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Early Tertiary Bentonites from Svalbard; a Preliminary Report*

By Henning Dypvik and Jenö Nagy **

Abstract: Paleontological and petrological studies of clay beds in the Basilika Formation (Tertiary age) are the subject of this paper. The petrology of the beds indicates that their main constituents were derived from volcanic activity and represent bentonites. Differing composition of the beds may suggest several spatially separated eruptions. The volcanic source area probably lay towards the north of the present Tertiary outcrops of Svalbard. Two foraminiferal assemblages are found in the bentonites: the lower is dominated by arenaceous forms while the upper consists of calcareous species.

Zusammenfassung: Es werden Ergebnisse paläontologischer und petrologischer Untersuchungen in der Basilika-Formation (Tertiär) vorgelegt. Die Petrologie der untersuchten Schichten zeigt, daß die Hauptgemengteile aus vulkanischer Tätigkeit abgeleitet werden können und als Bentonite vorliegen. Die unterschiedliche Zusammensetzung könnte von räumlich getrennten Eruptionen abgeleitet werden. Das vulkanische Ursprungsgebiet lag vermutlich nördlich der heutigen Tertiärvorkommen Svalbards. Zwei Foraminiferen-Gemeinschaften wurden in den Bentoniten gefunden: in den unteren herrschen Sandschaler vor, während die obere Kalkschaler enthält.

INTRODUCTION

The material described in the present paper was collected during the expeditions organized by the Norsk Polarinstitutt in the summers of 1960, 63 and 64. The bentonite beds investigated occur within marine claystones of the Basilika Formation. This unit is assigned to the Palaeocene by most authors (e. g. LIVSIC, 1974; KELLOGG, 1975).

The first report of bentonites in the Basilika Formation was published by GRIPP (1927) who described a thin bed of plastic clay from Fossildalen (west of Colesbukta) and assumed that the bed represented a bentonite. More conclusive petrographical evidence for the volcanic origin of this bed was given by MÜLLER (in GRIPP, 1927).

Subsequent to GRIPP's publication, occurrences of Tertiary tuff and/or clay beds were reported from different parts of the Spitsbergen trough by NAGY (1966), VONDERBANK (1970) and MAJOR & NAGY (1972). However, detailed analyses of the beds have never been published and the genesis of the deposits has therefore remained somewhat uncertain, in spite of their suggested volcanic origin.

The present study gives both a petrographical description of the different beds and an account of their microfauna. This new information on the origin and depositional environment of the beds is placed in a regional framework.

TECTONISM AND VOLCANIC ACTIVITY

The tectonic evolution of the Arctic during the Tertiary has been discussed in many publications. The following account is based on information given by HARLAND (1969), LOWELL (1972), PITMAN & TALWANI (1972) and TALWANI & ELDHOLM (1977).

The pre-drift reconstruction of the Arctic (Fig. 1) shows Svalbard in the Paleocene (anomaly 24 time) lying close to Ellesmere Island. During the late Cretaceous to early Tertiary (81—63 m. y. a.) the Amerasia Basin may have been under compression due to

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** Dr. Henning Dypvik and Dr. Jenö Nagy, Institutt for Geologi, Universitetet i Oslo, Box 1047, Blindern, Oslo 3 (Norway).

rapid spreading in the North Atlantic, with a rotation pole in northern Greenland. This compression was perhaps accommodated by subduction along the Alpha-Mendeleev Ridge Complex.

The opening of the Norwegian-Greenland Sea and the Eurasia Basin started between 60 and 63 m. y. a. (Between anomalies 24 and 25). From that time to about 38 m. y. a. (anomaly 13) the Labrador Sea, the Norwegian Sea and the Eurasia Basin opened and Greenland slid past Svalbard and the Barents shelf in a transcurrent fashion. The movement of Greenland relative to Svalbard is reflected by the Tertiary orogenic belt

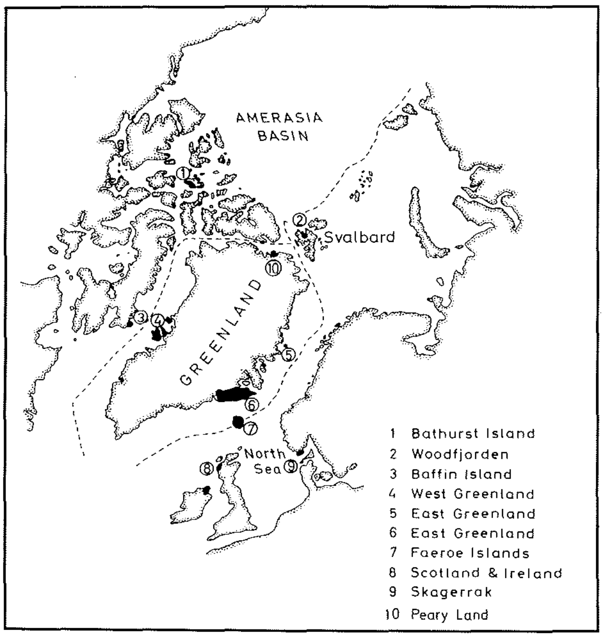

Fig. 1: Reconstruction of Arctic and adjacent areas prior to the Palaeocene opening of the Norwegian Sea. Stippled lines indicate Tertiary plate boundaries. Dark areas show the occurrences of Tertiary volcanics. (Compilation based on HERRON et al., 1974; KRISTOFFERSEN & TALWANI, 1977; LOWELL, 1972; and TALWANI & ELDHOLM, 1977).

Abb. 1: Rekonstruktion der Arktis und angrenzender Gebiete vor der paläozänen Öffnung des Nordatlantiks. Gestrichelte Linien zeigen die Plattengrenzen im Tertiär an. Dunkle Flächen geben die Verbreitung tertiärer Vulkanite an. (Zusammengestellt nach HERRON et al. 1974, KRISTOFFERSEN & TALWANI 1977, LOWELL 1972, und TALWANI & ELDHOLM 1977).

of western Svalbard which was formed by these strike — slip movements. However, about 38 m. y. a., transcurrent motion was replaced by oblique spreading in the Norwegian-Greenland Sea, north of the Greenland-Senja fracture zone. North of Svalbard spreading continued along the Nansen (Gakkel) Ridge. Extension in the Arctic during the past 63 m. y. has occurred solely at the axis of this ridge.

This short review of the Tertiary spreading history of the Arctic shows that several tectonic episodes have occurred. Volcanics related to this tectonism are found in different areas. Tertiary volcanic rocks are well known in the North Sea and adjacent areas (Fig. 1). KENT (1975) reported a wide distribution of the Palaeocene/Eocene tuff beds and noted the Skagerrak or the Hebridean provinces as possible sources.

Plutonic and volcanic rocks of the so-called Hebridean province occur along the western seaboard of Scotland and in northern Ireland. The age of most of these tholeiitic and alkaline basaltic lavas and granitic rocks is now regarded as Palaeocene/Eocene (BECKINSALE et al., 1970). JACQUÉ & THOUVENIN (1975) suggested that the North Sea tuffs (which have a basaltic composition) were probably derived from this province.

The Lower Tertiary tuffaceous beds of Denmark, called the Mo Clay, approx. 54 m. y. a. (BÖGGILD, 1918), were probably derived from the Skagerrak area where PEDERSEN et. al. (1975) suggest an episode of abortive spreading.

Volcanism started on the Faeroes block in the Palaeocene. The volcanic rocks of the Faeroe Islands consist of subaerial basaltic lavas which have a thickness of 3 km (RASMUSSEN & NOE NYGAARD, 1969; 1970). These alkalic and tholeiitic basalts erupted 50—60 m. y. a. (TARLING & GALE, 1968).

The Tertiary volcanics of East Greenland and the Faeroe Islands represent areas which were closely adjacent to each other prior to drift. In East Greenland tuff beds were deposited in the Upper Palaeocene, and effusive basalts were formed in three episodes in the Lower Eocene. The tuff beds pre-date the earliest formation of oceanic basement in the North-East Atlantic (SOPER et al., 1976).

Early Tertiary volcanics are also found in West Greenland. NOE NYGAARD (1974) described subaquatic and subaerial volcanics of tholeiitic and alkaline basaltic composition. In some southern areas he mentioned tuffs which were interbedded with early Tertiary sediments. On the opposite side of the Davies Strait, on Baffin Island, CLARK (1970) described Palaeocene rocks which are overlain by subaquatic basaltic breccias and picritic lavas. Further north, on Bathurst Island, KERR & TEMPLE (1965) described Tertiary sediments with interbedded basic volcanics.

Late Cretaceous/Early Tertiary volcanics are also found in northern Greenland, Peary Land, where the Kap Washington Group of rhyolitic lavas and tuffs is exposed (DAWES, 1973; DAWES & SOPER, 1971). The Kap Washington volcanics and the basic dikes of Peary Land are regarded as coeval to the earlier phases of the Morris-Jesup — Yermak Plateau formation in the Eurasia Basin off northern Greenland and Svalbard (VOGT, pers. comm. 1978).

These extensive early Tertiary volcanic episodes are probably also represented in the Woodfjorden area (northern Spitsbergen) where basaltic plateau-lavas are found (PRESTVIK, pers. comm. 1978). Radiometric (K/Ar) age determinations published by BUROV & ZAGRUZINA (1976) indicate ages from 22 to 60 m. y.

FIELD RELATIONS

The main area of Tertiary deposits in Svalbard is the central part of the Spitsbergen trough (Fig. 2). The Tertiary sequence in this region is more than 2 000 m thick and consists of alternating claystone and sandstone formations. The basal unit is the Firkanten Formation which was deposited in marginal marine to terrestrial environments. This unit is overlain by the marine Basilika Formation which contains the bentonite beds described here (Fig. 3).

The Basilika Formation generally consists of dark claystones with additional minor amounts of silt. Thin interbeds of fine-grained sandstone are present locally. The proportion of silt and sand gradually increases upwards in the upper part of the formation, forming a transitional regressive facies between the typical Basilika claystones and the overlying sandstones of the Sarkofagen Formation.

During deposition of the lower three Tertiary formations the depocenter lay to the west of the present Spitsbergen trough, while the principal clastic source areas were situated to the north and northeast (KELLOGG, 1975). The greatest thicknesses of the Basilika Formation are therefore seen along the western flank of the trough: 270 m at Grønfjorden, 350 m at Van Keulenfjorden, and 220 m at Storfjorden, east of Hornsund. The unit thins out towards the northeast, as shown by thicknesses of 60 m at Sveagruva, 63 m near Grumantbyen and 20—30 m south of Adventdalen.

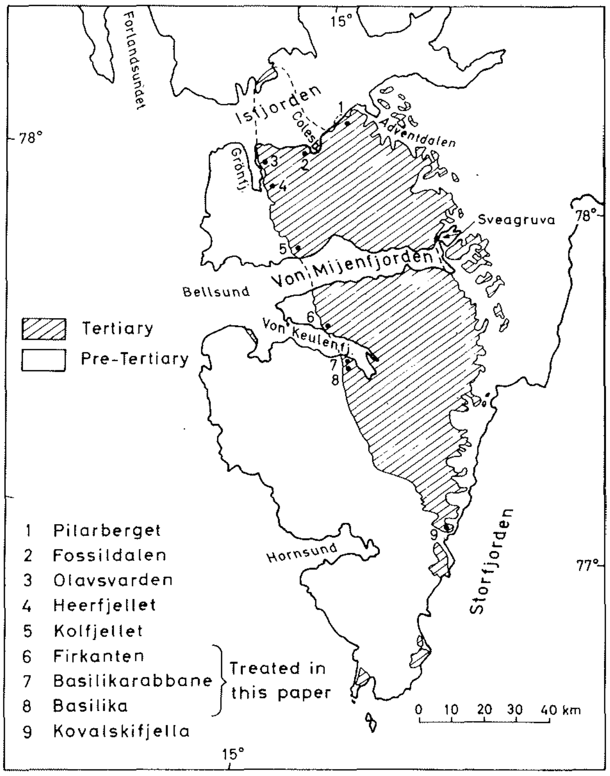

Fig. 2: Map of southern Spitsbergen showing the localities where bentonites or bentonite-like beds are found in the Basilika Formation.

Abb. 2: Karte des südlichen Spitzbergen mit den Vorkommen von Bentoniten oder bentonitartigen Lagen in der Basilika-Formation.

The present paper is based on bentonite samples collected from the three sections shown in Fig. 3. Sample numbers correspond to the bed numbers indicated in these sections. Sample 10 was taken from the transitional zone above bed 9 in the Basilika section.

The Firkanten section is located on the northern shore of Van Keulenfjorden on the Firkanten mountain. In this section, 9 bentonite beds are found, occurring in three groups situated about 9, 65 and 260 m above the base of the Basilika Formation. The thicknesses of these beds vary between 1 and 6 cm.

The Basilika section (on the southwestern slope of the Basilika mountain) contains 6 bentonite beds occurring in the lower 160 m of the formation. The thickness of the beds is 4 to 16 cm.

The third locality is Basilikarabbane, where four bentonite beds were found within a partial section of the Basilika Formation. The section covers 35 m of the formation, and the thickness of the bentonite beds ranges from 8 to 26 cm.

In good exposures the bentonites were observed to rest with a sharp contact on the underlying claystone. The contact between the bentonites and the overlying claystone is generally gradational. An example from the Basilika section is bed 9, which has a thickness of 16 cm and an upper transitional mixed zone of about 6 cm.

In addition to the sections described above and the locality mentioned by GRIPP (1927), bentonites or bentonite-like beds are reported from the following exposures of the Basilika Formation (Fig. 2): seven beds on Pilarberget, inner Isfjorden, with thicknesses

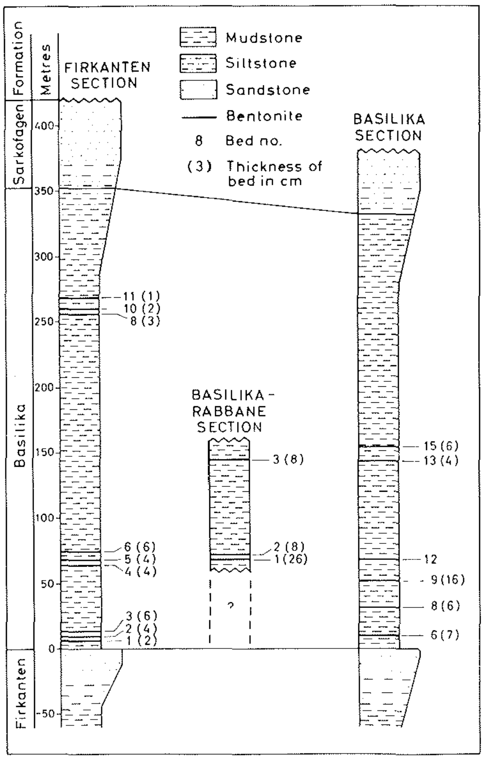

Fig. 3: Columnar sections of the Basilika Formation showing the position of the bentonite beds described in this paper.

Abb. 3: Säulenprofile der Basilika-Formation mit der Lage der Bentonit-Horizonte, die in dieser Arbeit beschrieben wurden.

ranging from 3 to 39 cm (MAJOR & NAGY, 1972); one to three beds with thicknesses of about 3 cm on Kolfjellet, Heerfjellet and Olavsvarden, in the area between Isfjorden and van Mijenfjorden (VONDERBANK, 1970); three beds on Kowalskifjella (Storfjorden) with thicknesses of 25 cm, 20 cm and 7 cm respectively (NAGY, 1966). These observations indicate that bentonite beds in the Basilika Formation are probably present throughout the entire Spitsbergen trough.

ANALYTICAL METHODS

9 samples have been studied in thin section, while 16 samples have been analysed by X-ray diffraction. The grain size distributions of 5 samples have also been established.

Thin section analyses

The samples were impregnated with araldite before thin sections were made. This method leaves structures and minerals unchanged, the araldite only filling the pore space of the samples.

X-ray diffraction analyses

X-ray diffraction determinations were made of unoriented rock powder slides (inverted Millipore slides). The clay minerals were determined according to CARROL (1970), based on the following treatments:

a. Untreated sample.
b. Glycolated sample.
c. Sample heated to 300° C.

The following minerals and peaks of untreated recordings were associated (fig. 4):

12 Å Illite/smectite mixed layer clay minerals
7 Å Chlorite + Kaolin
4.25 Å Quartz
3.22 Å Feldspar

In the semi-quantitative determinations peak height multiplied by width at half height on the X-ray diffractograms is supposed to represent reflection intensities (NORRISH & TAYLOR, 1962; DYPVIK, 1976). By calculating the total of the above mentioned peaks to be 100%, it is possible to estimate semi-quantitatively the amounts of the different minerals present (Tab. 1).

The different ratios presented have been calculated from these estimations (Fig. 5).

	SAMPLE	X-ray diffraction analyses Il./Smec. 12 Å	Chl. + Kaol. 7 Å	Quartz 4.26 Å	Feldsp. 3.22 Å	Thin section Max. grains. observed
BASILIKA SECTION	15	52	trace	33	15	0.30 mm
	13	52	trace	31	17	
	12	66	7	15	12	0.15 mm
	10	63	12	13	12	
	9	76	trace	24	trace	0.22 mm
	8	67	11	12	10	0.35 mm
	6	79	3	3	15	0.25 mm
FIRKANTEN SECTION	11	81	5	4	10	0.12 mm
	10	76	8	9	7	
	8	92	4	trace	4	0.10 mm
	6	60	5	26	9	
	5	61	6	16	17	0.40 mm
	4	44	14	36	6	
	3	82	2	trace	16	0.15 mm
	2	64	5	20	11	
	1	59	9	15	17	

Tab. 1: Table showing semi-quantitative estimations of mineral composition based on X-ray diffraction analyses. Maximum grain sizes observed in thin section are also noted.

Tab. 1: Die Tabelle zeigt halbquantitative Bestimmungen von Mineralzusammensetzungen, auf Röntgen-Diffraktions-Analysen beruhend. Die in Dünnschliffen beobachteten maximalen Korngrößen sind ebenfalls angegeben.

Grain-size analyses

The samples were dispersed by ultrasonic treatment and by Na-citrate solutions for a reduction of ferrous iron (MEHRA & JACKSON, 1960). The non-dissociated fractions were then estimated by binocular studies, and the amounts of completely dispersed samples were calculated (Fig. 6).

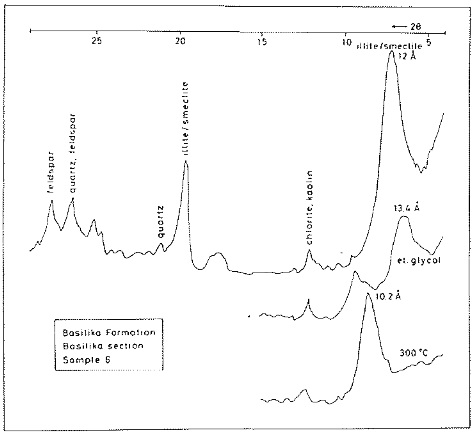

Fig. 4: X-ray diffractograms of sample 6 from the Basilika section, which is a typical bentonite sample from the Basilika Formation. The different minerals present are noted on the diffractograms; these represent three different treatments recorded with the same instrument conditions.

Abb. 4: Röntgendiffraktogramm der Probe 6 aus dem Basilika-Profil, einer typischen Bentonit-Probe der Basilika-Formation. Die verschiedenen vorkommenden Minerale sind am Diffraktogramm angegeben. Diese bilden drei unterschiedliche Behandlungen mit gleichen Instrumenten ab.

RESULTS

Mineralogy and petrology

The samples are generally yellow in colour, both in hand specimen and thin section. In thin section minor dispersed grains of quartz, feldspar and rock fragments (probably volcanic and shale clasts) can be seen (Fig. 7), while X-ray diffraction analyses show the major part of the samples to be made up of illite/smectite mixed layered clay

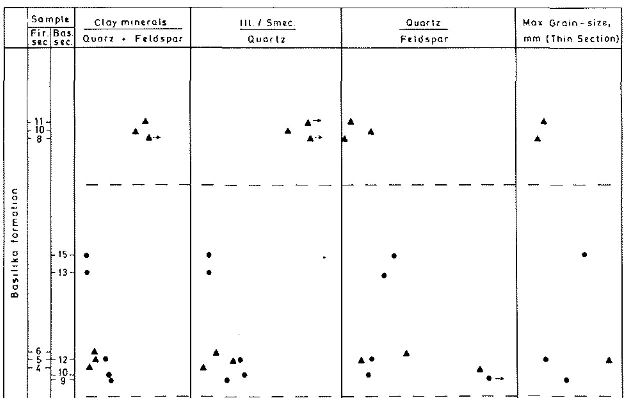

Fig. 5: Stratigraphical distributions of different mineralogical parameters from X-ray diffraction analyses and thin section studies of bentonite samples from the Basilika Formation. The samples from the two sections are plotted in their relative stratigraphical positions through the Basilika Formation. The samples from the Basilika section are marked with black dots, those from the Firkanten section with black triangles. Values are given in tab. 1.

Abb. 5: Stratigraphische Verteilungen verschiedener mineralogischer Parameter von Röntgen-Diffraktions-Analysen und Dünnschliffuntersuchungen an Bentonitproben der Basilika-Formation. Die Proben von den beiden Profilen sind in ihrer entsprechenden stratigraphischen Position innerhalb der Basilika-Formation eingetragen. Die Proben des Basilika-Profils sind mit schwarzen Punkten, die des Firkanten-Profils mit schwarzen Dreiecken gekennzeichnet. Die Werte sind in Tab. 1 angegeben.

minerals (Fig. 4). A few possible glass-shards have been observed in binocular studies. Two samples have been counted in thin section; these were found to consist of 70—80% matrix (mainly clay minerals), 10—20% grains of quartz and feldspar and only about

2% rock fragments (table II). In thin section the grain sizes of the quartz, feldspar and rock fragments generally vary between 0.02 and 0.10 mm, with the largest grain sizes measured ranging from about 0.1 to 0.4 mm (Fig. 5).

X-ray diffraction analyses suggest 3 different mineralogical types of clay beds. The lower beds, with a fine-grained texture, are characterized by low quartz/feldspar ratios, while the intermediate beds contain higher amounts of quartz and feldspar and a relatively high quartz/feldspar ratio. The uppermost beds, possessing low quartz/feldspar ratios, contain

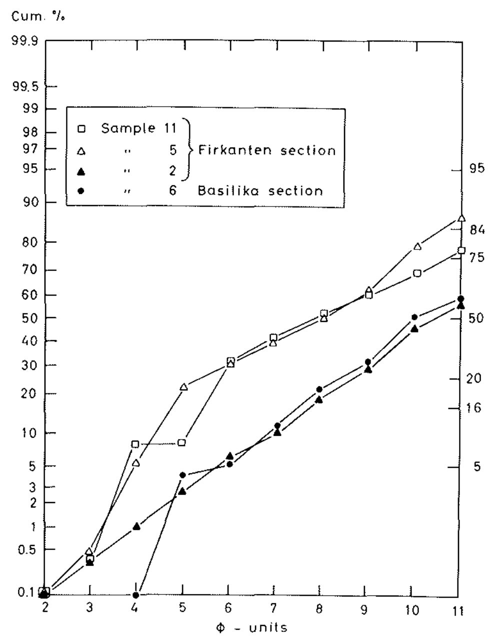

Fig. 6: Grain size distributions of several bentonite samples from the Basilika Formation. Black dots and black triangles are from similar stratigraphical horizons, from the Basilika and Firkanten sections respectively. Open triangles and squares show younger samples from the Firkanten section.

Abb. 6: Korngrößenverteilung von verschiedenen Bentonit-Proben der Basilika-Formation. Schwarze Punkte und Dreiecke stammen aus ähnlichen stratigraphischen Horizonten des Basilika- bzw. Firkanten Profils. Offene Dreiecke und Quadrate entstammen jüngeren Proben aus dem Firkanten-Profil.

a high amount of clays. In thin section the largest grain sizes are seen in the lowermost beds. The grain size distributions show, however, similar sorting upwards through each section, although somewhat higher amounts of coarser grains are found in the youngest beds (Fig. 6).

The Basilika and Firkanten sections are situated rather close to each other, and this is reflected in the mineralogy of the bentonites. The grain size distributions of samples taken from almost equivalent beds in the two sections show similar development and sorting, although coarser grains are found in the samples from the Firkanten section (Fig. 6). Larger amounts of quartz and feldspar are also found in the sample from Firkanten. This last observation is reflected in the X-ray diffraction analyses of comparative samples from these sections (Fig. 5): samples enriched in quartz and feldspar (lower $\frac{\text{clay mineral}}{\text{quartz} + \text{feldspar}}$ ratio and lower $\frac{\text{illite/smectite}}{\text{quartz}}$ ratio) are found in the Firkanten section, probably indicating the occurrence of coarser grains.

Palaeontology

From the three sections investigated several samples were treated for their microfauna, but only beds 1 and 3 in the Basilikarabbane section gave positive results. Bed 1 seems to have the same stratigraphical position as bed 12 of the Basilika section and beds 4—6 in the Firkanten section. Bed 3 has a position similar to that of bed 13 or 15 in the Basilika section.

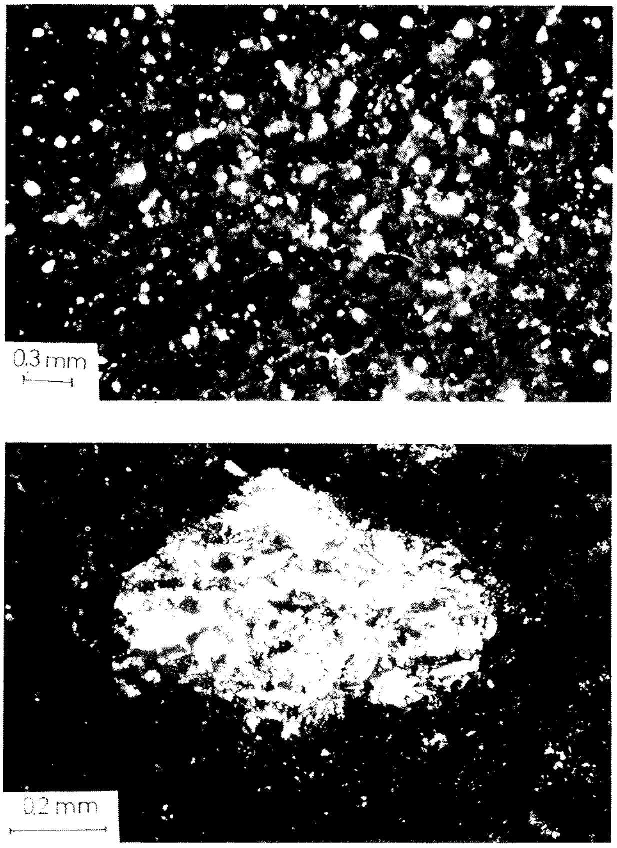

Fig. 7: Photos of thin sections of bentonite. The upper one shows pale grains of quartz and feldspar in a dense matrix of clay minerals and ferric oxides. The lower one shows a volcanic rock fragment with laths of feldspar in a dense matrix similar to that above.

Abb. 7: Photos von Bentonit-Dünnschliffen. Das obere zeigt helle Quarz- und Feldspat-Partikel in einer dichten Grundmasse von Tonmineralen und Eisenoxiden. Das untere Bild zeigt ein vulkanisches Gesteinsbruchstück mit Feldspatleisten in einer dichten Grundmasse ähnlich wie im oberen Bild.

The bentonite beds in Basilikarabbane are exposed in river cliffs which are probably quite fresh due to strong erosion. The bentonite beds of the other two sections are situated on mountain slopes and have probably been subjected to weathering for a longer period. A solution of calcareous material may have been caused here by water moving downslope in the thin zone above the permafrost during the summer. This water is conducted to the surface of the mountain slopes by the bentonites.

Bed 1 in the Basilikarabbane section contains the diatom *Coscinodiscus* sp. and a few calcareous valves of ostracodes. In addition, the following foraminifera have been found:

Ammodiscus sp.
Reophac cf. *curtus* CUSHMAN
Cyclammina spp.
Quinqueloculina sp.
Hoeglundina sp.

About 80% of the foraminifera belong to the suborder Textulariina. This high proportion of agglutinated forms indicates unstable or extreme environmental conditions. It is reasonable to assume restricted water circulation in the basin and, consequently, slightly stagnant bottom conditions. Whether these conditions were of a local or regional character is difficult to decide on the basis of the present material.

Bed 3 contains the following foraminifera, all of which belong to the surborder Rotaliina:

Nodosaria sp.
Astacolus sp.
Frondicularia cf. *gracilis* PERNER
Lenticulina cf. *punctata* RHEZAK
Lenticulina sp.
Marginulinopsis cf. *goajiraensis* BECKER & DUSENBURY
Marginulinopsis sp.
Pseudonodosaria sp.

The absence of representatives of the suborder Textulariina in bed 3 indicates more normal marine conditions than in bed 1. It is remarkable, however, that only the family Nodosariidae is represented in bed 3.

Planktonic foraminifera are not found in these two beds. This may be explained by the restricted influence of open marine environments during the deposition of the Basilika Formation. The deposition of the unit seems to have taken place in a more or less landlocked shelf sea.

As mentioned earlier, the age of the Basilika Formation is regarded as being Palaeocene by most authors. The palaeontological analysis given above is of preliminary character and provides no new information for a more definite dating.

DISCUSSION AND CONCLUSION

The laterally consistent clay beds in the Basilika Formation contain on average 80% illite/smectite clay minerals, and are therefore most probably of volcanic origin. Occurrences of glass-shards support this interpretation. Only volcanic eruptions with aeolian transport of volcanic dust may be able to explain the wide distribution of such fine-grained, badly sorted material. The erosion and later sedimentation of expanding clay minerals derived from weathering horizons would not produce such distributions, and a higher degree of mixing with other allogenic material would be expected in the latter case. We believe that the stratigraphical variation in composition which has been observed, mainly reflects differing source areas and transport mechanisms; consequently our interpretation implies that the major differences in composition of the tuffaceous beds indicate the existence of different volcanic sources. It is likely that the oldest and also the youngest beds, which are finer-grained than the intermediate ones, reflect either a more distant source, a minor volcanic eruption or weaker palaeowinds. The somewhat greater thicknesses of the intermediate beds would support one of the first two explanations. Further information is, however, needed for a more detailed understanding of the mineralogical variations observed. The similar mineralogical development in the Firkanten and Basilika sections indicates, however, good possibilities of extensive regional correlation of these and similar bentonites elsewhere in Svalbard.

Petrological comparisons of these two sections indicate that the beds in the Firkanten section contain more clastic, probably coarser grained material than those in the Basilika section. This may either reflect a higher influx of clastic material or mean that Firkanten's position is closer to the source area. This last explanation, if correct, indicates a northerly volcanic source area. Based on maximum grain-sizes of about 0.3—0.5 mm, and the assumption that these grains are aeolian-transported, a source 100 to 200 km away is most probable (cf. BÖGGILD, 1918). However, more exotic source areas cannot be excluded, at least for parts of the clay fraction. Volcanics found today beneath the Norwegian-Greenland Sea may represent possible source areas.

A certain amount of diagenetic alteration of the bentonites has occurred, and recent weathering probably has some impact on this alteration. These impermeable beds function today as drainage barriers, with melt-water draining along the tops of the different bentonite beds. This water may (because of the leaching of surrounding shales) have led to K-fixation of the original expanding clay minerals, resulting in the mixed layer assemblages identified here.

The bentonites are in themselves of minor economic importance. They may prove, however, significant as marker horizons in the Tertiary of Svalbard. Their occurrence neatly connects the Svalbard area to other Palaeocene/Eocene volcanic areas around the northern Atlantic

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