Triassic heavy–mineral associations in Denmark

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The investigation comprises heavy-mineral analyses of 14 samples from the Triassic sequence of Denmark. The geological significance of the heavy-mineral associations is discussed. In the Bunter a "Garnet province" including the South Danish/North German region occurs, supposedly of Scandinavian origin. Along the margin of the basin towards Fennoscandia a marginal facies of coarse arkoses is found. The heavy-mineral associations of these arkoses are interpreted as reflecting a detritus supply from locally exposed rocks. In the Keuper associations an inkling is given of a subdivision in heavy-mineral provinces, which locally are strongly obliterated by diagenetic destruction.

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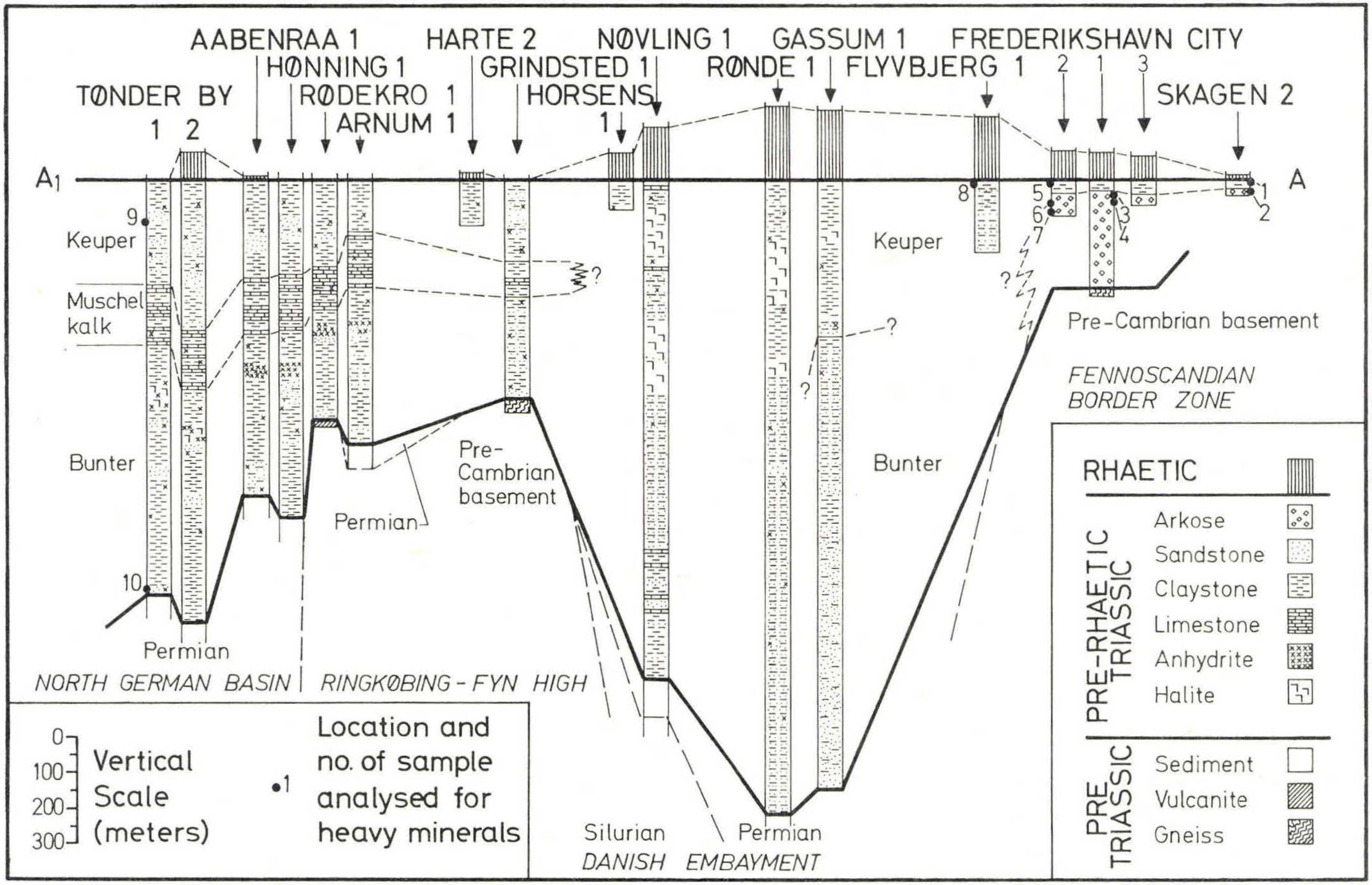
Triassic deposits in Denmark are known from a few outcrops in the southern part of the island of Bornholm (map fig. 1 b) (Hansen, 1942) and from several borings in other parts of the country made since 1935 (Gregersen & Sorgenfrei, 1951; Sorgenfrei & Buch, 1964; Rasmussen, 1972, 1974).

In the borings the Triassic sections have been subdivided and correlated mainly from lithological properties. Compared with the German Triassic four major units are recognized:

Rhaetic: dark shales and light sandstones.
Pre-Rhaetic Keuper: reddish-gray variegated claystones and marlstones with intercalations of sandstones and evaporites.
Muschelkalk: grayish marly limestones.
Bunter: red, clayey sandstones intercalated with evaporites.

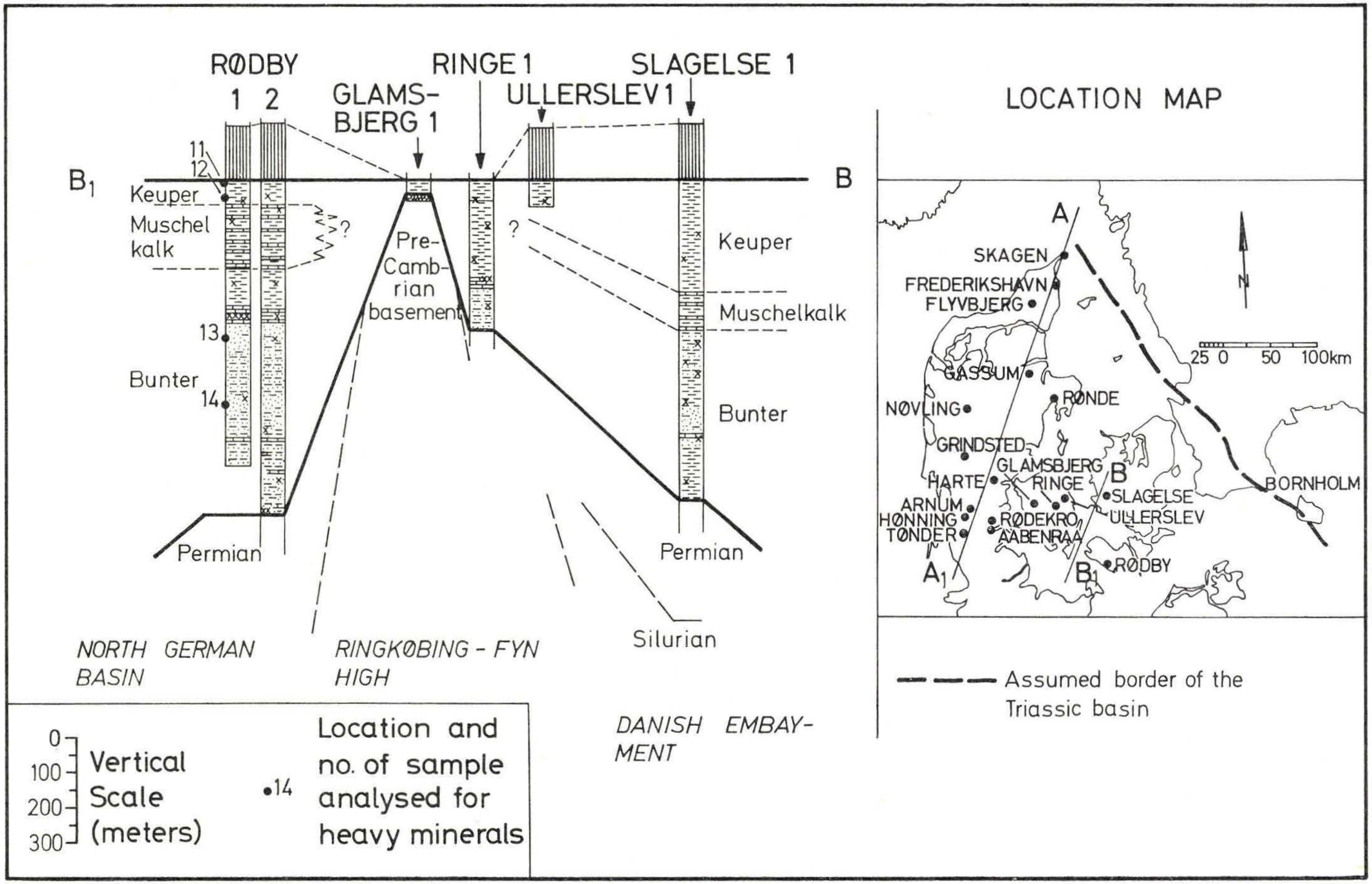
Lithologically the Rhaetic deposits differ from the other Triassic deposits whereas they are similar to those of the Jurassic and Lower Cretaceous. For this reason the Rhaetic has been treated in connection with the Jurassic and



AABENRAA 1
HØNNING 1
TØNDER BY
1 2
RØDEKRO 1
ARNUM 1
HARTE 2
GRINDSTED 1
HORSENS
1
NØVLING 1
GASSUM 1
RØNDE 1
FLYVBJERG 1
FREDERIKSHAVN CITY
2 1 3
SKAGEN 2
A1
A
Keuper
Muschel kalk
Bunter
Permian
Pre-Cambrian basement
Permian
Keuper
Bunter
Pre-Cambrian basement
FENNOSCANDIAN BORDER ZONE
NORTH GERMAN BASIN
RINGKØBING - FYN HIGH
Silurian
Permian
DANISH EMBAYMENT
Vertical Scale (meters)
0
100
200
300
Location and no. of sample analysed for heavy minerals
RHAETIC
PRE-RHAETIC TRIASSIC
Arkose
Sandstone
Claystone
Limestone
Anhydrite
Halite
PRE TRIASSIC
Sediment
Vulcanite
Gneiss

Fig. 1 a.

Fig. 1 b.


RØDBY
1 2
GLAMS-
BJERG 1
RINGE 1
ULLERSLEV 1
SLAGELSE 1
B1
B
11
12
Keuper
Muschel
kalk
13
Bunter
14
Pre-
Camb-
rian
basement
Keuper
Muschelkalk
Bunter
Permian
Permian
Silurian
NORTH GERMAN
BASIN
RINGKØBING - FYN
HIGH
DANISH EMBAY-
MENT
0
100
200
300
Vertical
Scale
(meters)
•14
Location and
no. of sample
analysed for
heavy minerals
LOCATION MAP
A
SKAGEN
FREDERIKSHAVN
FLYVBJERG
N
25 0 50 100km
GASSUM
RØNDE
NØVLING
GRINDSTED
GLAMSBJERG
B
HARTE
RINGE
SLAGELSE
ARNUM
HØNNING
RØDEKRO
ULLERSLEV
TØNDER
AABENRAA
BORNHOLM
A1
B1
RØDBY
Assumed border of the
Triassic basin

Lower Cretaceous in a previous work (Larsen, 1966). In this study samples from other parts of the Triassic sections have been analysed in a similar way. The origin of the sediments is discussed from interpretations of the heavy-mineral associations. Previously the subject has been briefly treated by Larsen (1967).

The Triassic sequence and the sample material

A total of 14 samples have been analysed. This is only a very poor representation of the entire Triassic sequence which is illustrated by the cross-sections in figs. 1 a and 1 b. These sections demonstrate the main features of the lithology in the pre-Rhaetic sequence as it appears from a number of deep borings. Compilation has been made from Sorgenfrei and Buch (1964) and Dinesen (1971, 1973). The surface of the pre-Rhaetic Keuper was used as base-line.

Some features of the regional development which may be seen from the figures will be pointed out briefly.

The deep structure (The North German Basin, The Ringkøbing-Fyn High, The Danish Embayment, The Fennoscandian Border Zone) is clearly reflected.

The southernmost borings represent the conditions in the northern parts of the North German Basin. Here Triassic is found resting on Permian deposits. The Bunter, which makes up a considerable part of the sequence, contains a well developed horizon with evaporites, referred to the Röt. Muschelkalk is represented by marine deposits which in the Rødby 1 boring are fossiliferous (Sorgenfrei & Buch, 1964). To the east the Keuper deposits, which are mainly claystones, are rather thin. In the western part the thickness increases and beds of sandstone occur as intercalations in the clayey sequence.

From the North German Basin the thickness of the Triassic sequence decreases towards the Ringkøbing-Fyn High where in the most elevated parts Precambrian gneisses form the substrate.

In the Danish Embayment a very thick sequence of Triassic deposits were laid down on a substrate of Permian sediments. The stratigraphic subdivision seems to be reliable as far as the southern parts are concerned as here parts of the sections are referred to Muschelkalk. In the central parts of the Danish Embayment the subdivision is less certain, as no beds are referred to Muschelkalk with certainty. According to Sorgenfrei (1969) and Dinesen (1971) the thick salt layers may correspond completely or partially to the German Muschelkalk, but this has not yet been verified.

Towards the Fennoscandian Border Zone the Triassic sequence thins out

Table 1. Localization of analysed samples. Depths are below rotary table.

Sample no.	Boring	Core depth
1	Skagen 2	1850′–1860′
2	»	1960′–1967′
3	Frederikshavn City 1	3450′–3460′
4	»	3460′–3470′
5	Frederikshavn City 2	3175′–3178′
6	»	3380′–3386′
7	»	3448′–3468′
8	Flyvbjerg 1	1483 –1489 m
9	Tønder By 1	3527′–3537′
10	»	7053′–7056′
11	Rødby 1	2237′–2257′
12	»	2301′–2314′
13	»	3775′–3790′
14	»	4486′–4506′

Table 2. Composition of non-opaque heavy-mineral fraction.

Sample no.	Zircon	Rutile	Anatase	Tourmaline	Titanite	Kyanite	Staurolite	Garnet	Epidote	Hornblende	Other minerals
1	9	9	–	8	6	1	1	16	42	6	2
2	1	3	–	4	19	–	–	67	3	+	3
3	17	12	–	9	37	–	–	24	1	–	–
4	15	8	–	9	24	–	–	43	1	–	–
5	78	11	2	1	3	–	–	2	1	–	2
6	9	1	–	2	17	–	–	71	–	–	–
7	19	–	1	5	36	–	–	39	–	–	–
8	43	20	8	11	–	–	–	17	–	–	1
9	1	7	–	19	43	–	+	27	–	–	3
10	37	4	–	8	–	–	–	51	–	–	–
11	36	20	1	22	–	1	8	7	1	–	4
12	14	28	6	42	–	2	–	6	–	–	2
13	34	3	–	11	–	–	–	52	–	–	–
14	17	4	5	20	–	–	2	52	–	–	–

rapidly. Here coarse arkoses are found directly on the Precambrian basement, and Keuper-clays overly these arkoses, which are clearly a marginal facies, probably corresponding to the Kågeröd Formation in Skåne (Sweden) (Troedsson, 1942). Therefore these rocks are referred to the

Triassic, although it must be stressed that the age of the arkoses is not clarified.

As mentioned, the 14 samples represent a very limited part of the Triassic sequence. Furthermore, as seen from figs. 1 a and 1 b, only the northernmost and southernmost regions of the depositional area in Denmark are represented by samples. The localization of the individual samples is shown in table 1.

The heavy-mineral analyses

Heavy-mineral analyses have been made on the grain-size fraction 75–250 μm from which the heavy-minerals were separated by means of bromoform (S.G. = 2.89). Upon mounting in Clearax (R.I. = 1.666) the composition of the non-opaque fraction was estimated by counting 200 mineral grains from each sample. The results of the analyses are shown in table 2.

Geological interpretation of the heavy-mineral analyses

The heavy-mineral analyses of table 2 reveal some features of the genetic history of the sediments. These features are discussed below.

1. Bunter

Bunter is represented by analyses from the borings Tønder By 1 and Rødby 1. In the map (fig. 2) these analyses have been put together with comparable analyses from Helgoland and Schwedeneck in Germany (Sindowski, 1957) and Höllviken in Sweden (Brotzen, 1950). Referring to figs. 1 a and 1 b the stratigraphic position of the samples from the Danish localities is assumed to be lower and middle Bunter as they occur below the evaporite horizon referred to the Röt. The German occurences represent middle Bunter (Sindowski, 1957). The material from Höllviken represents the upper part of the Bunter sequence.

As seen from fig. 2 the heavy-mineral associations from Helgoland, Tønder, Schwedeneck and Rødby are so alike that they must be assumed to represent a continuous heavy-mineral province, which might be called the "Garnet province" as garnet constitutes more than 50 % of the non-opaqe heavy-minerals. The stable minerals zircon, rutile and tourmaline constitute the remaining part of the associations.

To the south in the German Triassic basin the sediments have been supplied mainly from southerly and easterly directions. Here the heavy-mineral associations are of more miscellaneous composition. As a rule the stable minerals dominate while garnet is represented in rather small amounts (Sindowski, 1957). According to Heim (1966) apatite is a characteristic component in parts of the German Bunter.

These features indicate that the "Garnet province" is genetically unrelated to the southernmost occurences and as suggested by Sindowski (1957) the material is assumed to be of northern origin. The source area may have been parts of the Ringkøbing-Fyn High and/or Fennoscandia.

Concerning the nature of the source area it is a question whether it was dominated by older sediments or by crystalline basement rocks. The nature of the grain texture may yield conclusive evidence in this connection. It should be mentioned that according to Heim (1966) many of the garnets from parts of the middle Bunter of Helgoland are large idiomorphic grains. In the Danish material wearing of the garnets is not pronounced. This indicates that the material has not been reworked and so probably does not originate from old sediments but from basement rocks.

According to Noe-Nygaard (1963) the basement rocks of the Ring-

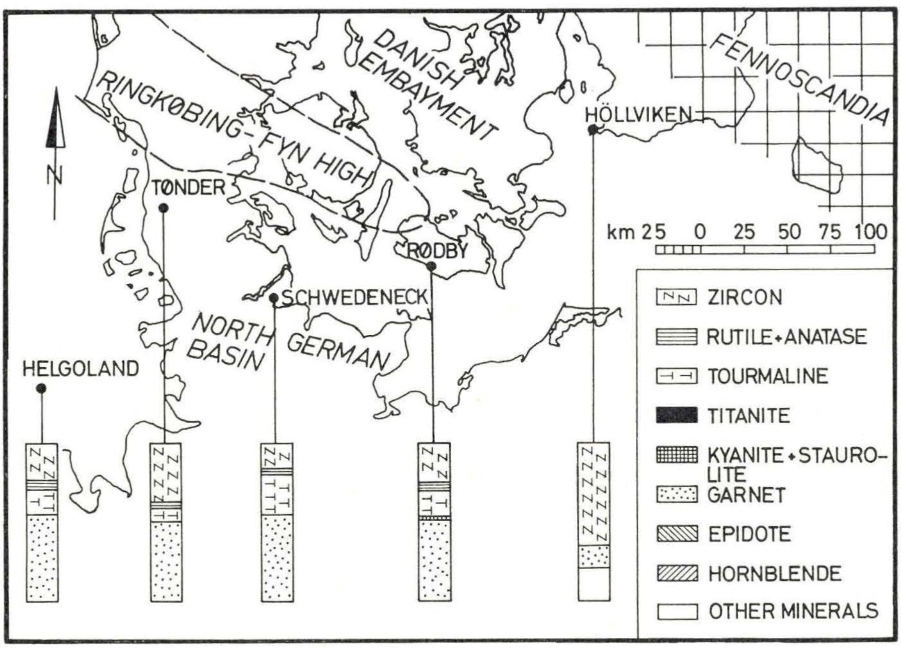


Fig. 2. Location and heavy-mineral associations of samples from the Bunter. The analyses from Helgoland and Schwedeneck are given by Sindowski (1957), the analysis from Höllviken by Brotzen (1950).

købing-Fyn High as known from a few borings do not contain garnet in appreciable amounts. Only in the Arnum boring was a block of garnet-hornblende-biotite gneiss found, indicating that garnet-bearing basement is present in the vicinity of this locality. Considering that this is the only occurence of garnet-bearing basement rocks from the Ringkøbing-Fyn High known at present and that considerable parts of the High were already covered in early Bunter time (cf. Grindsted 1) it seems unlikely that the rather widespred "Garnet province" originated from the Ringkøbing-Fyn High. Furthermore it should be mentioned that the Rhaetic heavy-mineral associations, which according to the distribution of sedimentary facies must be assumed to have originated from the High, only contain small amounts of garnet (Larsen, 1966).

Thus it is suggested that the Fennoscandian Shield was source area for the "Garnet province" of the Bunter. However a more precise specification is hardly possible. On the other hand it should be mentioned that an almost identical heavy-mineral association is found in the Rhaetic of the Gassum 1 boring (Larsen, 1966). This might reflect that the source area of the "Garnet province" was of considerable extent. It is unlikely that the heavy-mineral associations of the sediments reflect the composition of the source area directly as some of the less stable minerals (e.g. hornblende) may have been removed during the genesis of the sediments, either by weathering or by later diagenesis.

To illustrate the effects of diagenesis it should be mentioned that the garnet grains generally are only slightly corroded, and some completely non-corroded grains are still present. Considering the great depth of the samples (sample no. 10: 7053′–7056′) this feature seems surprising. In comparison to this, sediments from corresponding depth within the Danish Embayment display evidence of very intense diagenetic mineral destruction (Larsen, 1970).

So far only the "Garnet province" has been discussed. As seen from fig. 2 the heavy-mineral association of Höllviken strongly diverges from the homogenous "Garnet province". This is probably explained by the position of this locality, close to the margin of the Bunter depositional basin. In this marginal position the locally exposed source rocks may have influenced the composition of the sediments radically, as also proposed by Brotzen (1950).

2. Triassic marginal facies against Fennoscandia

The coarse arkose in northern Jylland (fig. 1 a) is interpreted as a marginal facies of the Triassic basin. Probably such a marginal facies is developed along the entire border zone between the basin and the Fennoscandian source area, cf. the Kågeröd Formation in Skåne (Sweden).

Analyses from Skagen and Frederikshavn, together with analyses representing the Kågeröd Formation at Ottarp, Skromberga and Höllviken are presented on the map (fig. 3). The analysis from Höllviken is given by Brotzen (1950).

A distinctive feature of the occurences in northern Jylland is the large amount of titanite. In the material from Skåne the extremely high content of garnet at Ottarp and Skromberga is remarkable, and the differences between the Danish and the Swedish arkoses are conspicuous. However this is to be expected of a coarse marginal arkose formed by detritus of mainly locally exposed rocks.

Both old sediments and basement rocks are known to have been exposed in the source area of the Kågeröd Formation (Troedsson, 1942). However the heavy-mineral associations show no sure signs of contributions from

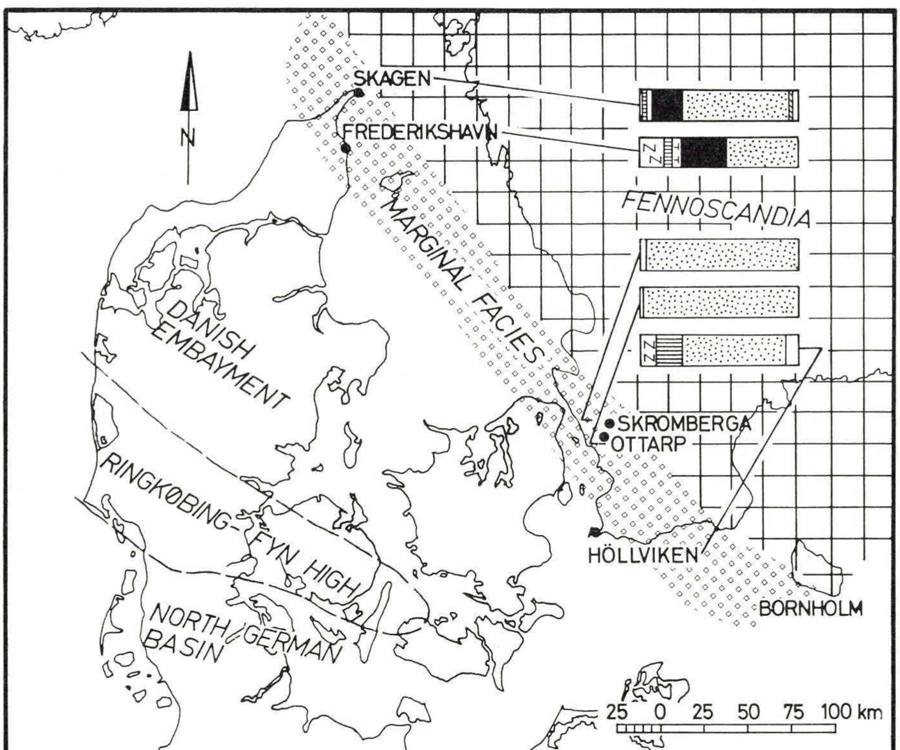


Fig. 3. Location and heavy-mineral associations of samples from the Triassic marginal facies. The analysis from Höllviken is given by Brotzen (1950). (See fig. 2 for legend to the heavy-mineral diagrams).

recycled older sediments. This may indicate that the supply from older sediments was very poor in heavy-minerals.

Also the material from northern Jylland seems to originate mainly from basement rocks. Garnets without signs of wear, some of them idiomorphic (plate 2, A) are presumed to have been derived directly from the crystalline rocks. This feature is most pronounced in the Skagen boring. Some of the zircons, tourmalines and garnets are rounded, especially in the Frederikshavn boring, indicating that parts of the material is recycled sediments. The large content of titanite is a peculiar feature which probably indicates a crystalline parent material, though the grain texture indicates that the original grain surfaces have been strongly modified by corrosion (plate 2, B). Not only titanites are corroded. Etched epidotes (plate 2, C–E) and staurolites have also been found from the Frederikshavn boring. In contrast to the Frederikshavn material epidote is found to be quite fresh in the Skagen material. Furthermore garnets from both borings are corroded to variable degrees. Compared to the Skagen boring the Frederikshavn boring generally shows evidence of a more intense diagenetic dissolution. As the Frederikshavn material occurs at greater depth than the Skagen material, this feature is in agreement with the general situation in the Danish Embayment where the intensity of diagenetic dissolution increases with depth (Larsen, 1970).

3. Keuper

From the Keuper sequence heavy-mineral analyses have been made on samples from Skagen, Frederikshavn, Flyvbjerg, Rødby and Tønder. All analyses refer to more or less sandy beds in the otherwise mainly clayey deposits. These analyses are shown in the map (fig. 4) which also gives an analysis of kaolinitic sand from Julegaard on Bornholm (Gry, 1936).

It is clear from the figure that the heavy-mineral associations are rather different from one region to another. The possible origin of the individual associations is discussed below.

The Skagen association is dominated by unstable minerals with epidote as the main component. This association is very close to that of the overlying Rhaetic beds (Larsen, 1966). Supported by information from the distribution of sedimentary facies, the Rhaetic association was assumed to originate from an area of Fennoscandia localized E or NE of Skagen. The same origin is suggested for the present material. The source area was probably a gneiss-complex of mainly intermediate metamorphic facies. During disintegration in the source area the influence of chemical weathering obviously was very small. Neither did diagenetic processes change the

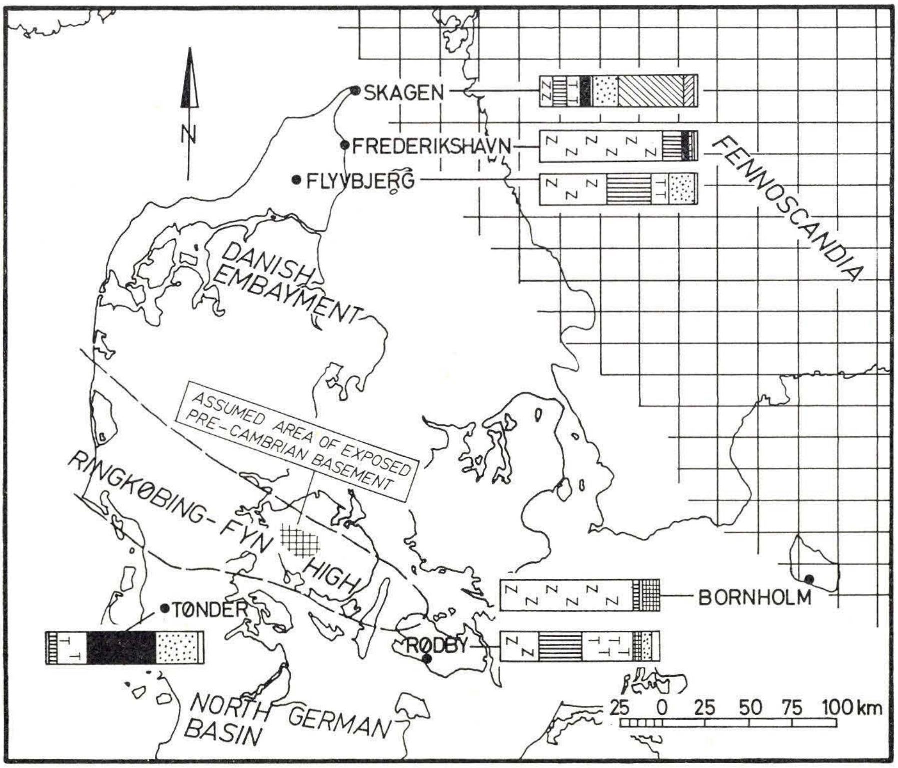


Fig. 4. Location and heavy-mineral association of samples from the pre-Rhaetic Keuper. The analysis from Julegaard (Bornholm) is given by Gry (1936). (See fig. 2 for legend to the heavy-mineral diagrams).

mineralogical composition appreciably as only few mineral grains are slightly corroded. At Frederikshavn a stable, zircon dominated association is found. The association from Flyvbjerg is very similar as it is also dominated by the stable minerals, although to a lesser degree. These associations may be regarded as the result of excessive chemical dissolution during weathering and/or diagenesis. The study of Rhaetic-Jurassic-Lower Cretaceous sediments demonstrated that intensive diagenetic destruction of heavy-minerals also dominates in the deeper parts in northern Jylland (Larsen, 1966, 1970). In this connection it is assumed that the strong dominance of stable heavy-minerals in Frederikshavn and Flyvbjerg was caused mainly by diagenetic dissolution. Furthermore it should be pointed out that zircon occur more frequently than tourmaline. This feature is common to the Rhaetic-Liassic associations in the entire northern Jylland (Larsen, 1966, fig. 41). This may suggest the outline of an extensive northern Keuper-Rhaetic-

Liassic heavy-mineral province in which the original uniform composition has been modified by subsequent diagenetic dissolution.

The occurence of kyanite and staurolite in the Keuper-association of Bornholm demonstrates that the material was derived from a source area outside Bornholm (Gry, 1936).

The heavy-mineral associations in Rødby are very similar to those of the Rhaetic-Liassic deposits above (Larsen, 1966). Refering to the distribution of sedimentary facies in the Rhaetic deposits, these sediments were interpreted as being recycled from older sediments exposed on the Ringkøbing-Fyn High. The Keuper-association probably originated from the same sedimentary source area. Thus a southern Danish heavy-mineral province seems to exist, reflecting a considerable permanence in detritus production and supply in Keuper-Liassic times.

In Tønder the heavy-mineral association is noteworthy for its large content of titanite. The titanites are generally fresh without signs of corrosion or extensive mechanical wear (plate 2, F–G). Also garnets are only slightly worn; furthermore biotites with an idiomorphic outline are found (plate 2, H). From these features it is deduced that the main part of the material was derived from a crystalline source area which was not very distant from Tønder. Thus it is natural to suggest that parts of the Ringkøbing-Fyn High supplied these sediments. The analysis refers to a sandy sequence within the Keuper. This part of the Keuper sequence is thought to correspond to the German Schilfsandstein. Wurster (1964) demonstrated that the Schilfsandstein was laid down by a system of rivers draining areas of Fennosarmatia. In this connection the sandbed in Tønder could have been deposited by a stream originating on the Ringkøbing-Fyn High and draining areas where the basement was still free from overlying sediments. The Glamsbjerg area obviously was a possible source area. From Noe-Nygaard (1963) it is known that the basement at Glamsbjerg contains the heavy-minerals zircon, titanite, apatite, hornblende and biotite. This composition is not identical to the heavy-mineral association in Tønder where apatite and hornblende are missing, while in Glamsbjerg tourmaline and garnet are absent. However, during weathering the unstable minerals apatite and hornblende may have been destroyed and tourmaline and garnet may have been supplied from other sources. This is only one possible explanation and others might be taken into consideration. However, it is important that the most conspicuous component of the Tønder association, the titanite, may be assumed to originate from the basement of the Ringkøbing-Fyn High. Furthermore it should be mentioned that Gry (1948) registered a remarkable high content of titanite from the Harte boring in beds which according to Christensen (1962) are of Keuper age.

As mentioned only faint traces of diagenetic dissolution of the heavy-minerals are seen in the Tønder association. This feature corresponds to the general tendency of the examined material that evidence of diagenetic dissolution are less pronounced south of the Ringkøbing-Fyn High than at corresponding depth in the Danish Embayment. However it must be emphasized that this conclusion is based on a very limited number of analyses.

Final remarks

During this study an attempt has been made to shed light on some of the problems concerning the origin of the Triassic deposits in Denmark. The general assumption that the sediments were supplied from Fennoscandia and the Ringkøbing-Fyn High has been illustrated. The location of the heavy-mineral associations and their mutual similarities and differences suggests the contours of a subdivision of the basin into heavy-mineral provinces. The varying influence of different source areas on the sediment production seems to be the main controlling condition for delineation of these provinces. However the picture is not very clear, partly because diagenetic mineral destruction in places was so intense that the original character of the associations may have been obliterated. Furthermore the examined material only represents small sections of the total Triassic sequence in Denmark.

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Dansk sammendrag

Trias aflejringerne udgør en betydningsfuld del af den danske undergrund. Det hidtidige kendskab til disse aflejringer er i det væsentlige begrundet i lithologiske undersøgelser. Med dette arbejde søges vor viden om det præ-rhætiske trias udbygget med nogle tungmineralanalysers vidnesbyrd.

Hovedtræk af lagseriens lithologiske opbygning er vist i tværprofilerne fig. 1 a og 1 b, hvor overfladen af det præ-rhætiske keuper er benyttet som referenceniveau. I figurerne er analyseprøvernes lokalisering vist. Som det ses, repræsenterer disse prøver kun et beskedent udsnit af den samlede lagserie.

Resultatet af tungmineralanalysen er vist i tabel 2. Tolkningen af disse mineralselskabers geologiske baggrund rummer flg. hovedpunkter.

For buntsandsteins vedkommende er de danske analyser sammenholdt med tilsvarende fra Nordtyskland og Sverige, fig. 2. Det ses, at selskaberne i det syddanske og nordtyske område, d.v.s. i det nordlige strøg i Det nordtyske bassin, indbyrdes er så ens, at de kan antages at udgøre en sammenhængende tungmineralprovins. Ud fra karaktermineralet betegnes den »Granat-provinsen«. Det findes sandsynligt, at den er af nordlig oprindelse, med et fennoscandisk grundfjeldskomplex som denudationsområde. Den diagenetiske mineralopløsning efter aflejringen synes ikke at have været særligt omfattende.

Langs trias aflejringsfeltets afgrænsning mod Fennoscandia optræder en randfacies af grovkornede arkoser. Kortet fig. 3 viser nogle nordjydske og skånske tungmineralselskaber fra denne randfacies. Det antages, at disse er opstået ved nedbrydning fortrinsvis af grundfjeldsbjergarter exponeret langs bassinranden.

Kortet fig. 4 viser tungmineralselskaber i keuper. I det nordjydske område svarer selskaberne så nøje til dem, man møder i de overliggende rhæt-lias lag, at der tegner sig et billede af en større nordjydsk keuper-rhæt-lias tungmineralprovins, opstået ved nedbrydning af fennoscandiske grundfjeldsbjergarter. I de dybereliggende dele af lagserien har diagenetiske opløsningsprocesser øjensynlig ført til en ret gennemgribende ændring af den oprindelige mineralbestand. Tungmineralselskabet i Rødby har stor lighed med de rhæt-lias selskaber, man møder både i Rødby og Ullerslev. Der kan således opstilles en syddansk keuper-rhæt-lias tungmineralprovins, hvis oprindelse antages at være fortrinsvis ældre sedimenter lokaliseret i Ringkøbing–Fyn højderyggen. Tønder selskabet har et bemærkelsesværdigt stort titanitindhold. Sandsynligvis er dette selskab opstået ved nedbrydning af titanitholdigt grundfjeld i de højereliggende endnu ikke sedimentklædte dele af Ringkøbing–Fyn højderyggen. Betragtes analyseresultaterne under ét spores en tendens til at de dybereliggende lag i det nordjydske område er stærkere præget af diagenetisk mineraldestruktion end lag på tilsvarende dybde syd for Ringkøbing–Fyn højderyggen.

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Plate 2

Microphotographs of heavy-minerals. Mounting medium: Clearax (R.I. = 1.666).

A. Idiomorphic garnet. Sample no. 2. Skagen.

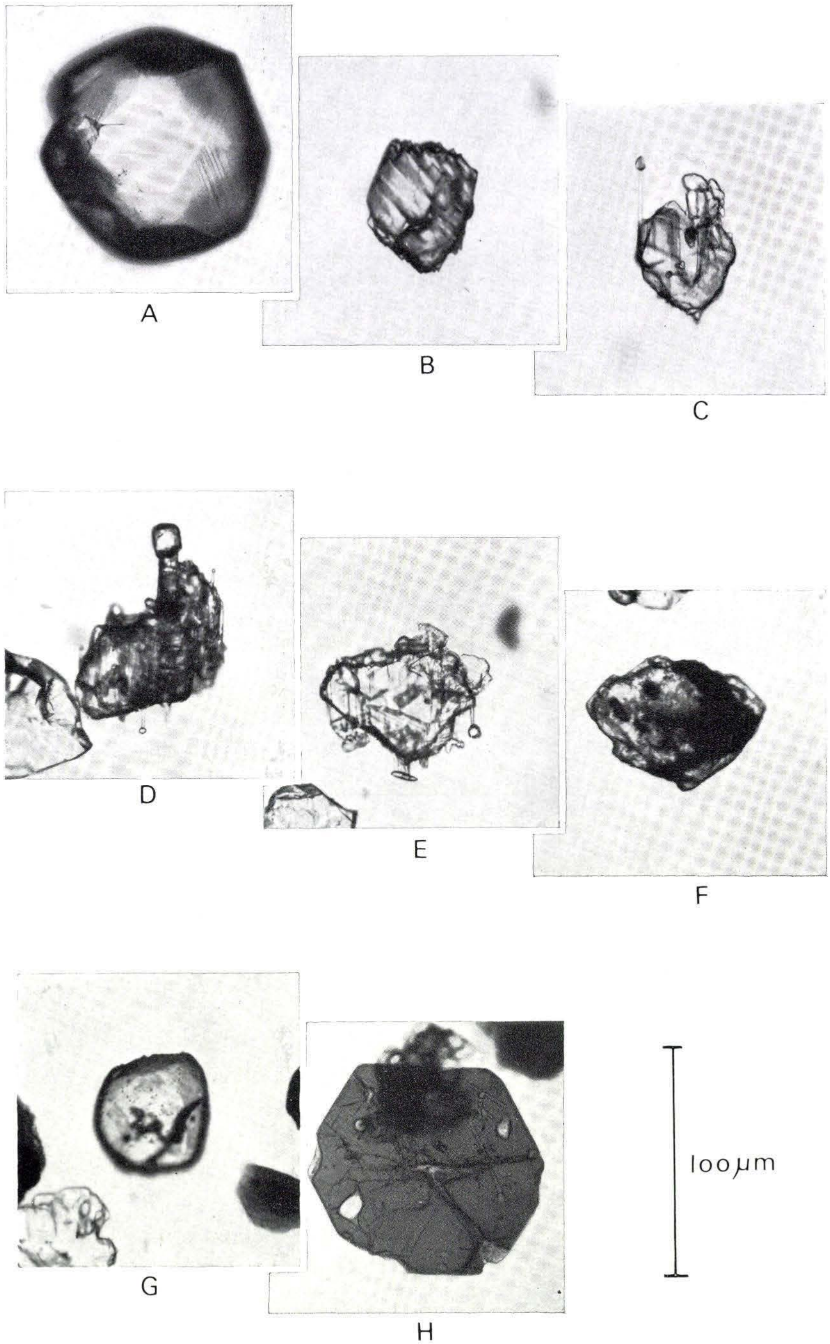
B. Heavily corroded titanite. Original outline obliterated. Sample no. 4. Frederikshavn.

C. Corroded epidote. Where protected by inclusions long spines of epidote have survived the diagenetic dissolution. Sample no. 3. Frederikshavn.

D–E. Corroded epidote. As C. Sample no. 4. Frederikshavn.

F–G. Fresh titanite. Sample no. 9. Tønder.

H. Idiomorphic biotite. Sample no. 9. Tønder.


A
B
C
D
E
F
G
H
100 µm