Abh. Geol. B.-A.	ISSN 0378-0864 ISBN 3-900312-61-3	Band 41	S. 287–300	Wien, April 1988

ASPECTS OF FORAMINIFERAL DISTRIBUTION AND DEPOSITIONAL CONDITIONS IN MIDDLE JURASSIC TO EARLY CRETACEOUS SHALES IN EASTERN SPITSBERGEN

by

J. NAGY, M. LØFALDLI and S.A. BÄCKSTRÖM

With 8 figures

Zusammenfassung

Die Foraminiferenfauna der Janusfjellet Formation (Bathonien–Hauterivien) in Spitzbergen wurde analysiert. Die Lithologie besteht vorwiegend in dunkeln bis schwarzen Schiefern mit überwiegend sandschaligen Foraminiferenarten. Wechselnde Ablagerungsbedingungen werden anhand der wichtigsten Faunenparameter (Diversität und Häufigkeit der Gattungen) in Verbindung mit lithologischen Eigenschaften (v.a. Gehalt an organischer Substanz) diskutiert.

Hohe Faunendiversitäten sind gewöhnlich mit niedrigen TOC-Werten (gesamtes $C_{org.}$) verbunden, während geringe Diversitäten sowohl bei hohen als auch bei niedrigen TOC-Werten auftreten. Die Gattungen *Trochammina* und *Haplophragmoides* zeigen die höchste Toleranz gegenüber den Umweltbedingungen während der Ablagerung von $C_{org.}$-reichem Schlamm. In den Intervallen mit den niedrigsten TOC-Werten tritt *Glomospira* besonders häufig auf.

Die „black shale“ Fazies im unteren Bereich der Formation hat gewöhnlich 3–8% organischen Kohlenstoff. Abgesehen von einem fossilfreien, anaeroben Horizont, findet sich eine Fauna mit niedriger Diversität, die dysaeroben Bedingungen entspricht. Der höhere Teil der Janusfjellet Formation hat niedrige bis mittlere TOC-Werte (meist 2,5%), verbunden mit wechselnder Faunendiversität und lokal signifikanten Häufigkeiten kalkschaliger Foraminiferen. Für diesen Teil werden normal marine Bedingungen des tieferen Schelfs angenommen, die von Delta-Einflüssen abgelöst werden.

Abstract

Foraminiferal faunas have been analysed in the Janusfjellet Formation (Bathonian-Hauterivian). The dominant lithologies are dark to black shales with faunas consisting mainly of arenaceous species. Changing conditions during deposition of the formation are discussed on the basis of major faunal parameters (diversities and frequency of genera) combined with lithological features (mainly the organic content).

High faunal diversities are, as a rule, associated with low TOC values, while low diversities occur in both high and low TOC samples. The genera *Trochammina* and *Haplophragmoides* display the highest tolerance to environmental conditions during the deposition of organic-rich mud. Floods of *Glomospira* occur in the interval with the lowest TOC.

Nagy, J., Institute of Geology, University of Oslo, P.O. Box 1047, Blindern, N-0316 oslo 3, NORWAY.
Løfaldli, M., Arabian Gulf Explor. Comp., Benghazi, LIBYA.
Bäckström, S.A., Saga Petroleum A/S, P.O. Box 9, N-1322, Høvik, NORWAY.

The black shale facies, developed in the lower part of the formation, has commonly 3-8% organic carbon. Apart from a barren, anaerobic horizon, it contains a low diversity fauna ascribed to dysaerobic conditions. The upper part of the formation has low to intermediate TOC content (mostly $< 2.5\%$) associated with increased faunal diversities and locally significant amounts of calcareous foraminifera. Normal marine to deep shelf conditions, succeeded by deltaic influence, are proposed for this part of the formation.

INTRODUCTION

The present foraminiferal analyses cover the Janusfjellet Formation, a sequence up to c. 600 m thick consisting predominantly of dark to black shales. The formation, ranging in age from Bathonian to Hauterivian, includes sediments deposited in littoral, marine shelf and delta-influenced shelf environments. Shales formed under dysaerobic or anaerobic conditions are of special interest. The objective of the present paper is to delineate the main features of the foraminiferal distribution and, by combining these with lithological data, to elucidate certain aspects of the depositional conditions.

The main exposures of the Janusfjellet Formation are found along the western flank of the Spitsbergen Trough from Sørkapp Land to the northern coast of Isfjorden, along the northeastern flank of the trough from Sassenfjorden to Agardhbukta, and in eastern Spitsbergen from Agardhfjellet to Wilhelmøya (figure 1). Minor outcrops are also present in western Sørkapp Land and in Kong Karls Land.

Investigations of the foraminiferal stratigraphy of the Janusfjellet Formation are of quite recent date. The first information published consisted of short notes about species occurrences recorded by Pchelina (1967) at Agardhbukta, and by Klubov (1970) on Wilhelmøya. A brief account of the foraminiferal distribution in the Agardhfjellet section was given by Løfaldli and Thusu (1976). More detailed studies of the foraminiferal stratigraphy of the Hårfagrehaugen section in Kong Karls Land, and of the Keilhaufjellet section in southern Spitsbergen, were published by Løfaldli and Nagy (1980, 1983). The regional features of the foraminiferal distribution in the Janusfjellet Formation were discussed preliminarily by Nagy and Løfaldli (1981).

Geological history

The Janusfjellet Formation rests on Rhaetian and Early Jurassic sandstones and shales composing the Wilhelmøya Formation which was deposited under shallow shelf to marginal marine conditions (figure 2). As a consequence of Middle Jurassic regression (culminating probably in the Bathonian) the Wilhelmøya Formation has been subjected to partial erosion and reworking (Bäckström and Nagy 1985). Transgression in Spitsbergen possibly started near the end of the Bathonian, contemporaneously with the global elevation of sea level at the Bathonian-Callovian boundary. During this transgression, renewed erosion of the Wilhelmøya Formation and final reworking of its coarser constituents, among these phosphorite pebbles, resulted in a conglomerate of considerable regional extent, the Brentskardhaugen Bed.

As water energy decreased during the Bathonian-Callovian transgression, a fining upwards sequence developed in the lower part of the Janusfjellet Formation in central Spitsbergen. The sequence starts with the Brentskardhaugen conglomerate, continues in ooid bearing carbonates and terminates with black shales.

The dominant rock types of the Janusfjellet Formation are dark and black marine shales. The

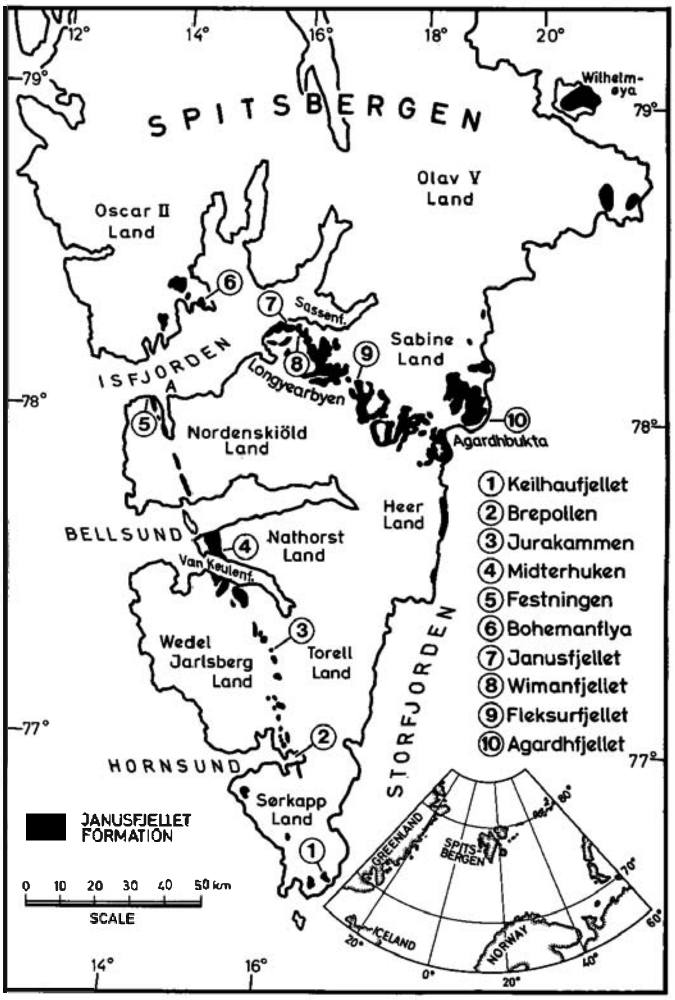

Fig. 1.
Map of Spitsbergen showing position of the localities discussed in the report.

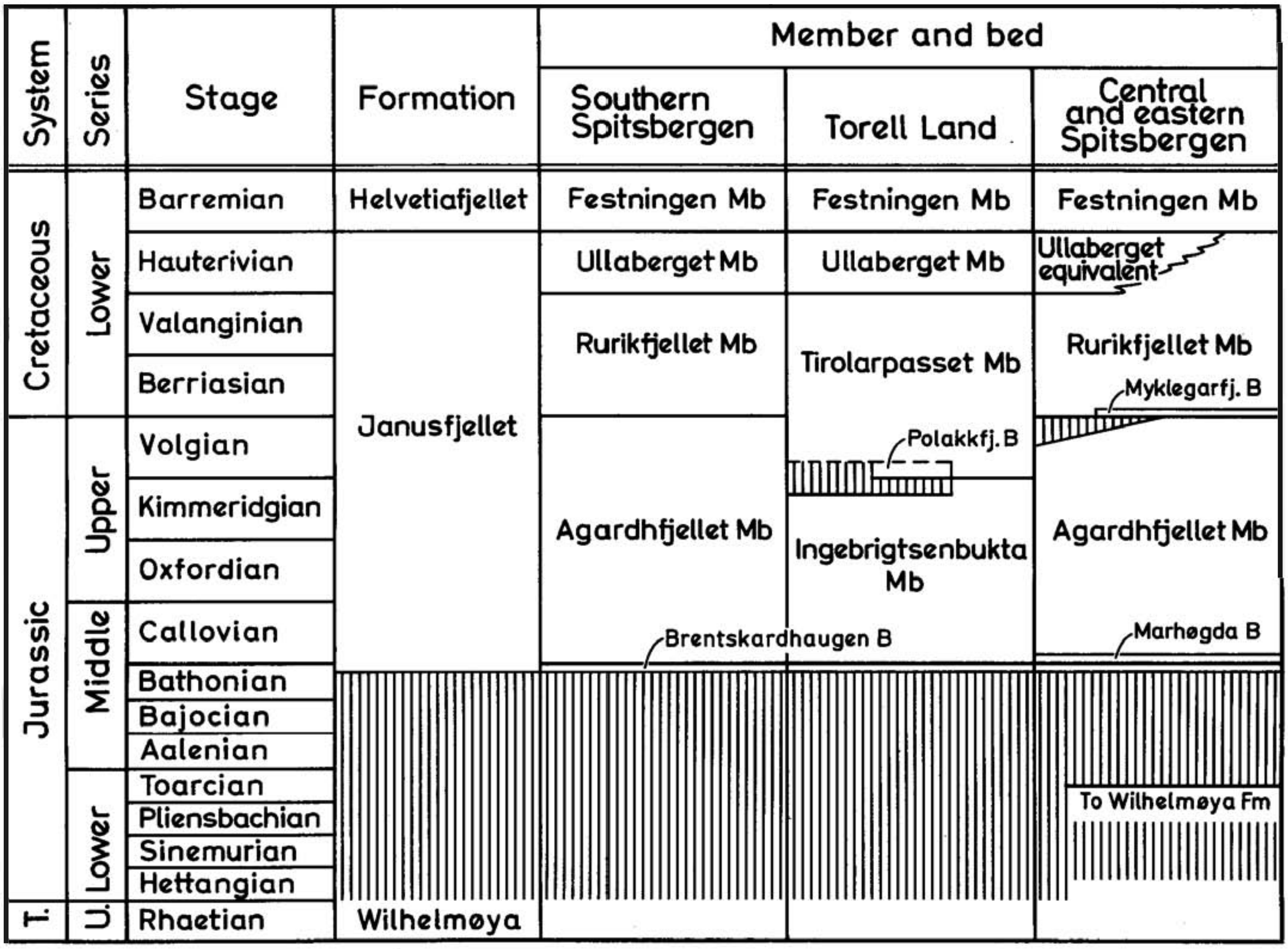

Fig. 2.
Stratigraphical scheme for Jurassic and Early Cretaceous deposits in Spitsbergen showing subdivision of the Janusfjellet Formation and adjacent strata.

highest sedimentation rates occurred along the western flank of the Spitsbergen Trough where the formation has its maximum thickness of approximately 600 m in the Jurakammen, Midterhuken and Festningen sections. The thickness of the formaiton decreases southwards to 427 m on Keilhaufjellet. Intermediate thicknesses are also found on Wimanfjellet (342 m) and Agardhfjellet (414 m) along the northeastern flank of the trough. A minimum thickness of 270 m was measured on Bohemanflya, on the northern shore of Isfjorden, by Dypvik and Hvoslef (personal communication). The strongly reduced thickness on Fleksurfjellet (282 m) is believed to have been caused by tectonic disturbances in Tertiary time.

The Janusfjellet Formation is overlain by the Helvetiafjellet Formation which is of Barremian age and consists mainly of fluviodeltaic deposits. The approach of this deltaic facies is reflected in the upper part of the Janusfjellet Formation by the local presence of regressive, sandy intercalations.

Stratigraphical framework
The base of the Janusfjellet Formation is marked by the Brentskardhaugen Bed, which is developed in nearly all areas of central, eastern and southern Spitsbergen. This bed is a condensed deposit containing phosphorite, chert and quartz pebbles in a sandy carbonate matrix. The average thickness of the bed is 60 cm. Its macrofossil content, mainly bivalves and ammonites, has been derived from Toarcian, Aalenian and Bajocian strata.

Around Wimanfjellet and Fleksurfjellet, the Brentskardhaugen Bed passes gradually upwards into a 30-150 cm thick limestone containing quartz and chert grains, ooides and glauconite. The name Marhøgda Bed has been introduced for this unit by Bäckström and Nagy (1985). It is overlain by siltstones and silty shales succeeded by black shales.

The Janusfjellet Formation is usually subdivided into threemembers. There are, however, regional differences both in nomenclature and boundary positions as shown in figure 2 and the following account.

The Agardhfjellet Member: This unit was deposited during the Callovian to Volgian interval and is characterized by bituminous and silty shales with yellow and red weathering lenses, and thin beds of siltstone cemented by siderite or dolomite. The black, bituminous, fissile shales are characteristic for the lower half of the member. Most of the carbonate beds were probably deposited during periods with reduced clastic supply (Dypvik 1978).

The upper boundary of the member corresponds locally to a Late Volgian hiatus. On Myklegardfjellet (west of Agardhfjellet), the junction between the Agardhfjellet and Rurikfjellet Members is marked by a yellow clay horizon up to 1 m thick, the Myklegardfjellet Bed of Birkenmayer (1980). The bed is interpreted as weathered doleritic material (Parker 1967) and decomposed volcanic tuff or lava (Birkenmayer *op. cit.*).

The Rurikfjellet Member: This is composed of dark-gray to gray-green shales containing dark brown to red ironstone nodules. Bituminous, fissile shales are absent. Horizons of yellowish clay including the Myklegardfjellet Bed are usually present at the base of the member in the region between Sassenfjorden and Agardhbukta. The Rurikfjellet, together with the locally developed Ullaberget Member, represents the Berriasian-Hauterivian time span.

The Ingebrigtsenbukta Member: The main constituents of the unit are black, bituminous, often silty shales. Stratigraphically, it corresponds to the lower and middle part of the Agardhfjellet Member. It is distinguished only in Torell Land, where a conglomeratic sandstone horizon, the Polakkfjellet Bed, defines its upper boundary. The bed is developed in connection with a minor Late Kimmeridgian hiatus (Rozycki 1959; Birkenmayer 1975).

The Tirolarpasset Member: This consists of black, often bituminous, sometimes silty shales. The separation of this unit from the underlying Ingebrigtsenbukta Member is only possible where the Polakkfjellet Bed is present. The Tirolarpasset Member is correlative with the upper part of the Agardhfjellet, and lower part of the Rurikfjellet Member.

The Ullaberget Member: This unit comprises a succession of interbedded shales, siltstones and sandstones developed in the upper part of the Janusfjellet Formation. It forms a transition between the marine Janusfjellet shales and the fluviodeltaic, sand-dominated Helvetiafjellet Formation. The unit was originally defined in northwestern Torell Land, but its name was derived from Ullaberget on the northern coast of Van Keulenfjorden (Rozycki 1959; Birkenmayer 1975).

The studied sections

The present paper is based on samples collected from Agardhfjellet and Fleksurfjellet. On Agardhfjellet, the Janusfjellet Formation is 414 m thick, and is covered by samples, taken generally at 2 m intervals, from 54 m above the base of the unit to its upper boundary. The lower 54 m of the formation is scree-covered except for an interval between 24 and 28 m which has been sampled. The sampling was carried out by a field party from the Continental Shelf Institute, Trondheim, in 1974.

On Fleksurfjellet, the Janusfjellet Formation is 182 m thick, and is covered by 75 samples. The spacing of the samples is somewhat uneven, depending on the presence of exposures. The profile measured on Fleksurfjellet is cut by the eastern branch of the Billefjorden fault zone. The original thickness of the formation has presumably been reduced by movements along this fault line in Tertiary time. Sample collection from this profile was done by a field party from the University of Oslo in 1980.

Methods

The shales on the Janusfjellet Formation are well lithified except in the softer beds occurring in the lowermost part of the formation and around the Jurassic-Cretaceous boundary in the eastern outcrop areas. The kerosene method was used for disintegration of samples. Dry sediment was soaked in kerosene for about 30 minutes. After decanting the kerosene, the sediment was boiled in a solution of sodium hydroxide for one hour or more depending on the degree of consolidation. The disintegrated samples were washed through a 0.125 mm mesh diameter sieve. The foraminifera were then hand-picked from the residue. Sediment samples of 80-100 g were used for the analyses.

The specific diversities are given by the number of species, including forms identified with known species as well as forms designated by open nomenclature. For the Agardhfjellet section, the generic diversity is expressed by the number of genera and by the Shannon-Wiener index. The latter is calculated from the equation:

$$H = -\sum_{i=1}^{S} p_i \ln p_i$$

where S is the number of genera and p_i the proportion of the ith genus. Diversity indices based on species frequencies have not been calculated because a considerable number of specimens could not be confidently identified on the species level, as a consequence of insufficient preservation.

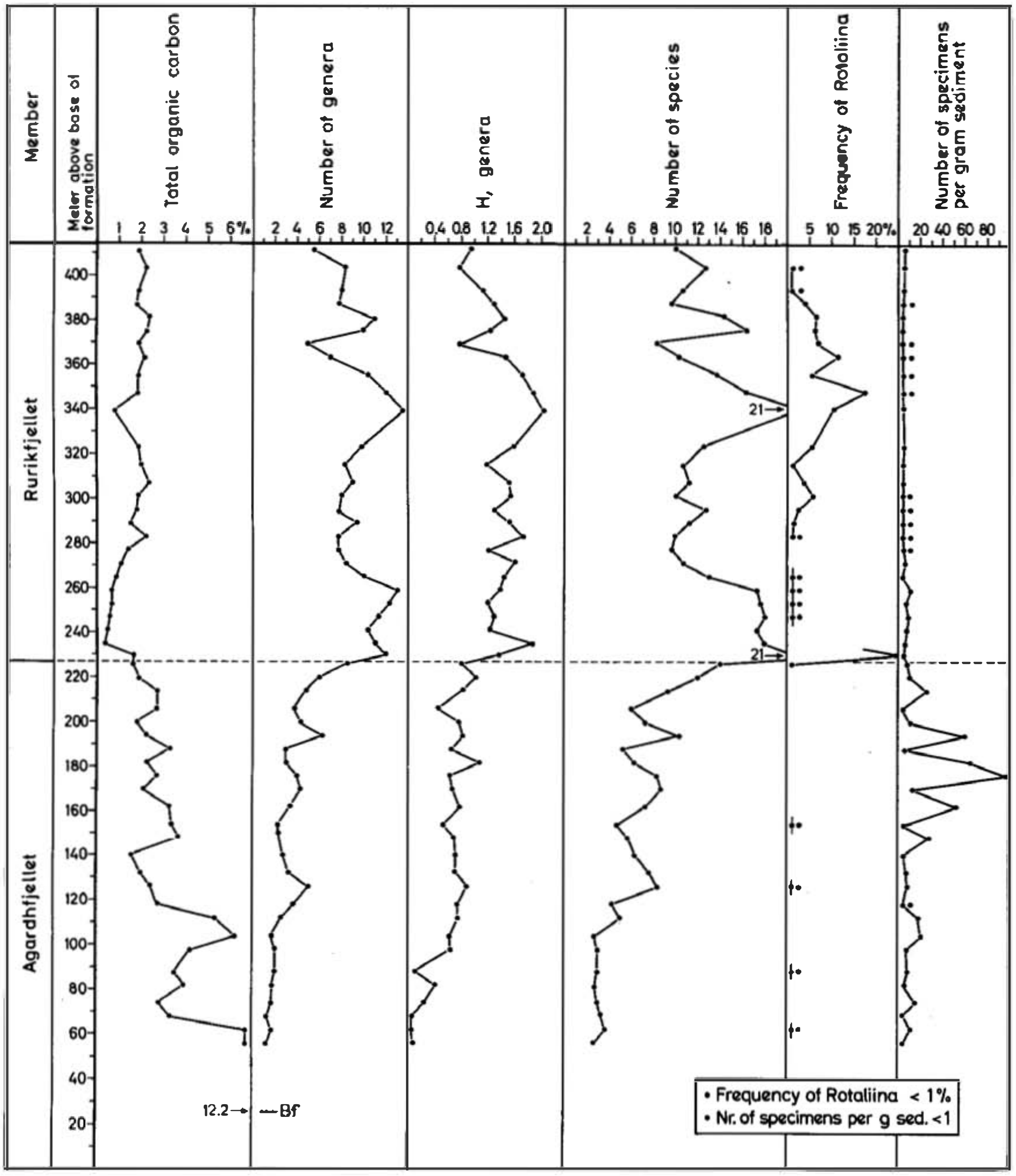

Fig. 3.
Distribution of TOC and major faunal parameters through the Janusfjellet Formation, Agardhfjellet section. Each value is the average of three samples (Bf = barren of foraminifera).

MAIN FAUNAL FEATURES

The foraminiferal faunas of the Janusfjellet Formation consist mainly of agglutinated forms as demonstrated in earlier papers and by the present study. Calcareous species are more common at the base and in the upper half of the Rurikfjellet Member in the Agardhfjellet section (figure 3). Calcareous foraminifera also occur in a few restricted horizons of the Agardhfjellet Member in other areas.

The majority of the agglutinated tests are compressed or irregularly deformed. Among the commonest genera, *Recurvoides*, *Glomospira* and *Glomospirella* are the best preserved. Calcareous species are generally not deformed diagenetically.

It seems to be generally accepted that foraminiferal populations consisting of, or dominated by, agglutinated forms did not develop under normal marine shelf conditions. The following environments are usually assumed to produce such populations: marginal marine areas, such as estuaries and hyposaline lagoons; regions of great depth (below CCD); low temperature; rapid sedimentation; stagnant bottom conditions. It must be noted, however, that post-mortem destruction of foraminiferal tests (both calcareous and agglutinated) can change the faunal composition.

Such changes potentially reduce the value of quantitative faunal analyses concerning stratigraphy and paleoecology.

Original composition of faunas

It is still an open question to what degree the fauna analysed represents the living populations or is diagenetically altered due to selective decomposition of calcareous tests and agglutinated tests with carbonate, or little resistant organic cement. The following observations lead to the assumption that the faunas through most of the analysed sequence are not radically changed by diagenetic processes, the result of selective decomposition of calcareous tests and agglutinated tests with carbonate, or little resistant organic cement: 1) Calcareous foraminifera occur sporadically in several samples, and in more significant amounts in certain intervals: 2) Calcareous shells of ammonites and bivalves, and belemnite guards, occur throughout most of the formation. It must be noted, however, that impressions of ammonites without preserved shell material are also observed; 3) Thin carbonate beds are observed in all the sections investigated; and 4) The faunal diversity varies from very low to intermediate values; low diversity assemblages are well known from Recent extreme or changing environments.

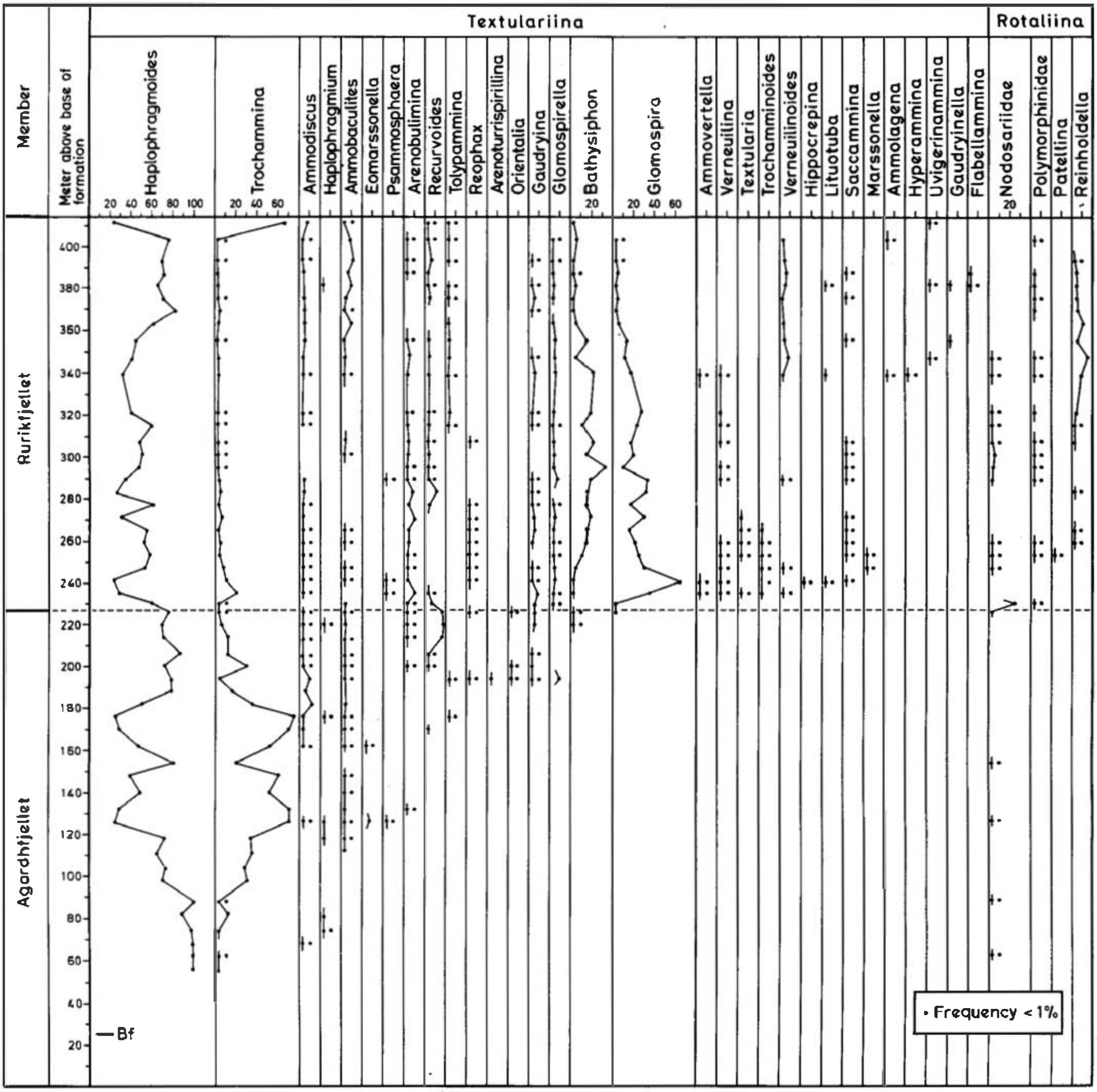

Fig. 4.
Percentage distribution of foraminiferal genera through the Janusfjellet Formation, Agardhfjellet section. Each value is the average of three samples (BF = barren of foraminifera).

Faunal diversities
In the Agardhfjellet section the number of species and genera, and the H values of genera, follow essentially similar trends showing upwards increasing amounts in the Agardhfjellet Member and relatively high values in the Rurikfjellet Member (figure 3). Generally, the diversity values vary inversely with the TOC (total organic carbon)

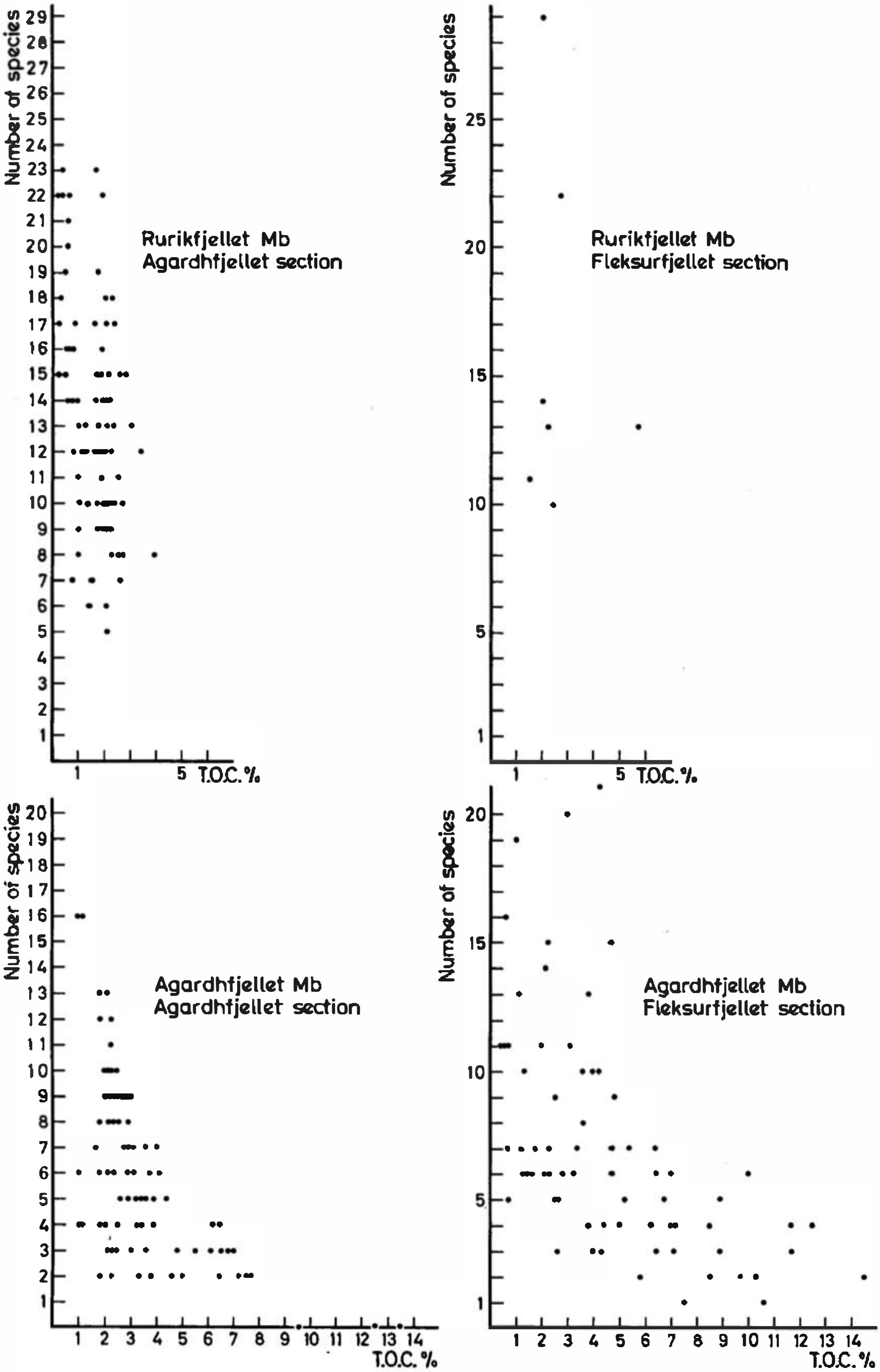

Fig. 5.
Organic carbon content in relation to number of species in the Janusfjellet Formation, Agardhfjellet and Fleksurfjellet sections. Values for the Agerdhfjellet and the Rurikfjellet Members are shown separately.

content, although there are divergences from this pattern.

The relation between the TOC and number of species is further illustrated in figure 5, showing that high numbers of species are as a rule associated with low TOC content, while low numbers are associated with both high and low TOC values. The relation between these two parameters shows different patterns within the Agardhfjellet and Rurikfjellet Members, reflecting different environmental regimes during the deposition of the two units. The regional persistence of these regimes is expressed by the fact that the distribution pattern of the two parameters found in the Agardhfjellet section is essentially similar to that observed in the Fleksurfjellet section, although the Rurikfjellet Member here is only sparsely covered by samples (figure 5). The distance between the two sections is 45 km.

The relation between generic diversities and TOC content is presented in figure 6. It demonstrates that the number of genera has a distribution pattern essentially similar to that of the number of species, both in the Agardhfjellet and Rurikfjellet Members. The Shannon-Wiener index (H) based on genera shows a less clear correspondence with the number of species in the Agardhfjellet Member, although differences between the two members are also expressed by this parameter.

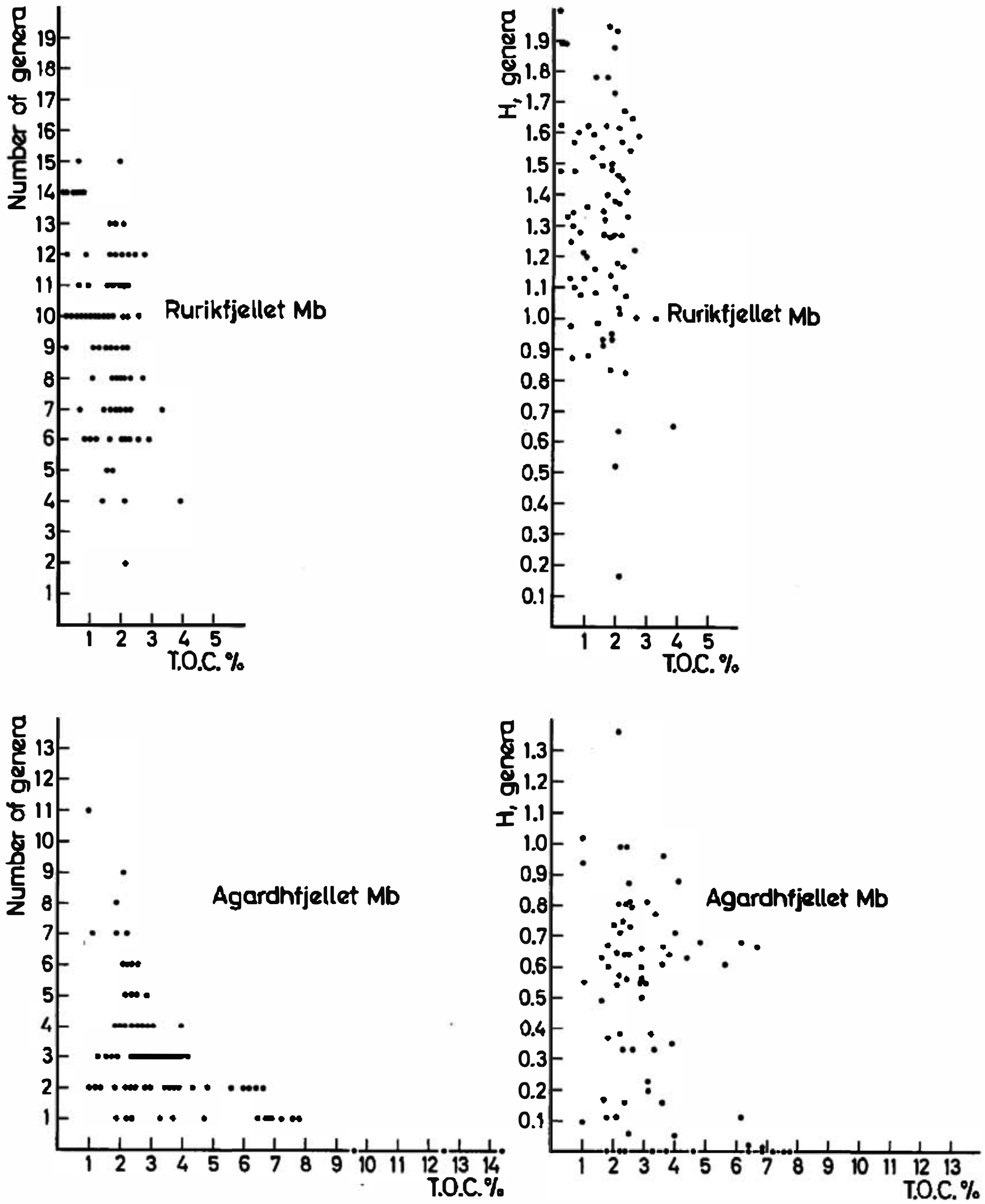

Fig. 6.
Organic carbon content in relation to number of foraminiferal genera and Shannon-Wiener index (H) of genera in the Janusfjellet Formation, Agardhfjellet section.

The occurrence of low diversity foraminiferal faunas in shales with high organic content in the Agardhfjellet Member indicates that the environments producing mud rich in organic matter had a restricting effect on the foraminiferal fauna. In such environments, low oxygen levels are expected in association with a reduced pH. It may be assumed that the lowered pH will have produced low diversity agglutinated assemblages, consisting generally of species with organic cement. Calcareous foraminifera and agglutinated forms with carbonate cement will be partially or wholly excluded.

A study of Recent foraminiferal faunas in the Oslo Fjord shows that under low pH conditions, destruction of carbonate tests takes place before burial (Alve and Nagy 1986). Corrosion and dissolution of calcareous species start after decay of the living protoplasm protecting the test, and result in post-mortem reduction of diversity.

Distribution of genera
The faunas of the Agardhfjellet Member are strongly dominated by *Haplophragmoides* and *Trochammina*. Their frequency in the Agardhfjellet section varies inversely, because of the low quantity of other genera (figure 4). At some horizons *Recurvoides* and *Ammodiscus* are common.

The Rurikfjellet Member is dominated by *Haplophragmoides*, *Glomospira* and tube-like fragments referred to as *Bathysiphon*. Among common genera are *Ammobaculites*, *Arenobulimina* and *Recurvoides*. Calcareous genera occur only sporadically, except *Lenticulina* and *Reinholdella* which show increased frequencies at the base of the member and in its upper part, respectively.

FAUNAL AND FACIES PATTERNS THROUGH THE JANUSFJELLET FORMATION

Basal transitional facies
In central and eastern Spitsbergen, the lowermost part of the Agardhfjellet Member is essentially a fining upwards sequence starting with the Brentskardhaugen Bed and terminating with the black shales of the Agardhfjellet Member. The sequence represents a transition from littoral to deeper shelf conditions, and was formed during the Upper Bathonian-Lower Callovian transgression.

In the Fleksurfjellet section (figure 7), the littoral to nearshore deposits represented by the Brentskardhaugen and Marhøgda Beds are overlain by siltstones and silty shales with faunas dominated by *Trochammina* and *Haplophragmoides*, and to a lesser extent by *Ammobaculites* and *Recurvoides*. These faunas show comparatively high diversities and a few samples contain some calcareous specimens. The increased diversity suggests that the depositional area had a normal marine aspect, although a larger content of calcareous specimens and higher diversities would be expected under fully normal marine conditions. The low TOC content and the relatively coarse-grained (silty and sandy) sediments indicate aerobic conditions in the bottom water layer.

Black shale facies
Black shales are usually ascribed to anaerobic and dysaerobic depositional environments. The development of low diversity agglutinated foraminiferal assemblages in sediments formed under dysaerobic conditions seems to have two main causes: 1) Agglutinated species have an apparently varying, but generally greater tolerance for low oxygen levels than calcareous species and 2) High CO_2 content, commonly associated with a large organic supply, excludes calcareous foraminifera by dissolution of tests.

In the analysed sections, the Bathonian-Lower Callovian transgression introduced shelf conditions with increasing depth and a vigorous supply of organic matter to the bottom sediments. As a result, a black shale facies developed, which in the studied sections is most pronounced in the lower part of the Agardhfjellet Member where the maximum values of TOC are found. The shales here are very finely laminated and do not display bioturbation.

In the Agardhfjellet section (figure 3), the maximum TOC content is found 24-28 m above the base of the Agardhfjellet Member, where values of 9.5%, 12.5% and 14.5% were measured. These samples were barren of foraminifera, suggesting anaerobic conditions. Higher up in the member, in the 45-110 m interval, the TOC is reduced to an average of 4.7%. The foraminiferal faunas here consist almost exclusively of *Trochammina* and *Haplophragmoides*, and the average number of species is only 3.2. The low diversities combined with the still comparatively high TOC values suggest dysaerobic bottom water conditions.

The middle and upper parts of the Agardhfjellet Member contain benthic macro-invertebrates (mostly bivalves) at various horizons. In the upper half of this member, the TOC content has an upward decreasing trend although it shows marked variations (figure 3). Along with this decrease, the number of species and genera increases (in spite of pronounced oscillations) suggesting an improvement of bottom conditions, particularly near the top of the member. The explanation of this improvement must be sought primarily among the

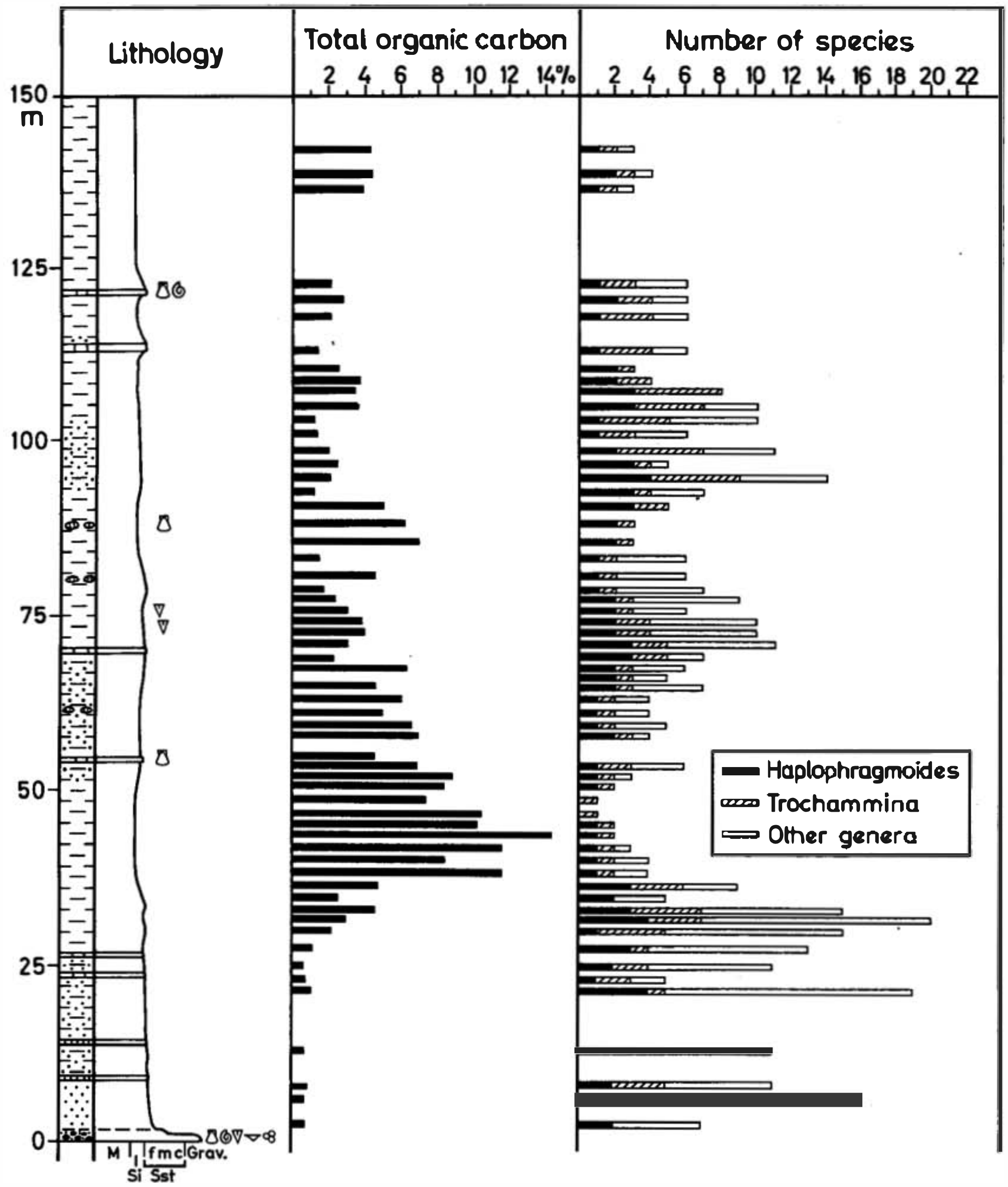

Fig. 7.
Number of species and organic carbon content through the lower 150 m of the Agardhfjellet Member, Fleksurfjellet section.

following factors: increased oxygenation because of shallowing of the depositional area, reduced supply of organic matter, increased vertical circulation in the basin, increased water exchange with extra-basinal areas.

On Fleksurfjellet the highest TOC contents (up to 14%) occur in an interval of paper shale around 40 m above the base of the Agardhfjellet Member (figure 7). The foraminiferal fauna of the interval shows a minimum in diversity (down to 1 or 2 species), with a total dominance of *Trochammina* and *Haplophragmoides*. Consequently, these genera must be regarded as especially tolerant of bottom conditions developed during deposition of mud which was particularly rich in organic matter. On Fleksurfjellet there is also a second maximum of organic carbon (6.6%) about 85 m above the base of the Agardhfjellet Member, characterized by much reduced diversities and a nearly total dominance of *Haplophragmoides* and *Trochammina*.

Facies changes at the Jurassic-Cretaceous boundary
A thin stratigraphical horizon forming the base of the Rurikfjellet Member in the Agardhfjellet section contains a mixed calcareous-arenaceous assemblage of high diversity. Calcareous species comprise up to 28% of the fauna and the dominant genera are *Haplophragmoides* and *Lenticulina*. The assemblage suggests that more or less normal marine conditions developed for a short period just above the Jurassic-Cretaceous boundary.

This period with increased oxygenation was probably associated with a shallowing of the depositional area, although there are also other possible interpretations such as basinward (downward) migration of the dysaerobic zone, or increased water exchange due to a disappearance of thresholds. The ultimate reason for the environmental change was obviously an episode of tectonic activity at the Jurassic-Cretaceous transition which activated the north-south fault system of central and eastern Spitsbergen.

Subsequent deepening of the depositional area in the earliest Cretaceous (discussed below) is also referred to this tectonic event. It is of interest to note that the Agardhfjellet section lies about 10 km east of the Lomfjorden fault, while the Fleksurfjellet section is located directly over a branch of the Billefjorden fault zone.

Early Cretaceous shale sequence
The tectonic event affecting the basin at the Jurassic-Cretaceous transition introduced fundamental changes in the depositional regime of the Janusfjellet Formation, at least in central and eastern parts of Spitsbergen. The changes are expressed by the new types of foraminiferal faunas characterizing the Rurikfjellet Member.

In the lowermost part of the member (figure 3), above the mixed assemblage, there is less than 0.2% TOC. From this minimum the organic carbon content increases upwards, and varies around 2% through the middle and upper parts of the unit.

The lower part of the Rurikfjellet Member reveals relatively high faunal diversities and contains large quantities of *Glomospira*, particularly in the interval with minimum organic carbon content (figure 4). Higher up, *Bathysiphon* appears in greater amounts. These sediments were probably deposited in well oxygenated deeper waters with reduced availability of $CaCO_3$ for the fauna, as suggested by the almost exclusively arenaceous assemblages with increased diversities, the low TOC content, the abundance of *Glomospira*, and only sporadic occurrences of calcareous foraminifera.

In Recent bathyal waters, *Glomospira* is regarded as a ubiquitous genus by Bandy (1960). In the lower part of the Rurikfjellet Member, this genus is mainly represented by *G. charoides* (Jones and Parker, 1860). In Recent faunas of the Gulf of Mexico, *G. charoides* is particularly characteristic at depths below 400 m, but also occurs as shallow as 65 m (Phleger 1951). According to Höglund (1947), the species is fairly common at his deepest stations in the Skagerrak. There it is most abundant at 700 m and decreases in frequency upwards to C. 200 m.

The frequency of *Glomospira* and *Bathysiphon* decrease gradually through the upper half of the Rurikfjellet Member, while the calcareous genus *Reinholdella* appears in significant amounts. These faunal changes presumably reflect a shallowing of the depositional basin. This shallowing is connected with a gradual development of pro-delta conditions during which the depositional area came under increasing influence of the prograding delta complex of the Helvetiafjellet Formation.

Upper transitional facies
The uppermost part of the Janusfjellet Formation on Agardhfjellet shows a gradually increasing silt-sand content forming a coarsening upwards sequence below the base of the Helvetiafjellet Formation. A pronounced sandstone-siltstone-shale development is present in the uppermost part of the formation on Wimanfjellet and Janusfjellet. With regard to facies and stratigraphical position, these deposits are equivalent to the Ullaberget Member.

Knowledge of the foraminiferal fauna of the transitional deposits is still very incomplete. There is a strong dominance of *Trochammina* in two samples taken from these beds of the Agardhfjellet section.

Shale-siltstone-sandstone units equivalent to the Ullaberget Member are well known south of the member's type area in Torell Land. At Hyrnefjellet, north of Brepollen, a transitional sandy sequence was recorded by Birkenmayer (1975) between the Janusfjellet shales and Helvetiafjellet Formation. Four coarsening upwards shale-sandstone sequences are described by Mørk (1978) from Strykejernet and Hornholmen (inner Hornsund). Similar coarsening upwards units are recorded by Edwards (1976) from Kikutodden (near Keilhaufjellet).

The Ullaberget Member of southwestern Torell Land seems to have been deposited in regional continuity with the transitional sequences of Hornsund and Sørkapp Land. Occurrences of this facies in central and eastern Spitsbergen are probably more local developments. It is natural to conclude that the succession was deposited in connection with delta progradation. Some of the shales apparently are of lagoonal origin, while the sandstones probably include barrier bar deposits.

SUMMARY AND CONCLUSIONS

The aim of this paper is to achieve new information about the depositional conditions of the Janusfjellet Formation, a shale sequence up to 600 m thick deposited in Middle Jurassic to Early Cretaceous time. The study is based on foraminiferal analyses of the Agardhfjellet and Fleksurfjellet sections located in eastern Spitsbergen. The approach employed is a combination of main faunal parameters (specific and generic diversities and percentage frequency of genera) with lithological features (mainly TOC content).

The foraminiferal faunas of the Janusfjellet Formation consist mainly of agglutinated species, suggesting generally reduced availability of carbonate. Two members of the formation, the Agardhfjellet (Bathonian-Volgian) and the Rurikfjellet (Berriasian-Hauterivian) reveal different distribution patterns of both faunal diversity and frequency of genera, reflecting the different depositional regimes of the two units.

By application of the combined approach mentioned above, the following main stages are recognized in

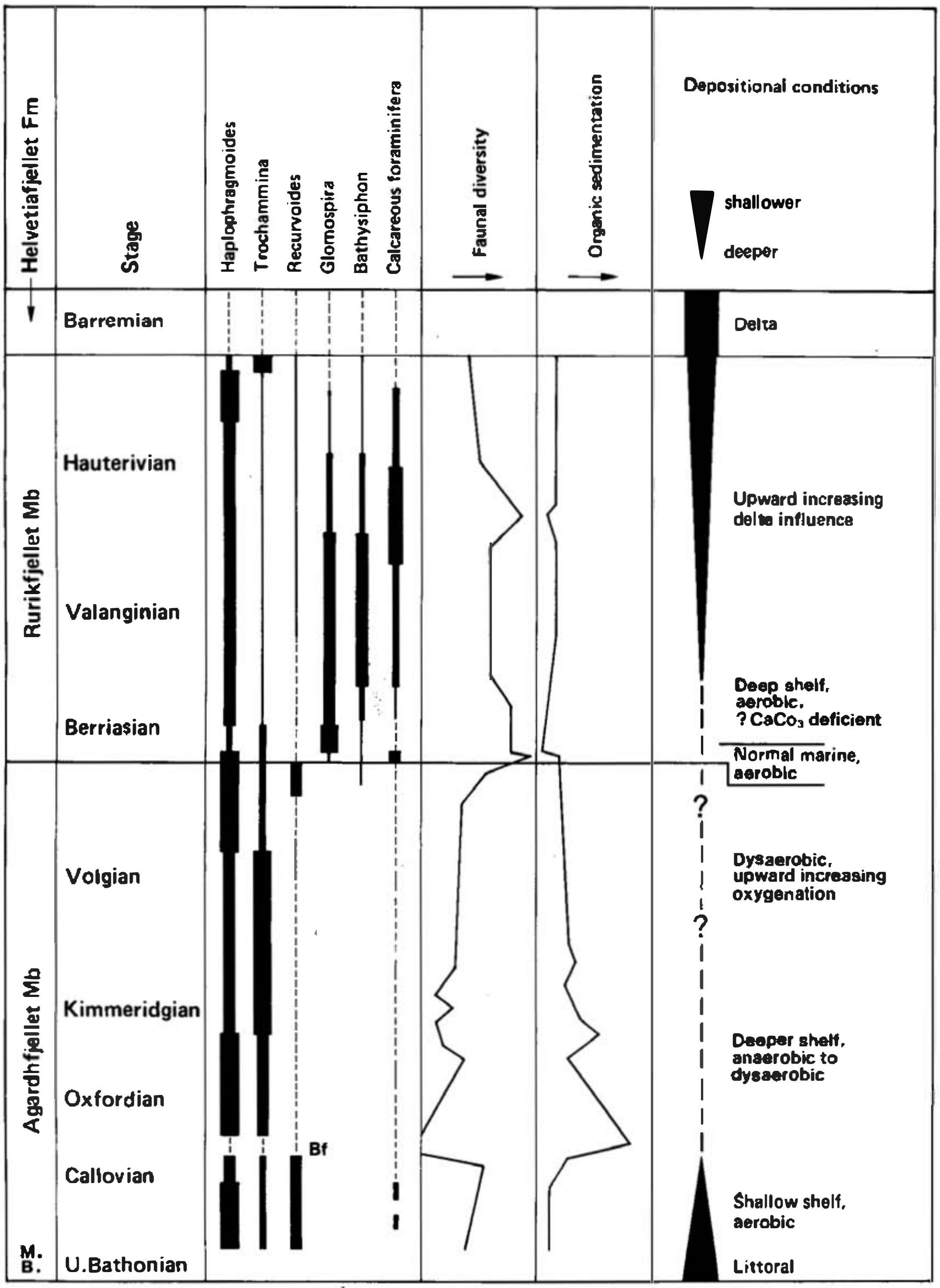

Fig. 6.
Diagrammatic distribution of major stratigraphical features and deduced environmental conditions through the Janusfjellet Formation. The graph is based on the Agardhfjellet section with information from the Fleksurfjellet section included in its lowermost part.
B = Brentskardhaugen Bed; M = Marhøgda Bed; Bf = barren of foraminifera.

the depositional history of the Janusfjellet Formation:

1) The lowermost part of the Agardhfjellet Member is in principle a fining upwards sequence representing a transition from littoral to deeper shelf conditions. The organic carbon content is low and the faunal diversity comparatively high (figure 8) suggesting aerobic conditions.

2) The transitional sequence is succeeded by black shales with high TOC values (maxima between 9.5 and 14.5%). Low faunal diversities observed in these deposits suggest dysaerobic conditions, while total absence of foraminifera indicates anaerobic bottom water.

3) In the middle and upper part of the Agardhfjellet Member the upwards decreasing TOC content and increasing faunal diversities reflect an improvement in bottom water conditions. The environment was, however, still dysaerobic as suggested by generally low diversities and nearly exclusively agglutinated faunas.

4) At the Jurassic-Cretaceous boundary, a mixed arenaceous-calcareous assemblage occurs, associated with a diversity maximum. It suggests the development of more or less normal marine conditions for a short period, apparently in connection with an episode of tectonic activity.

5) In the lower part of the Rurikfjellet Member, strongly reduced TOC values, relatively high faunal diversities, a nearly total absence of calcareous species and the common occurrence of *Glomospira* indicate deepening of the depositional basin and an aerobic bottom.

6) In the upper part of the Rurikfjellet Member, the frequency of *Glomospira* decreases while the calcareous genus *Reinholdella* appears, probably as a response to shallowing of the basin with the approach of the Helvetiafjellet delta. The Ullaberget Member and equivalent marginal marine strata represent the final phase in the filling up of the marine basin.

ACKNOWLEDGEMENTS

We would like to thank the organizations and persons who by their support contributed to this paper. The presented results form part of a project financially supported by B.P. Norge A/S, Elf Aquitaine Norge A/S, Norsk Hydro A/S and Unionoil Norge A/S. The project was administered by the Continental Shelf Institute, Trondheim. Special thanks are extended to M.A. Kaminski (Woods Hole Oceanographic Institution) for constructive criticism of the manuscript, and to Adrian Read (Institute of Geology, University of Oslo) for revising the language.

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