in the hartschiefer.

Banding is a macroscopical feature of many hartschiefer and in the more massive and schistose types banding of smaller dimensions is generally also seen under the microscope by the alternation of zones of different colour and mineralogical composition.

The separation of biotite and muscovite (including pale green and pale brown mica) is sometimes pronounced. There are bands which nearly entirely consist of muscovite and there are bands in which biotite is the only mica which occurs together with much quartz and felspar. But often the separation of the two micas is not pronounced and in some bands they are found together in about equal quantities with varying amounts of felspar and quartz. There are also quartzitic bands and bands with felspar and quartz in different relative proportions in which no mica is found.

The biotite only occurs in crystals of microscopic dimensions. The largest crystals are found in the coarse grained felspathic intercalations, where they have crystallized in thick crystals without a definite orientation after the breaking-down of the felspars in places of relief from stress. The muscovite is generally also of microscopical dimensions, it is exceptionally found in large crystals up to 2 cm in diameter and it always tends to take on a definite orientation.

The relations between the felspathic intercalations and the hartschiefer in the Abiskojokk prove that these rocks have, at least partly, been formed from coarse grained highly felspathic rocks by recrystallization proceeding concurrently with the cataclastic process. The muscovite has been formed at the expense of the potash felspars and the initial stage of this mineralogical change can still be seen where thin films of muscovite occur along planes of discontinuity, which intersect the felspathic intercalation. In a more advanced stage there is a thickening of the muscovite bands and an increased breaking-down of the felspars. The quartz and biotite, which crystallized in the felspathic bands at places of relative relief from stress, are more and more influenced by the directional element imported into the process of recrystallization. In the muscovite bands, which grow at the expense of the felspathic bands with quartz and biotite, a recrystallization of biotite — often together with some quartz — can be observed. The separation of biotite from muscovite was pronounced during the earlier cataclastic stages when cracks opened in the large felspar crystals. The surfaces of discontinuity, along which the muscovite was formed, gradually increased in number, the felspathic bands were rolled out further and the biotite in these bands recrystallized in smaller and thinner crystals.

In the rocks with felspar eyes on the lower slopes of Mt Nuolja the separation of biotite and muscovite is not nearly so pronounced. The other minerals (garnet, titanite, epidote etc.) are mainly concentrated in zones which are also rich in both muscovite and biotite and the original stratification has not been entirely obliterated by differential movement and recrystallization. The large muscovite crystals, which occur in some of these rocks, show bending and undulous extinction, which proves that the movements have continued after their crystallization.

Summary.

A series of rocks, which partly still shows the characteristics of felspathic sediments with a varying felspar content was involved in the great overthrusts of caledonian time and reached a considerable depth of cover. Banded rocks were formed by cataclastic changes which proceeded concurrently with recrystallization and the temperature was high enough for the crystallization of both biotite and muscovite. In some banded rocks the felspars have been reduced to lenticular shape and an original stratification has not been entirely obliterated. In other banded rocks the banding has no relation to an original stratification, but in them a mineralogical heterogeneity was set up as a mechanical effect in the first stages of metamorphism and was extended during the later stages.

Particularly in the latter rocks there was a pronounced separation of biotite from muscovite during the early stages of metamorphism. In cracks, which opened in the felspars, biotite crystallized in thick crystals with the more soluble minerals at places of relief from shearing stress. In these stages there may have been relatively broad bands without muscovite and mainly consisting of large felspar fragments, quartz and biotite. During the later stages of rolling out and recrystallization the felspathic bands decreased in thickness and a stronger influence of the directional element was imported into the process of recrystallization, while there was only a minor selective effect with regard to the separation of the — now small and thin — crystals of biotite. from muscovite.

In other petrogenetic processes the separation of the micas is also found. It is well known in magmatic differentiation, and in sedimentary differentiation biotite is much more affected by weathering and transportation with the result that muscovite is the common mica in sedimentary rocks.

Physics. — *La pression du toit sur le charbon près du front dans les exploitations par tailles chassantes.* Par F. K. TH. VAN ITERSON. (I).

DEUXIÈME CHAPITRE.

Répartition des pressions après écrasement du charbon.

(Communicated at the meeting of January 27, 1940.)

§ 1. *Introduction.*

Dans le premier chapitre nous avons calculé d'après la méthode de la théorie de l'élasticité, la distribution des pressions autour d'une fente dans le rocher, comprimé également dans tous les sens.

Ce problème était identique à celui de calculer les pressions autour d'un vide créé par l'exploitation de la veine de charbon sur une largeur limitée sous la supposition que l'épaisseur de la veine est négligeable ou plus précisément dit, nous avions pour ce calcul remplacé le charbon par de la matière indéformable, ou pour le dire en terme mathématique, nous avions admis que la surface de contact entre roche et charbon restait platte.

Plus loin dans cette étude on verra que ce problème, traité dans le chapitre premier, est intéressant pour l'ingénieur des mines, mais pour le moment nous nous y référons pour démontrer qu'en réalité la solution ne s'applique pas au cas indiqué par le titre de notre étude précédente.

Le résultat des calculs du chapitre premier est représenté dans la figure 1. En formule la pression σ_z sur le charbon en fonction de y est

$$\sigma_z = \frac{y}{\sqrt{y^2 - b^2}}\, p$$

or la pression au ras du front pour $y = b$ devient infiniment grande. p étant la pression uniforme régnant à une telle distance de l'exploitation que l'influence de celle-ci peut être considérée comme amortie.

Mais les surfaces du charbon en contact avec le rocher ne peuvent pas être considerées comme indéformables, au contraire notre houille est très fragile, la résistance à l'écrasement est de l'ordre de 35 kg par cm^2.

A présent les Mines de l'Etat néerlandais exploitent des couches situées entre 400 et 800 m de profondeur. Le poids spécifique des morts terrains et du terrain houiller évalué à 2,5 en moyenne, la pression dans le terrain vierge p est de 100 à 200 kg par cm^2. Cette pression y règne dans tous les sens. Mais, comme nous avons prouvé dans notre étude préalable, les pressions dans le toit et dans le mur (le sol) sont nulles près des surfaces