ON THE PETROGRAPHY OF THE SILURIAN SHALES FROM HADELAND, NORWAY

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A b s t r a c t. By means of microscope, X-ray, and D.T.A., constituents of the Silurian shales from Hadeland are determined to be: quartz, calcite, mica, chlorite and illite. Some chemical data are given, together with suggestions concerning the low phosphorous-content and the high manganese- and MgO-content in the same shales. The problem of red colour in shales from stage 7c is discussed briefly, as is an occurrence of speckled shale in the same stage.

Introduction.

This investigation is a part of a thesis for the degree of cand. real. at the University of Oslo. The stratigraphical part of the thesis will be printed as a separate paper. Therefore, only a short summary of the stratigraphy and structure will be given here.

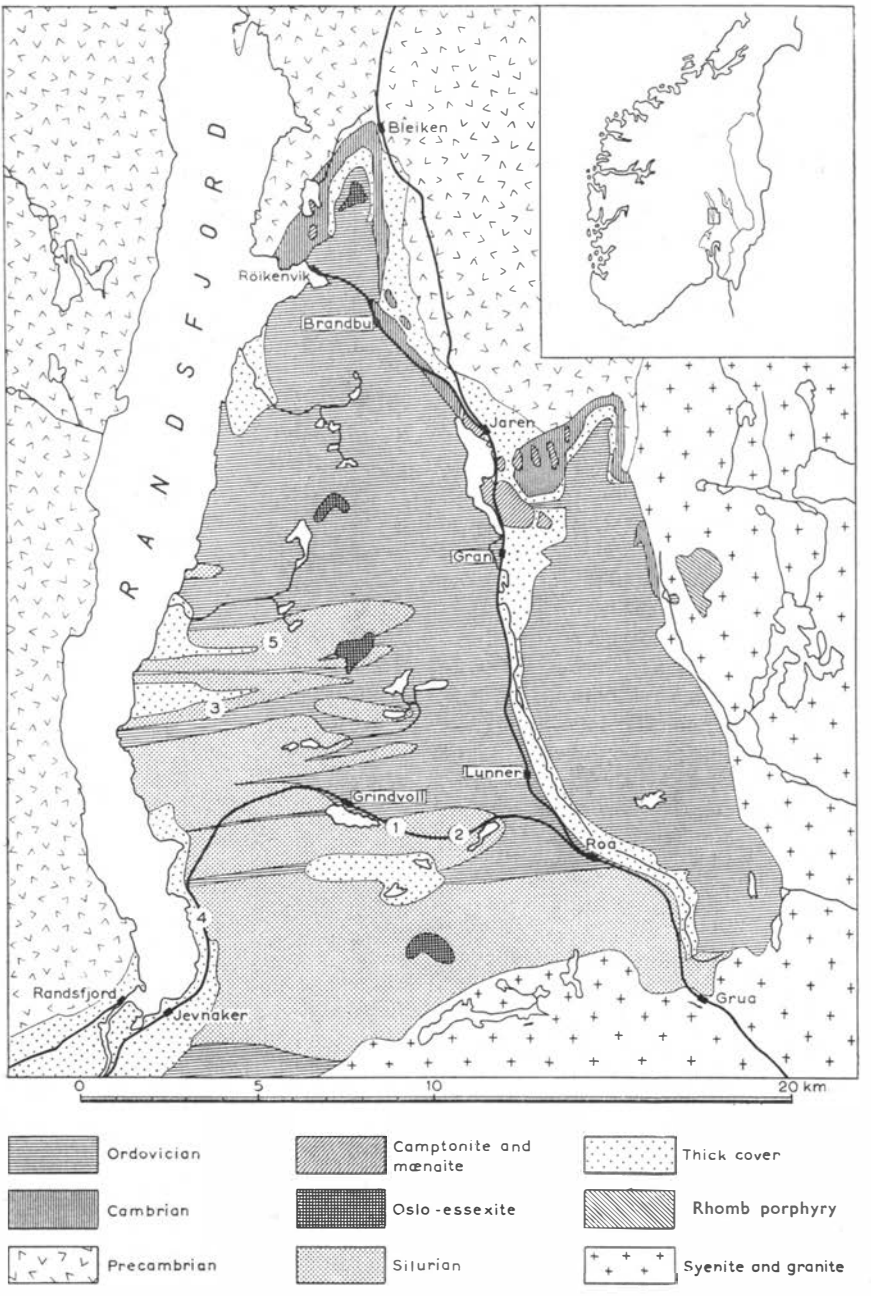

Fig. 1. Geological map of Hadeland.
Mainly after Kiær (1908) and Holtedahl and Schetelig (1923). Silurian drawn from my own observations. 1. Storskjæringa. 2. Askelsrud. 3. Heier. 4. Gulla. 5. Skattum.

The Cambro-Silurian district of Hadeland (fig. 1) is a sunken area. Its western boundary is marked by a N—S Permian fault along the Randsfjord; the southern continuation of this fault, trending SE, forms the boundary between the Ringerike and Hadeland districts, to the S and E there are Permian igneous rocks. In the NNE part of the area the Precambrian peneplane dips westward below the Cambro-Silurian sediments. The thick Silurian sandstones and limestones form large, gentle folds with an E—W strike.

Several geologists have visited Hadeland, but most of their work is of a stratigraphical nature. The petrography of the sediments has been dealt with in only a few papers. O. HOLTEDAHL (1917) gives a description and some chemical analyses of the economical important limestones in the area. In a later paper, the same writer (O. HOLTEDAHL 1927) gives values for the P_2O_5-content of some sediments from Hadeland.

MAJOR (1945) describes «Pipe-Rocks» in stage 6 from Hadeland. In connection with his studies of the oldest Silurian sediments of the northern part of the Oslo—Region (MAJOR 1946) he also examined the sediments occuring in stage 6 at Hadeland.

Fig. 2 is a schematic section through the Silurian sediments at Hadeland. The Silurian sequence begins with a sandstone (ca. 120 m thick), which is rather uniformly developed and contains very few fossils. The Gastropod-limestone (5 a), which underlies the sandstone, becomes sandier upwards. Ca. 3 m below the boundary between the sandstone and the limestone, a thin conglomerate occurs, which I have interpreted as a possible boundary between the Gastropod-limestone and stage 5 b.

Above the sandstone lies the Borealis-limestone (ca. 5 m thick) which is succeeded by the Penta-

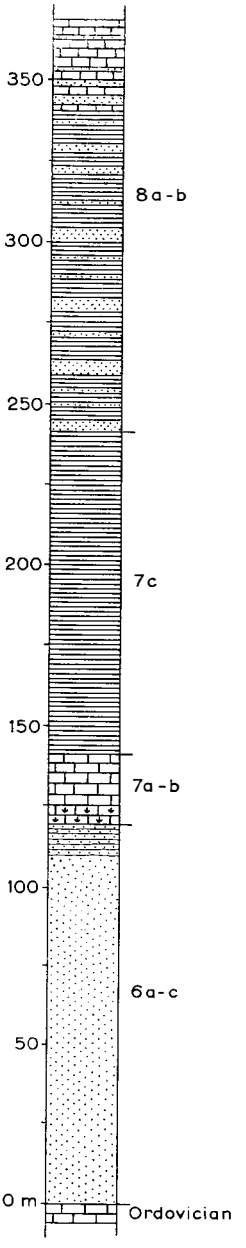

Fig. 2. Schematic section through the Silurian sediments at Hadeland.

merus-limestone, and the Upper Coral-limestone (ca. 11 m thick). All these limestones belong to stage 7a—b. The Upper Coral-limestone grades into the following units: 7c α—β Lower «Crotalocrinus» shale, 25—40 m thick and 7c γ Upper «Crotalocrinus» shale, 70—80 m thick. Some horizons with black, graptolitic shales, are found in stage 7c, and in the lower part of this stage, 4 bentonite beds occur. 7c is overlain by stage 8a—b, which consists of alternating olive-green shales, and sandstone beds.

Microscopic investigations.

The Silurian shales of the Hadeland district are very fine-grained, the grain-size mostly being less than the thickness of the thin sections. It has, therefore, been difficult to obtain satisfactory results from a study of such sections. Consequently, only the following 6 thin sections have been examined:

Sample 1. Black shale with graptolites (7c). From 29.30—31.30 m in the Storskjæringa section.
— 2. Green shale with limestone-lens (7c), near sample 1.
— 3. Red shale with mica (7c). At ca. 34.80 m, Storskjæringa.
— 4. Black shale with graptolites (7c). At 40.90—41.30 m, Storskjæringa.
— 5. Shale with graptolites (7c). Askelsrud.
— 6. Green shale (8a). At 20 m, Gulla.

In all these shales, quartz and calcite (possibly dolomite) are the dominant constituents, but several samples also contain mica and opaques. The size of the mineral fragments varies between 0.02 and 0.05 mm. They are sharp-edged and occur in a very fine-grained ground mass. The principal difference between the samples is the proportion of the constituents: quartz, calcite and mica.

X-ray.

X-ray analyses have been made of samples belonging to stage 7c at Askelsrud and Gunnstad. Also 3 samples from the transitional beds 7c—8a at Skattum have been examined. The X-ray examination has been undertaken at the X-ray laboratory of the Geological Museum. 9 cm camera and filtered iron radiation has been used.

All the samples give the same pattern, the films showing mainly quartz-, calcite- and mica-lines. There also appear some other, less characteristic lines. Among these there are two which are rather strong; one at 2.56 Å, and one at 7.07 Å. These values are in good accordance with the data published for chlorite.

Cand. real. E. Dahl has been so kind as to analyse a sample of shale from stage 8a, Gulla, on the X-ray spectrometer of the Chemical Institute at Blindern. This sample shows, among others, lines at 14.7 Å, 7.20 Å and 3.95 Å. This pattern is typical for chlorite; but the lines might also be produced by a mixture of a 14 Å and a 7 Å mineral. Therefore the sample was treated with 2 N HCl at 100° C for 1 hour and then examined again. The lines at 14 Å and 7 Å disappeared and the line at 3.59 Å was replaced by a weak line at 3.56 Å. This indicates chlorite. The other lines, caused by quartz, mica and possibly feldspar, become more distinct. The X-ray examination thus indicates that the shales consist mainly of quartz, calcite, mica, chlorite, and possibly feldspar.

Differential thermal analyses (D.T.A.)

In order to determine the composition of the fine ground mass in the shales I have made several differential thermal analyses. These analyses have been carried out at the soil laboratory of the Norwegian Geological Survey, in cooperation with State Geologist R. Selmer-Olsen. Each sample was ground until the maximum grain-size did not exceed 20 μ. For each D.T.A. ca. 0.5 g of the ground sample was used.

The D.T.A. apparatus is built mainly after the instructions given in SPIEL, BERKELHEIMER, PASK and DAVIES (1945). The furnace-system is closed and has a permanent arrangement of the specimen holder and the thermoelement. A Pt-PtRh10%-Pt differential thermocouple is used. As inert comparison powder, α-Al_2O_3 is used. The temperature rises 10° C per minute. In the beginning, the apparatus did not have an automatic heat regulator and recording unit. However, when the apparatus was made automatic, the original arrangement was kept intact. The following samples were analysed before the apparatus became automatic: No. 1, 3, 4, 5, 6, 7, 11, 12, 13, 14, 15, and 16.

D.T.A. has not been used heretofore in the examination of our Cambro-Silurian shales. I shall, therefore, give a rather thorough description of the results obtained.

The following samples have been analysed (Plates I—V): (For comparison purposes 3 samples from Mjøsa and Ringerike and 2 samples of chlorite have also been examined).

1. 7b, at 25.40 m, Heier.
2. 7c, at 34.80 m, Storskjæringa.
3. 7c, at 7 m, Gulla.
4. 7c (green), Gunnstad.
5. 7c, Askelsrud.
6. 7c, Eksbakken, Mjøsa.
7. 7c, Vik, Ringerike.
8. 8a, at 1.20 m, Gulla.
9. 8a (HCl), at 1.20 m, Gulla.
10. 7c—8a, Skattum.
11. — —
12. — —
13. 8 ?, Vassjø.
14. 8a, Garntangen, Ringerike.
15. Chlorite, Gravdal.
16. — , Snarum.

ENDOTHERMIC REACTIONS AT 100°—200°C.

All the curves have one endothermic peak in the 100°—200° temperature range. However, in most of the curves, this peak is rather small, its maximum varying between 100° and 150°. It must, however, be said that the D.T.A. apparatus used, is not built for exact investigations of reactions at such low temperatures, and the results obtained do not, therefore, allow any far-reaching conclusions.

It is customary, when examining D.T.A. curves of clay and clay minerals, to find that more or less distinct endothermic reactions appear between 100° and 200°. Generally these reactions are interpreted as loss of water adsorbed by the mineral particles in the clay.

EXOTHERMIC REACTIONS AT 250°—550°C.

At these temperatures all the curves show one or more exothermic reactions. Some of the peaks are very broad, and the maximum of the reactions varies through the whole temperature range. Sample 1. has the lowest maximum temperature (250°), and also has an exothermic reaction with the maximum at 320°. Such double peaks are also observed in several of the other curves, but in these the maximum for the first peak comes at a little higher temperature than in sample 1. In sample 4., the two peaks occur at 340° and 510°; sample 6: 330° and 410°; sample 8: 320° and 450°; sample 9: 330° and 550°; sample 12: 330° and 460°; sample 13: 330° and 440° (this sample also shows a little exothermic reaction at 490°); sample 14: 350° and 480°.

Maxima for most of the curves are found in the 310°—350° interval. The curves having two peaks, reach their second maximum in the 410°—510° interval.

These peaks are probably caused by the combustion of organic matter and/or iron sulphide. GRIM and ROWLAND (1944, p.13, 19) found that the combustion of organic matter takes place at temperatures of 200°—700°, and causes a broad exothermic peak which might mask other reactions. The above mentioned authors also found that pyrite and marcasite give a distinct exothermic peak at 400°—550° and a weaker endothermic peak at 600°—700°.

ENDOTHERMIC REACTIONS AT 550°—700°C.

In this interval all the curves have a broad and very characteristic endothermic peak. The peak maximum varies between 570°—620°. Generally, a broad peak at these temperatures is interpreted to be caused by clay minerals. Members of this group which give endothermic reactions in this interval are: all mica-like clay minerals (except vermiculite), kaolinite, anauxite, halloysite, endellite, beidellite and nontronite. However, most of these minerals are relatively rare, and only a few of them have been found in Paleozoic sediments. The most probable minerals in our Cambro-Silurian shales are: illite, montmorillonite and kaolinite. Montmorillonite, however, ordinarily produces a peak at a little higher temperature (50°—100°),

and except for beds of probable bentonitic origin, this mineral has not yet been observed in Paleozoic sediments (GRIM 1953). When considering the possibilities for kaolinite, it must be pointed out that the peak caused by kaolinite is ordinarily relatively deep and sharp. The curves are more characteristic for illite in that they have lower and broader peaks. It seems probable, therefore that the clay mineral present is illite. GRIM (1953) reports that illite may give peaks within the 550°—650° temperature range. These peaks are connected with loss of water from the lattice.

Most of the published D.T.A. curves for illite show a peak maximum at a little less than 600°, whereas the samples from Hadeland have a peak maximum above 600°.

The X-ray examinations have shown that chlorite is present; consequently one cannot exclude the possibility that this peak is caused by that mineral. Therefore, for purpose of comparison I have included two samples of chlorite, analysed by State Geologist R. Selmer-Olsen (sample 15 and 16). These curves show a strong and very distinct endothermic reaction at 630° and one at ca. 800°. According to GRIM (1953, p.239), many analysed samples of chlorite show a very sharp reaction in the 500°—700° range. Most of these also have a sharp endothermic reaction at ca. 800°. This accords well with the results obtained by Selmer-Olsen.

These data, however, are from well crystallized chlorites, and variation in the clay mineral chlorites might occur. GRIM (1953, p.239) suggests, however, that clay mineral chlorites would show the same thermal reactions as well crystallized chlorites, but perhaps at somewhat lower temperatures.

In order to determine whether the strong endothermic reaction shown by most of the samples is produced by a mixture of illite and chlorite, or only by chlorite, I treated the sample from stage 8a at Gulla with HCl. This treatment should destroy the chlorite. The acidized sample gives a curve which is much smoother than that produced by the untreated sample from the same locality. The two exothermic peaks in the 200°—550° temperature interval become more pronounced and, at the same time, the broad peak at 615° is divided into two, a small one at 590° and a broad one at 655°. This may be interpreted in the following way: in the untreated sample,

chlorite masks the small peak at 590°, which peak possibly indicates a small content of illite. The 655° peak may be connected with the possible iron sulphides (giving the peak at 550°), and might have been covered in the untreated sample.

The same effect has also been observed in my investigations of Silurian bentonites from the Oslo—Region.

ENDOTHERMIC REACTIONS AT 700°—900°C.

In the 700°—900° temperature range all curves indicate a more or less sharp endothermic reaction. The sharp peaks at ca. 850° are certainly due to calcite. As to the temperature of dissociation for calcite and dolomite, different scientists have reached some divergent conclusions. NORIN (1941, p. 222), KERR and KULP (1948, p. 407) and several others have found that calcite gives a peak at 960°—990°, whereas others (CUTHBERT and ROWLAND, 1947, p. 113; GRIM and ROWLAND, 1944, p. 10) found the peak maximum to be ca. 120° lower.

The dissociation of dolomite occurs in two steps. According to GRIM and ROWLAND (1944, p. 13) the first maximum is found in the 730°—800° interval; the other occurs at the same, or a little lower temperature as for calcite. SOVERI (1950) has analysed mixtures of calcite and clay and found that the maximum varied between 775° and 860°, when the calcite content varied from 2 % to 15 %. It seems, therefore, that the maximum is dependent on how much calcite the sample contains.

Rough investigations show a rather high percentage of $CaC0_3$ in the shales from Hadeland. The peak maximum should, therefore, be expected at a rather high temperature. It may be noticed that in the acid treated sample from stage 8a, Gulla, no peak occurs in this interval.

In connection with the sharp calcite peak there is also a strong exothermic reaction. Reactions at such high temperatures are difficult to interpret and at present there is some uncertainty as to what happens.

In summary, the D.T.A. investigations indicate that the fine groundmass consists mainly of chlorite, illite and calcite.

Chemical composition.

Only a very few analyses of Cambro-Silurian shales from the Oslo—Region have been published, so little is known about the exact composition of these sediments. KVALHEIM (1949), however, has published analyses of two Silurian (7c α) shales from Askelsrud (Hadeland) and Sandvika, in the Oslo—Region. (Tab. 1). From these analyses it is apparent that there are certain differences in the chemical composition of samples from the two localities.

Table 1.

	7c α Askelsrud	7c α Sandvika
SiO_2	50.91	42.13
TiO_2	0.94	0.86
Al_2O_3	15.62	12.98
Fe_2O_3	4.40	3.36
FeO	3.15	2.79
MnO	0.20	0.33
MgO	3.50	3.07
CaO	7.27	15.89
Na_2O	0.91	0.70
K_2O	3.71	2.80
P_2O_5	0.07	0.07
S	0.05	0.38
CO_2	5.47	12.37
C	0.15	0.04
H_2O — 110° C	0.40	0.53
H_2O + 110° C	2.68	1.70
	99.43	100.00
— O for S	—	0.09
	99.43	99.91

(Analyst B. Bruun)

I have determined the content of some elements in a green shale with dark dots, which occurs at ca. 25.40 m in the Heier section. (Tab. 2). The analysis was made in order to determine whether or not the dark dots were phosphorite. A complete silicate-analysis was, therefore, not carried out. The low phosphorous content, however, excludes the possibility of phosphorite, but the loss on ignition indicates an organic origin of the material.

Table 2.

Fe_2O_3) FeO)	8.33
MgO	4.38
CaO	4.17
P_2O_5	0.05
Loss on ignition	6.38

O. HOLTEDAHL (1927) gives determinations of the P_2O_5 content in two shale samples from stage 7c, Hadeland. The localities are labelled: East of Grindvoll st. Probably the samples were taken in the railway-cutting called Storskjæringa. The phosphorous content of the two samples shows considerable differences; one (from the upper part of 7c) contains 0.14 % P_2O_5, whereas the other has only 0.075 % P_2O_5. The last value accords well with those Kvalheim and I have found. O. HOLTEDAHL (1927) gives 0.16 % P_2O_5 as average for the shales from stage 7—8 in the Oslo-Region. This average includes, however, one sample from Bærum which shows an exceptionally high (0.64 %) P_2O_5 value. If this sample is omitted, the average for the 7 other samples analysed, is 0.094 %, which seems to be in better accordance with figures from other analyses. If Kvalheim's two analyses and mine from Heier are taken together, with the corrected average from Holtedahl, the average becomes: 0.085 % P_2O_5. Holtedahl reports an average P_2O_5 content of 0.21 % for Norwegian Quarternary clays. He also cites CLARK (1924) who has found the P_2O_5 average of 51 analysed Paleozoic shales to be 0.15 %. The phosphorous content of the shales from stages 7 and 8 is, consequently considerably lower than common in other Paleozoic shales. An explanation for this may be found in the circumstance that phosphorous seems to be particularly abundant in deep-sea sediments (LANDERGREN 1954) whereas geological evidence (ripple marks etc.) indicates that the red shales in stage 7c from Hadeland were deposited in relatively shallow water.

Another interesting feature of the two analyses is the rather high content of manganese (0.20 % and 0.33 % MnO). GOLDSCHMIDT (1954) gives the average MnO content in 36 Paleozoic shales to be 0.12 % and the average of 78 Norwegian Quarternary clays is 0.11 %. An explanation for the relatively high Mn content in the red Silurian shales is probably to be found in the geochemical properties of manga-

nese. According to GOLDSCHMIDT (1954) the fate of manganese by weathering depends on two chemical processes: one, a leaching of di-valent manganese in solution, mainly as bicarbonate; the other, a precipitation of very insoluble hydroxydes and oxydes of 3- and 4- valent manganese.

In the case of natural compounds of manganese, the lowest stage of oxidation produces the most mobile irons. This is a result of the fact that the ionic-radius of divalent manganese is relatively large, leading to a low ionic potential for Mn^{2+}. Divalent manganese, therefore, will be more susceptible to leaching even by very weakly acid solutions. 3- and 4-valent manganese has a much higher ionic potential. This will lead to precipitation from even rather acid aqueous solutions.

The red colour of the shales in 7c suggests that they were deposited under aerobic conditions. Therefore, during deposition the manganese could have been oxidized to a higher state, leading to its precipitation.

The analyses also show a rather high MgO content in relation to the Al_2O_3 content. This may indicate that the samples contain dolomite, but there are also other possibilities.

GOLDSCHMIDT (1926) has pointed out that a high content of MgO in relation to Al_2O_3 in clay sediments indicates that the sediment was derived from a magnesium-rich rock, and he has also shown that in the Ogygiocaris-shale of the Oslo-Region there is a rather high content of Mg. This is interpreted to suggest a possible supply of volcanic ash from vulcanism in the Trondheim-area. He reports that the Al_2O_3/MgO ratio is about 10 in our oldest Paleozoic shales (e.g., the Phyllograptus-shale), whereas for the Ogygiocaris-shale it is 3—4. For the two analysed samples from stage 7c, the relation between Al_2O_3/MgO is ca. 4.5 and 4.2 for Hadeland and Sandvika respectively. I suggest that this may be connected with the vulcanism that produced the bentonite beds in stage 7c.

The conclusions reached are based on only a few analyses, consequently, the results must be regarded as preliminary.

The problem of red colour in shales from stage 7c.

The significiance of the red colour of sediments is a much debated problem. The colouring matter of such sediments is ferric anhydride (ocherous hematite), (PETTIJOHN, 1949, p.170). Several authors

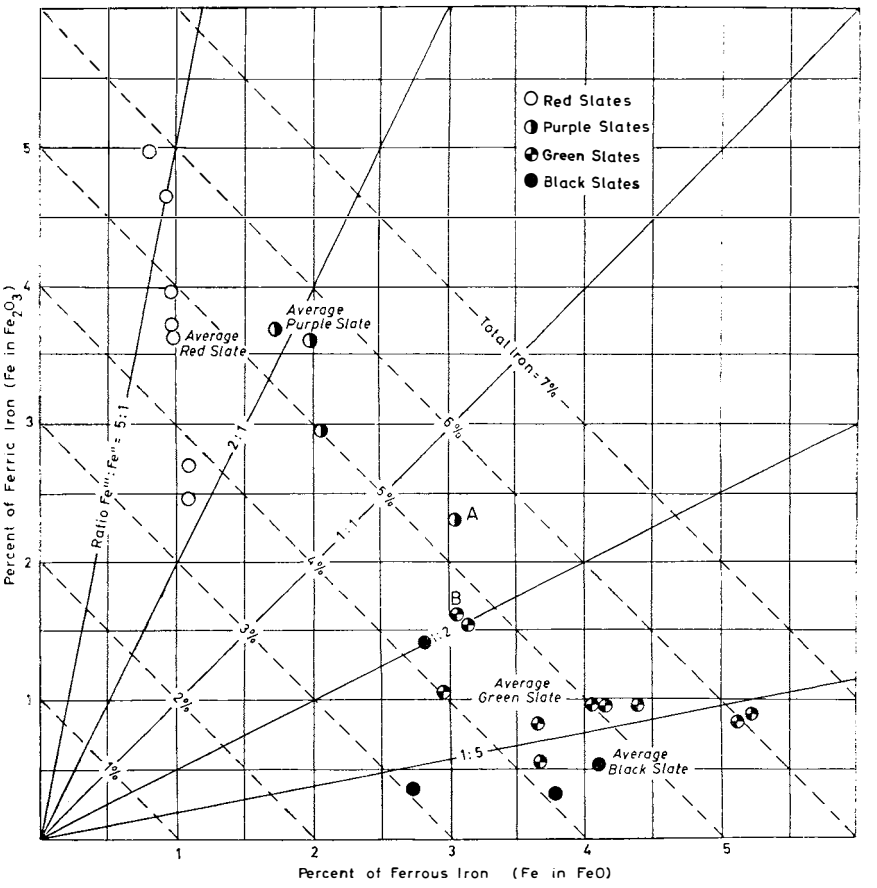

Fig. 3. Relation of ferrous-ferric iron to colour of slates. After Pettijohn (1949, p. 171). Analyses of the iron content in two samples from Gunnstad (Hadeland) are also plotted. A. red shale. B. green shale.

have shown that red sediments do not contain more iron than sediments of other colours (fig. 3).

Analyses of the iron content in samples from Hadeland are shown in table 3., and plotted in fig. 3.

Table 3.

	7c (green) Gunnstad	7c (red) Gunnstad	7c (grey) Askelsrud
FeO	3.05 %	3.03 %	3.26 %
Fe_2O_3	1.53 %	2.32 %	1.28 %
Total	4.58 %	5.35 %	4.54 %

The problem of the red colour is one of finding conditions under which dehydration of ferric oxides can occur, rather than determining the conditions under which ferric oxide is produced.

It is commonly assumed that the red oxide present was deposited in this state. After thorough investigations, DORSEY (1926) concluded that dehydration must have taken place before deposition, suggesting that such a reaction should be contingent upon a warm, moist climate. Furthermore, in order to retain the red colour, the sediments must have deposited subaerially or in areas where there was no reduction in greater scale. He concludes that this may be the reason why red sediments are, in most cases, continental. Most sediments are carried to the sea where they are subject to reducing agents caused by the decay of marine organisms. The fact that marine red beds are sometimes found suggests that real marine conditions — the reducing agencies — have been pushed off the coast contemporary with deposition of the sediment. Dorsey believes that this will result in red «wedges» in the marine sediments. Such conditions have been observed, for example in the Atlantic near the mouth of the Amazonas (MURRAY, 1891, p.234).

Dorsey mentions that such shifts are inclined to be periodical and it is therefore possible to find fossils of marine animals which have been «buried» in these brackish sediments. As an example he mentions red Silurian shales from the eastern part of N. America in which brachiopods are found.

Sections through stage 7c at Hadeland show an alternation of green and red beds. The total thickness of the green beds is greater than that of the red beds. If the green beds are primary, and there is nothing to contradict such an assumption, a periodical shift as proposed by Dorsey seems to fit quite well with the conditions at Hadeland.

The fact that brachiopods, crinoid stems etc. are found in the red beds at Hadeland, however, does not necessarily mean that these animals lived just there. In other localities in the Oslo-Region (Gjettum, Slependen etc.) it can be shown that crinoid stems, corals etc. were washed together after death by strong currents.

Speckled shale.

South of Tømmeråsis found a small exposure of graptolitic, dark shale in which there are small grey-green lumps. The lumps have the form of small lenses, branches, and flat worm-like bodies,

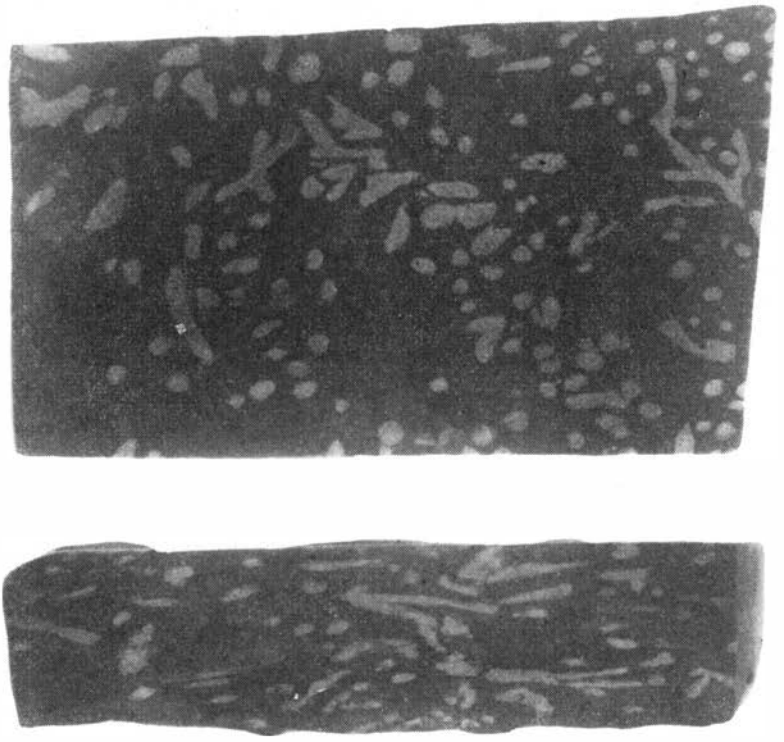

Fig. 4. Upper, a piece of speckled shale from Tømmerås, which has been polished parallel to the bedding planes. Lower, the same piece polished normal to the bedding planes. Both ca. 2.5 X.

and their greatest extension parallel to the bedding planes. The boundary between the dark shale and the lumps is sharp (fig. 4).

No difference between the dark shale and the lumps is seen in thin sections. The rock consists of a very fine-grained groundmass in which small (0.02 mm), sharp quartz fragments appear to be relatively abundant. Opaques and one plagioclase fragment (ca. 30 An) are also observed.

In cores from the deep borings at Kinnekulle HENNINGSMOEN (1948) observed that, in the Tretaspis series, speckled shale occurs between dark shale and grey-green mudstone. From dark shale to speckled shale there is a gradual transition; the speckled shale then changes into grey or grey-green shale. The fauna found in the speckled shale is a mixture of the faunas found in the dark and the grey shales. Henningsmoen assumes that the lumps are primary and

concludes that the speckled shale developed when the sediments were deposited and when conditions, at least near the bottom, were alternating between stagnant and ventilated conditions.

The investigations from Kinnekulle show that the rhytmic alternation between stagnant and ventilated conditions is perhaps only a local phenomenon, for the speckled shale does not seem to be common in corresponding layers outside Kinnekulle. As a possible explananation, Henningsmoen visualizes a basin in which renewal and aeration of water at times could cause more ventilated conditions. Considering that the foul water was probably overlain by a layer of ventilated water, as indicated by the rich planktonic fauna, another possible explanation is that here the (somewhat oscillating) boundary between the layers of water lay near the bottom.

It is difficult to make definite conclusions as to conditions during the deposition of the speckled shale at Tømmerås, because the shale is found only in a very small exposure. It is therefore impossible to get an impression of the transitional beds. The nearest exposure, ca. 10 m South, shows only red shale belonging to 7c. It seems probable, however, that an explanation similar to the one given for the speckled shale at Kinnekulle may also apply in this case. In the Storskjæringa section there are found some beds with dark graptolitic shale which indicate that an alteration of the depositional conditions took place during this period.

Acknowledgements.

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chemical analyses; to Miss I. Lowzow, who drew the map and the diagrams; and to Mr. E. Fjellet who prepared the thin sections. Dr. W. C. Sweet revised the manuscript, for which I would like to thank him.

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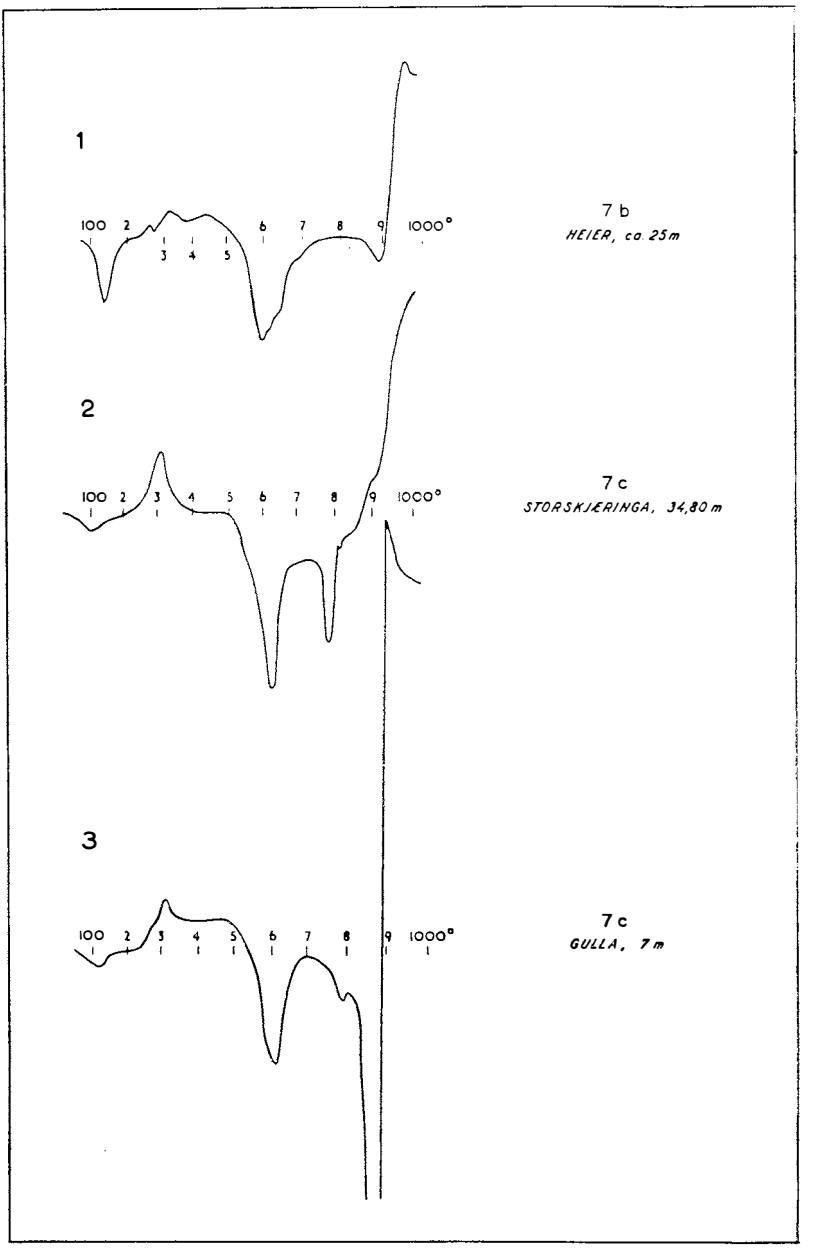
PLATES I—V

D.T.A. CURVES

PLATE I


1
100 2 3 4 5 6 7 8 9 1000°
7 b
HEIER, ca. 25m
2
100 2 3 4 5 6 7 8 9 1000°
7 c
STORSKJERINGA, 34,80 m
3
100 2 3 4 5 6 7 8 9 1000°
7 c
GULLA, 7 m

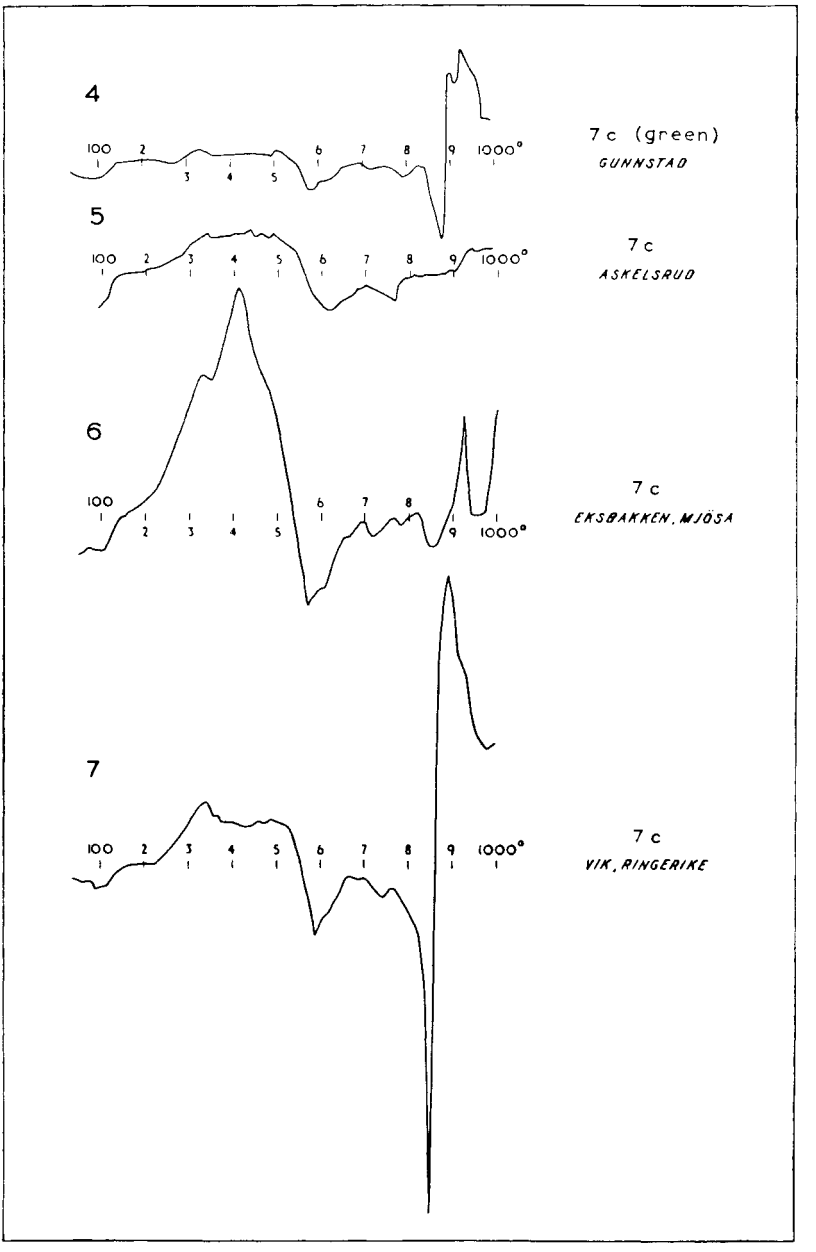
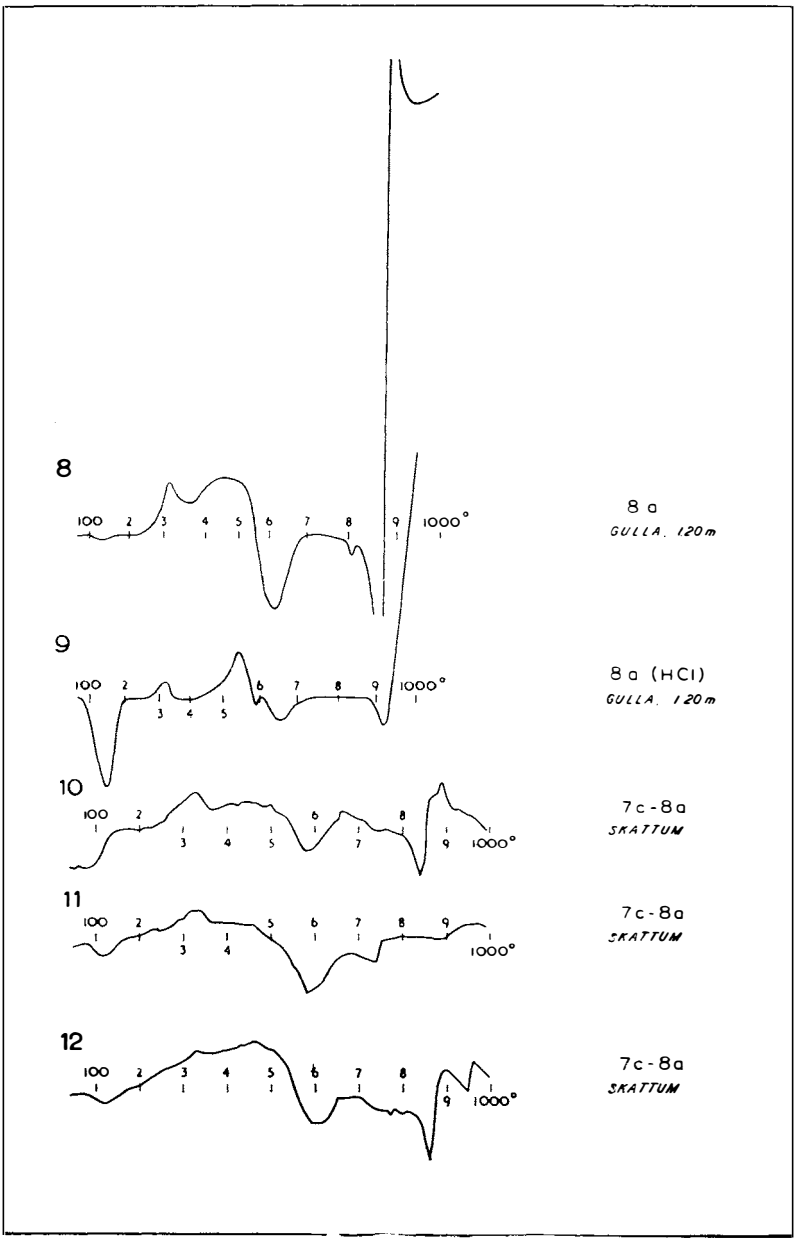

4
100 2 3 4 5 6 7 8 9 1000°
7 c (green)
GUNNSTAD
5
100 2 3 4 5 6 7 8 9 1000°
7 c
ASKELSRUD
6
100 2 3 4 5 6 7 8 9 1000°
7 c
EKSBAKKEN, MJÖSA
7
100 2 3 4 5 6 7 8 9 1000°
7 c
VIK, RINGERIKE

PLATE III


8
100 2 3 4 5 6 7 8 9 1000°
8 a
GULLA. 120m
9
100 2 3 4 5 6 7 8 9 1000°
8 a (HCl)
GULLA. 120m
10
100 2 3 4 5 6 7 8 9 1000°
7c-8a
SKATTUM
11
100 2 3 4 5 6 7 8 9 1000°
7c-8a
SKATTUM
12
100 2 3 4 5 6 7 8 9 1000°
7c-8a
SKATTUM

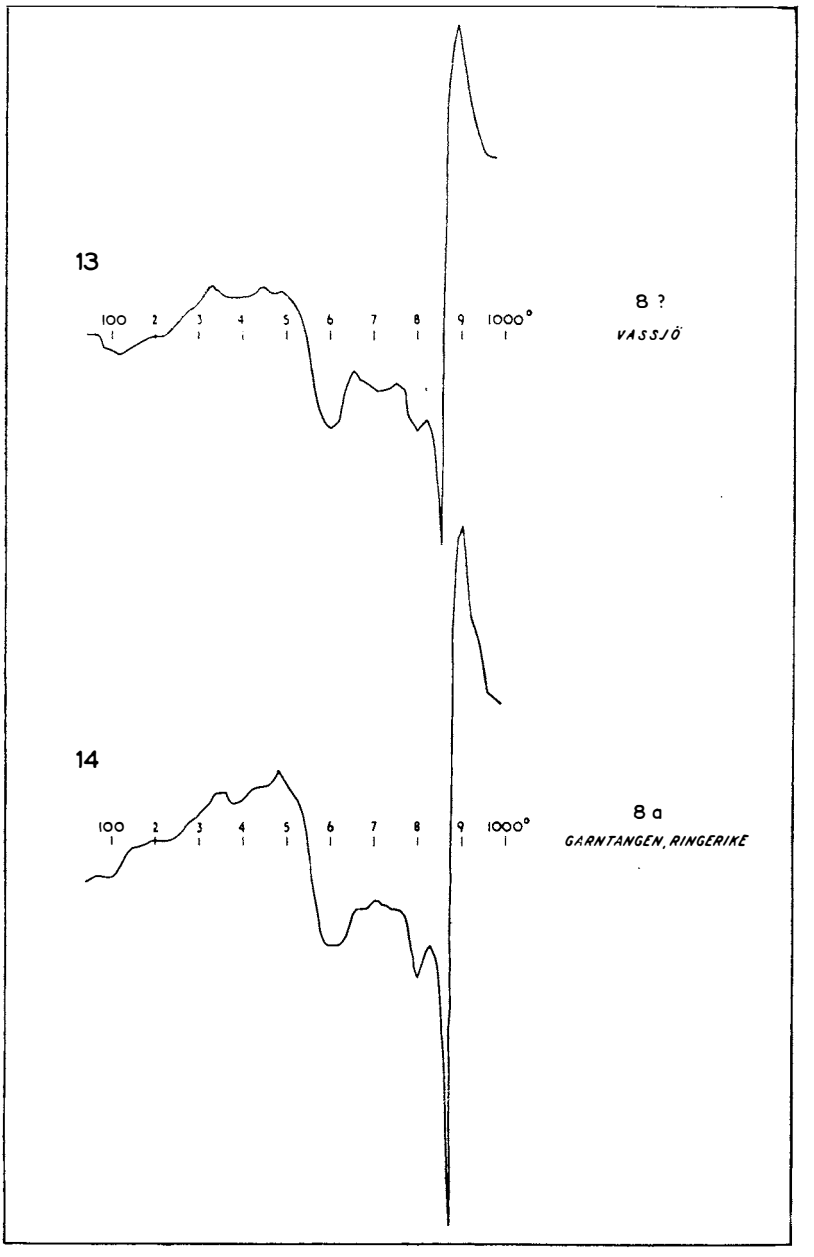
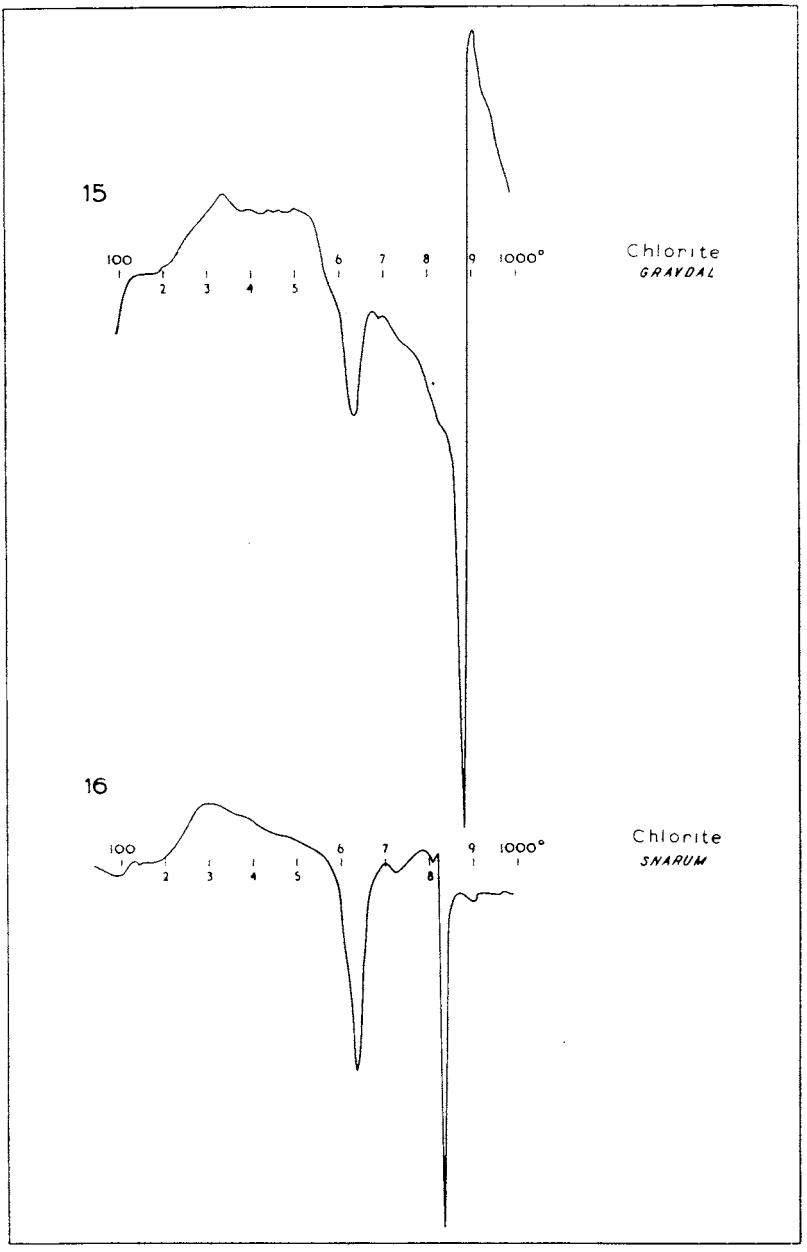

13
100 2 3 4 5 6 7 8 9 1000°
8 ?
VASSJÖ
14
100 2 3 4 5 6 7 8 9 1000°
8 a
GARNTANGEN, RINGERIKE

PLATE V


15
100
1
2
3
4
5
6
7
8
9
1000°
Chlorite
GRAVDAL
16
100
2
3
4
5
6
7
M
8
9
1000°
Chlorite
SNARUM