The Janusfjellet Subgroup (Bathonian to Hauterivian) on central Spitsbergen: a revised lithostratigraphy

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The Janusfjellet Subgroup is a marine shelf to prodeltaic succession dominated by shales with subordinate siltstones and sandstones. The subgroup comprises a lower Agardhfjellet (Upper Bathonian – Berriasian) and an upper Rurikfjellet (Berriasian – Hauterivian) formation. Based on field work in central Spitsbergen the following subdivisions of the formations are proposed (units listed in ascending order).

The Agardhfjellet Formation (up to 290 m thick) contains four members: Oppdalen – a fining upwards succession from conglomerates to shales; Lardyfjellet – black paper shales; Oppdalsåta – grey shales with siltstones and sandstones; and Slottsmøya – grey shales and black paper shales. Within the Oppdalen Member three beds are recognised: Brentskardhaugen – phosphoritic conglomerate; Marhøgda – glauconitic sandstones; and Drønbreen – siltstones and shales.

The Rurikfjellet Formation (thickness up to 226 m) is composed of two members: Wimanfjellet – grey and partly silty shale sequence, containing the Myklegardfjellet Bed (of plastic clays) at its base; and Ullaberget – silty and sandy shales with siltstones and sandstones.

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In light of the latest stratigraphical information generated by recent structural, sedimentological and paleontological investigations (Andresen et al. unpubl.; Dypvik et al. 1988; Nagy et al. 1990; Dypvik et al. in press), a revision of the Jurassic/Cretaceous stratigraphy of central Spitsbergen appears to be required. The revised stratigraphical subdivision proposed below aims to facilitate detailed geological mapping and stratigraphical correlation, to increase the resolution potential of the structural geology and to act as an improved framework in ongoing sedimentological discussions (Figs. 1 and 2). The study is concentrated around the region between Sassenfjorden, Kjellstrømdalen and Agardhbukta, designated here as central Spitsbergen.

The Bathonian to Hauterivian time-span in Spitsbergen is represented by an approximately 400 m thick sedimentary succession composed mainly of shales with subordinate siltstones and sandstones deposited in shelf environments (Dypvik 1985). This succession is the Janusfjellet unit (Fig. 1), which was ranked originally as subgroup (Parker 1967) but changed subsequently to formation. The present contribution revises the stratigraphy of the Janusfjellet unit, and the main items of this revision are: redefining the Janusfjellet unit as subgroup; elevating the rank of its two subunits (the Agardhfjellet and Rurikfjellet) from member to formation; providing a new and detailed subdivision of these formations.

The basis of the present stratigraphical study is extensive field work carried out at Bohemanflya,

New or revised definitions of stratigraphic units in Norway (including the Norwegian polar areas) are to be registered and confirmed by the 'Norwegian Committee on Stratigraphy' (NSK). A subcommission, the 'Committee on the Stratigraphy of Svalbard' (SKS), has recently (1990) been established to develop a formal stratigraphic nomenclature for the bedrock stratigraphy of the mainland of Svalbard. Until this work has been completed, SKS will not accept individual applications. Authors are requrested not to submit formal definitions of stratigraphic units in Svalbard during this time without first consulting SKS (c/o Norwegian Polar Research Institute, P.O. Box 158, N-1330 Oslo Lufthavn).

The present article was submitted prior to the establishment of SKS and has therefore been treated as an exception. The stratigraphy presented has not yet been confirmed by NSK and will be considered along with other proposed stratigraphic subdivisions.

Fig. 1. The Janusfjellet Subgroup at Wimanfjellet, seen from Isfjorden (WI-Wilhelmøya Formation, JA-Janusfjellet Subgroup).

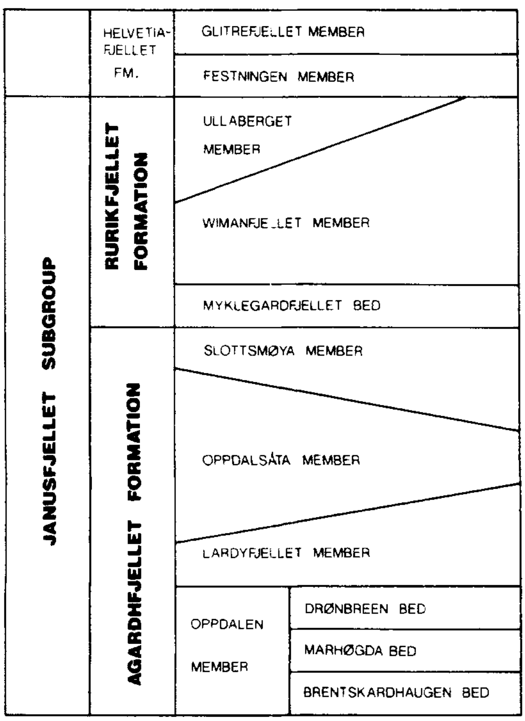


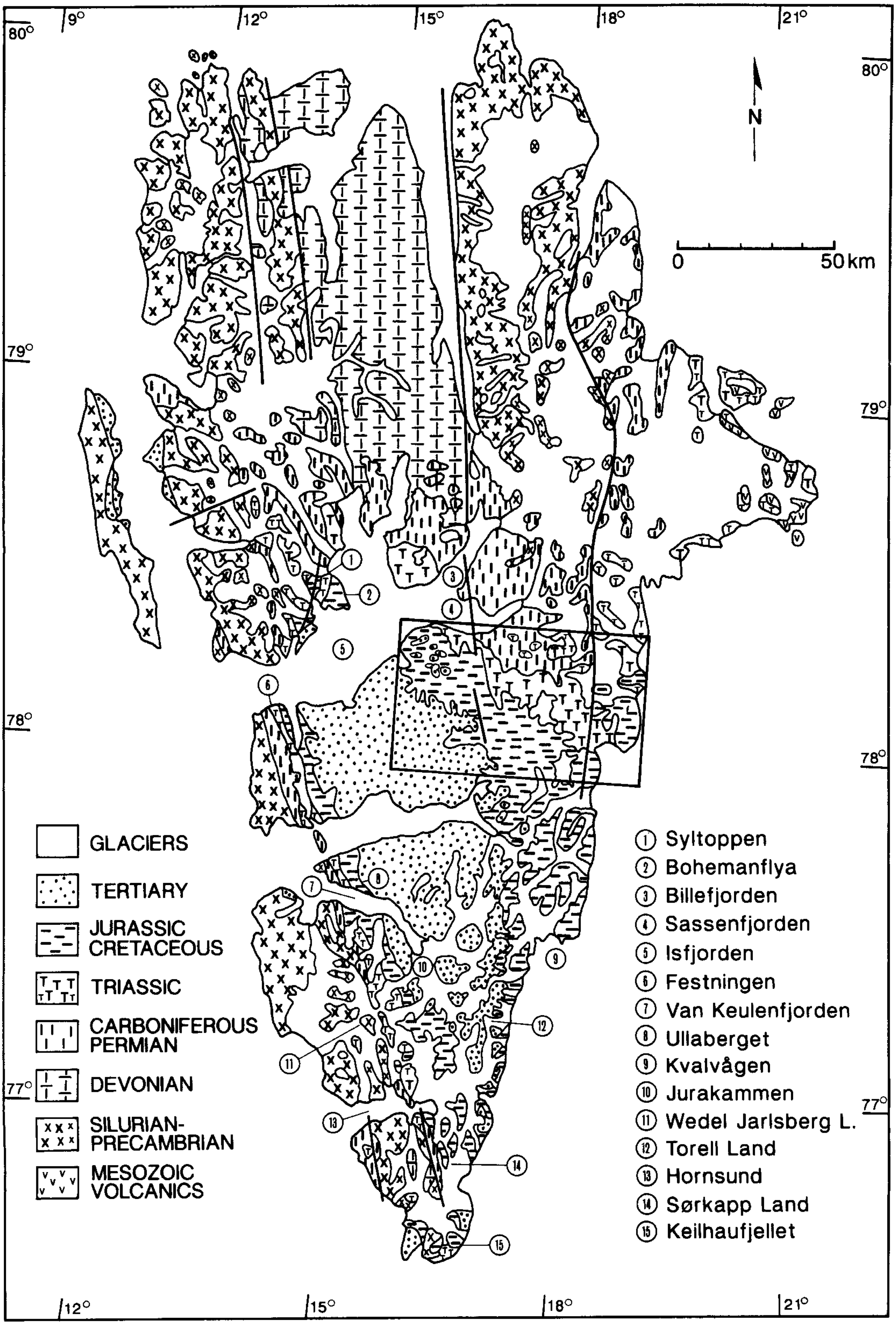
Fig. 2. Revised stratigraphical scheme of the Janusfjellet Subgroup for central and eastern Spitsbergen.

Festningen, Janusfjellet, Wimanfjellet, Knorringfjellet, numerous sections in the Adventdalen-Reindalen area, Lardyfjellet in Kjellstrømdalen and sections at Agardhbukta (Figs. 3 and 4). The preliminary results of these investigations have partially been published elsewhere (Dypvik et al. 1988; Nagy et al. 1990), and the present paper is devoted to the more general features of stratigraphical relevance. A proposed sedimentological model based on the new data from the subgroup will be presented in a separate paper (Dypvik et al. in press).

General stratigraphy of the Janusfjellet Subgroup

The Middle Jurassic to Lower Cretaceous succession in Spitsbergen forms a single major stratigraphic unit, the Adventdalen Group originally proposed by Parker (1967), which contains a fluviodeltaic and three marine formations. The

Fig. 3. Geological map of Spitsbergen showing position of localities discussed in text. Central Spitsbergen, boxed in, is enlarged in Fig. 4.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PERMIAN
DEVONIAN
SILURIAN-
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MESOZOIC
VOLCANICS
① Syltoppen
② Bohemanflya
③ Billefjorden
④ Sassenfjorden
⑤ Isfjorden
⑥ Festningen
⑦ Van Keulenfjorden
⑧ Ullaberget
⑨ Kvalvågen
⑩ Jurakammen
⑪ Wedel Jarlsberg L.
⑫ Torell Land
⑬ Hornsund
⑭ Sørkapp Land
⑮ Keilhaufjellet

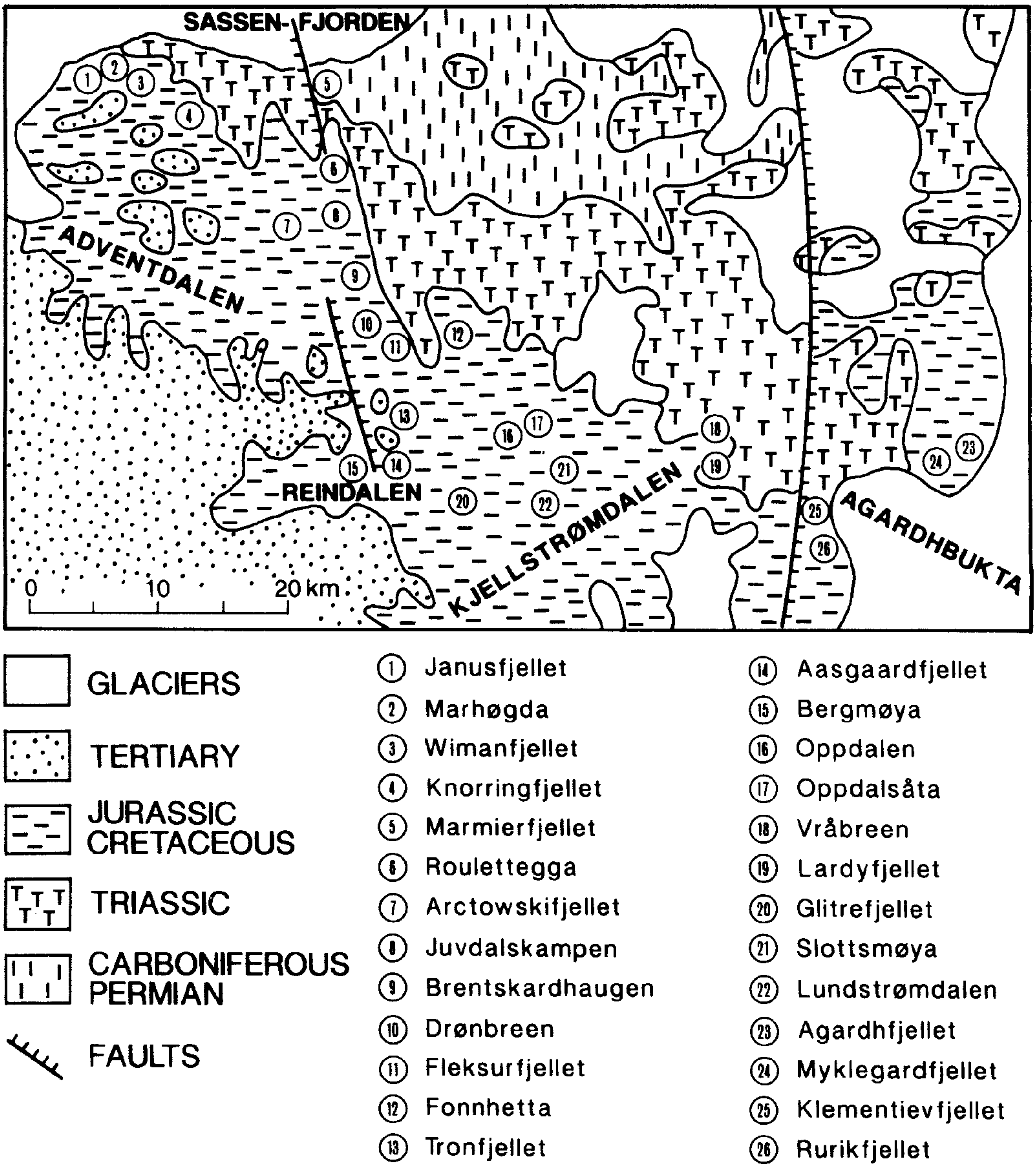


Fig. 4. Geological map of Central Spitsbergen. Position of localities discussed in text indicated.

group unconformably overlies the large hiatus which comprises much of the Middle Jurassic, while the top of the group corresponds to an extensive Late Cretaceous hiatus. The lower, shaley part of this succession has long been recognized as a major single unit variously designated as Aucellensichten (Nathorst 1897; Hoel & Orvin 1937) or Aucellen shale (Hagerman 1925; Orvin 1940). The unit was formally termed the Janusfjellet Subgroup by Parker (1967), and this usage was shared by Flood et al. (1971). Later on the unit was currently ranked as formation. The subgroup rests on shallow shelf to marginal marine sandstones and shales of the Wilhelmøya Formation. It is overlaid by fluviodeltaic sandstones of the Helvetiafjellet Formation.

The Janusfjellet Subgroup is composed of the Agardhfjellet Formation of Late Bathonian to Berriasian age, and the Rurikfjellet Formation of Berriasian to Hauterivian age. These two units are separated by a thin interval (usually <2 m) of yellowish weathering clays.

Agardhfjellet Formation

This unit was originally defined as formation (Parker 1967), but became changed in rank to member in several papers (Major & Nagy 1972; Birkenmajer et al. 1982; Løfaldli & Nagy 1983). Detailed studies in central Spitsbergen demonstrated that the unit has a varied lithology, which together with its large thickness warrants its ranking as formation.

The lower part of the Janusfjellet Subgroup is made up of the few decimeter to some meter thick Brentskardhaugen Bed, containing pebbles of phosphate, chert, rock fragments, etc. (Bäckström & Nagy 1985). The position of the Brentskardhaugen Bed with regard to higher category is not well established. The bed was first claimed to be part of the Janusfjellet Subgroup (Parker 1966, Pchelina 1965a, b; Buchan et al. 1965). Parker (1967), however, preferred to place the Brentskardhaugen Bed at the top of the Kapp Toscana Group, due to lithological similarities between the matrix of the conglomerate and the sandstones forming the uppermost part of the group. These sandstones belong to the Wilhelmøya Formation introduced by Worsley (1973) and subsequently discussed by Mørk et al. (1982).

In more recent literature the Brentskardhaugen Bed is regarded by some authors as the uppermost unit within Wilhelmøya Formation (Worsley 1973; Harland et al. 1974; Bjærke & Dypvik 1977). On the other hand, Flood et al. (1971), Major & Nagy (1972), Birkenmajer (1975), Bäckström & Nagy (1985), and Birkenmajer et al. (1982) claim the Brentskardhaugen Bed to be a part of the Janusfjellet Subgroup.

The Brentskardhaugen Bed is a remanié unit containing bivalves and ammonites representing the Toarcian. In addition its content of younger fossils suggests that partial presence of the Aalenian to Bathonian interval is not unlikely. After a regressive/transgressive event in Middle Jurassic time the bed was finally deposited under littoral condition in its present state in the uppermost Bathonian or at the transition between this stage and the Callovian (Bäckström & Nagy 1985). Maher (1989) discusses a storm-related origin for the Brentskardhaugen Bed. Directly on top of this conglomerate, the oolitic sediments of the Marhøgda Bed follow in an upward fining development.

The lower part of the Agardhfjellet Formation is dominated by somewhat silty and sandy sediments, grading upwards into black (often papery) and grey shales forming the main part of the unit. The age of this formation is Late Bathonian to Berriasian as deduced from the literature including Pchelina (1965a, b); Løfaldli & Nagy (1983); Parker (1967); Erschova (1983); Kopik & Wierzbowski (1988) Wierzbowski (1989); Nagy et al. (1990). The thickness of the Agardhfjellet Formation varies between 165 m at Keilhaufjellet to 255–290 m in the Van Keulenfjorden and Festningen areas. The dark shales of the Agardhfjellet Formation contain some siltstone and sandstone beds, but generally represent deposition in oxygen-deficient shelf environments characterized by sedimentation of fine-grained material such as clay and organic matter (Dypvik 1985). The dark coloured siltstones and sandstones of Callovian age, commonly observed in Central Spitsbergen, have also been noted by Pchelina (1965a, b) in the Festningen and Van Keulenfjorden areas (Fig. 3). The Oxfordian and Kimmeridgian parts of the sequences are dominated by bituminous intervals of black paper shales (Pchelina 1965a, b; Nagy & Løfaldli (1981). Based on a combination of lithological and faunal evidence, Nagy et al. (1988) argue that the shales mainly represent dysaerobic depositional conditions in a shelf environment.

The Polakkfjellet Bed is a coarse-grained subunit of the formation. In Wedel Jarlsberg Land the bed is developed as a 5 m thick sandstone unit in the lower part of the Tirolarpasset Member (Rozycki 1959; Birkenmajer 1975). Comparable sandstone beds in the middle part of the formation (the Oppdalsåta Member discussed below) occur at several localities and are assumed to have been deposited as shelf sand ridges.

The palynological assemblages of the Agardhfjellet Formation are characterized by dinoflagellates with minor amounts of bisaccate pollen and spores (Bjærke et al. 1976). The foraminiferal fauna of the formation consists almost exclusively of arenaceous species. Intervals with high organic carbon content show low species diversities or are barren of foraminifera (Nagy et al. 1988).

Rurikfjellet Formation

The Rurikfjellet unit was originally proposed by Parker (1967) as formation, but in later current usage it became lowered to member rank (Birkenmajer 1980; Steel & Worsley 1984; Nagy et al. 1988). The dominant lithologies of the Rurikfjellet Formation are shales, siltstones and sandstones composing several coarsening-upward sequences deposited in marine shelf to prodeltaic environments.

The formation varies in thickness from 123 m at Keilhaufjellet (Løfaldli & Nagy 1983) to 225 and 290 m in the Festningen and Van Keulenfjorden areas. The age of the Rurikfjellet Formation is Berriasian to Hauterivian (Parker 1967; Pchelina 1967). Harland (1972) claimed, however, the Berriasian Stage not to be present in Spitsbergen, arguing that the formation contains only Valanginian to Upper Hauterivian deposits. Pchelina (1965) demonstrated the presence of beds from Valanginian and Hauterivian, based on macrofossil evidence.

An important stratigraphical marker horizon in central and eastern Spitsbergen is formed by the yellow weathering clays in the middle of the Janusfjellet Subgroup at the boundary between the Agardhfjellet and Rurikfjellet formations. The origin of these beds is not clearly understood, but explanations such as bentonites, glauconitic beds, weathering products of carbonate beds and weathered dolerites may be suggested. It should be noted that Pchelina (1965b) found no sharp boundary between the Agardhfjellet and the Rurikfjellet formations in the Van Keulenfjorden area.

In previous studies sediments from the Berriasian had not been recognized, and deposits of this time interval were supposed to be absent from the succession (Harland 1972). Parker (1967) suggested that the boundary between the two formations actually is a Late Volgian non sequence. Birkenmajer (1975) claimed, however, that sedimentation was continuous across the Jurassic-Cretaceous transition in Torell Land. In accordance with this the presence of the Berriasian is demonstrated by Pchelina (1967) in Sørkappland. In central Spitsbergen the Myklegardfjellet horizon is referred to as the Ryazanian (Late Berriasian) by Nagy et al. (1990), based on foraminiferal evidence.

The upper part of the Rurikfjellet Formation in several areas is dominated by siltstones and sandstones, and these coarser-grained intervals were named the Ullaberget Series in the western part of Spitsbergen by Rozycki (1959). The name was later formalised to Ullaberget Member by Birkenmajer (1975). The distribution of this unit is also discussed by Parker (1967), who claimed that it was only locally developed and confined to western areas. The sandstones within the Ullaberget Member were shown by Edwards (1976) to occur in coarsening-upward sequences, interpreted as shallow marine and prodeltaic deposits in Sørkappland. A similar explanation is applied also on the Ullaberget sandstones in Hornsund by Mørk (1978). This opinion was shared by Øxnevad (1986) and may also be applicable to central Spitsbergen (Dypvik et al. in press). The upward-coarsening units show depositional direction towards the S-SE and represent upward-increasing current and wave activity, a response to a generally prograding deltaic development. Øxnevad (1986) shows both fluviodeltaic processes and geostrophic storm currents with transport direction towards S-SW to have distributed and deposited the sandy sediments in the uppermost part of the Rurikfjellet Formation.

The time equivalent deposits of the Janusfjellet Subgroup on Kong Karls Land were assigned to the Kongsøya Formation by Smith et al. (1976). This unit consists mainly of grey to black shales and clays with some siltstones – lithologies essentially similar to those of Spitsbergen.

The Festningen Member of the Helvetiafjellet Formation (Barremian) consists of fluviodeltaic, coarse-grained, light-coloured sandstones deposited, with erosion at base, directly on the Rurikfjellet Formation. The Festningen Member represents the delta-dominated coastline which succeeded the prodeltaic sediments seen in the Rurikfjellet Formation (Nemec et al. 1988; Steel 1977). The regional regression is first reflected by the coarsening-upward developments of the Rurikfjellet Formation, which were connected to deltas prograding from northern to westerly areas. The Helvetiafjellet Formation is dominated by the deltafront and floodplain deposits of these deltas.

The Festningen Member consists of multistorey sandbodies, with southerly transport directions in its lower part (Steel 1977). In the middle part of the member some eastern transport directions are observed. The lithological development of the member is quite uniform throughout Spitsbergen (Edwards 1976; Steel 1977; Steel & Worsley

1984). The latter two authors claim the Festningen Member to be more deltaic than fluvial in origin. Nemec et al. (1988) note the presence of rotated faultblocks, slides, and mudflows within the delta front deposits of the Kvalvågen area.

Tectonic and magmatic activity

The Janusfjellet Subgroup shows marked regional thickness variations on Spitsbergen. These changes have previously to a large extent been explained either as several episodes of syndepositional movement or as differences in sediment accumulation. Birkenmajer (1975) claims that the increased thickness of the subgroup in western areas mainly reflects the depositional axis of the basin. The thickness changes are also discussed by Steel & Worsley (1984), who favored Mesozoic normal faulting to be a major controlling factor. In Central Spitsbergen, along the Billefjorden Fault Zone, Parker (1966) and Harland et al. (1974) claimed that tectonic events had taken place, resulting in extensive erosion at the Jurassic/Cretaceous transition. The absence of the Agardhfjellet Formation in some areas along the fault zone is by these authors explained by the same tectonic events. Recent investigations, however, have shown that this is not the case, and Haremo et al. (1990) have demonstrated that most of the thickness variations found within the Janusfjellet Subgroup can be explained by Tertiary compressional tectonics including thrusting.

Mesozoic magmatic activity is documented by the presence of dolerite sills and dykes in large parts of Spitsbergen and on Kong Karls Land (Burov & Livsic 1970; Smith et al. 1976; Tyrell & Sandford 1933). The dolerites have been dated (K-Ar) by Gayer et al. (1966) and by Firsov & Livsic (1967) and given ages of about 110 to 143 my. In Agardhbukta, dolerites have been found to pass through the Agardhfjellet Formation but not the Rurikfjellet Formation (Parker 1967); consequently they are attributed to magmatic events at the transition between the Jurassic and Cretaceous systems (Burov & Livsic 1970; Tyrell & Sandford 1933). On Kong Karls Land, however, the volcanics are of Kimmeridgian to Barremian age, with peaks in the Volgian and Valanginian (Smith et al. 1976). The bulk of the Spitsbergen dolerites are sills (Tyrell & Sandfjord 1933) with a uniform tholeiitic composition, characterized by plagioclase with An 45 to 65. Burov & Livsic (1965) described four types of dolerites, which were distinguished mainly by their quartz content. The influence of magmatism on the sediments of the Agardhfjellet Formation at Agardhfjellet is probably reflected by the somewhat higher vitrinite reflectance values found in this unit, compared to the overlying Rurikfjellet Formation (Bjærke et al. 1976).

Parker (1966) claimed that three major episodes of tectonic activity took place in Svalbard in post-Paleozoic times: in the mid-Triassic, at the Jurassic-Cretaceous transition and in the post Eocene period. He assumed that the structures of the Billefjorden Lineament die out south of Kjellstrømdalen, which is, however, not the case, as demonstrated by Haremo et al. (1990). According to Parker (1966), when the effects of Tertiary tectonism are removed, a pre-Cretaceous anticlinal structure is left in the middle and eastern parts of Spitsbergen. He suggests that the Janusfjellet Subgroup in the west acted as a decollement zone during the Tertiary tectonic movements.

According to Parker (1966) and Harland et al. (1974) the tectonic highs formed at Marmierfjellet and Fleksurfjellet along the Billefjorden Fault Zone, also controlled sedimentation of the Rurikfjellet Formation. The products of erosion of the Agardhfjellet Formation in connection with the tectonic activity at the Jurassic-Cretaceous boundary should, then, be the main reason for the thickness variations observed. Harland (1972) claims that movements have taken place along two fault zones. Recent investigations reduce the importance of these tectonic movements, but suggest that the Marmierfjellet-Fleksurfjellet areas may have appeared as shallow banks in the Jurassic shelf area.

Subdivision of the Agardhfjellet Formation

The Oppdalen Member

The Oppdalen Member forms an upward-fining sequence, from conglomerates through sandy and silty beds to shales, making up the lower part of the Agardhfjellet Formation (Figs. 2, 5, and 6). The member consists of three subunits with transitional boundaries (from base upwards): the Brentskardhaugen, Marhøgda and Drønbreen beds. The type section of the member is located to the lowermost part of Oppdalsåta, in the innermost part of Oppdalen (Figs. 3 and 4).

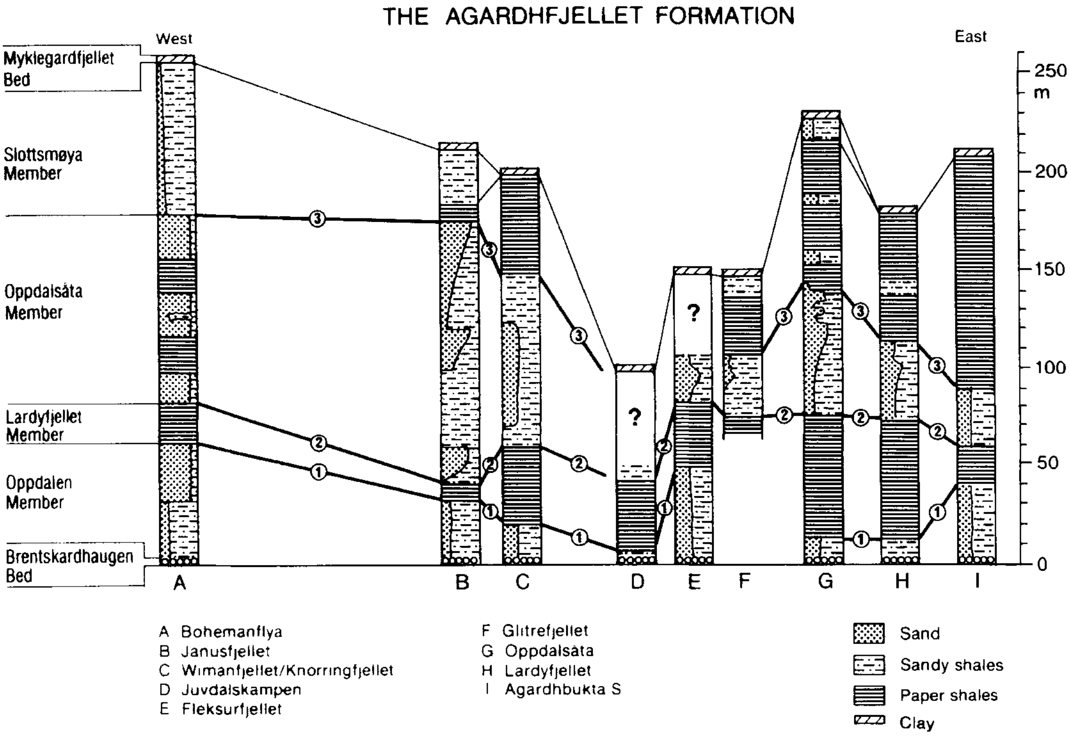


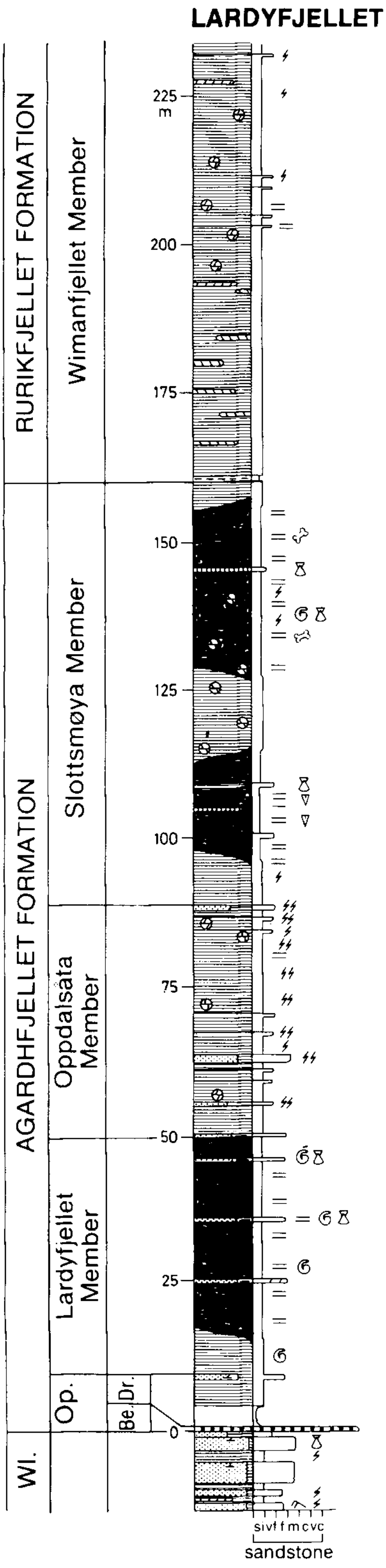
Fig. 5. The regional stratigraphical development of the Agardhfjellet Formation in Central Spitsbergen.

The Brentskardhaugen Bed. – The name Brentskardhaugen Bed was proposed by Parker (1967) for the 'phosphatic conglomerate' or 'Liassic conglomerate' of earlier workers. The type locality is Brentskardet, at the head of Adventdalen, where the unit is 1.3 m thick. The fauna of the Brentskardhaugen Bed at Sassenfjorden has been recorded by Wierzbowski et al. (1981). Bäckström and Nagy (1985) discuss in detail the lithology and fauna of the unit, covering several regions of Spitsbergen.

The bed is from 0.2 to 4 m thick and consists of phosphorite, quartzite, and chert clasts in a matrix-supported texture, dominated by well-cemented sandy material (Fig. 7). The pebbles contain several marine fossil groups and pieces of wood. Ammonites and bivalves indicate clast ages of Toarcian to probably Bajocian, while the matrix age and consequently the age of the conglomerate bed as a lithological unit is regarded as probably Upper Bathonian (Bäckström & Nagy 1985). The Brentskardhaugen Bed has been observed in the study area in somewhat varying developments as discussed by Bäckström & Nagy (1985). The conglomerate is found to be only 20 cm thick at Vråbreen (inner part of Kjellstrømdalen, Fig. 3) where it is dominated by minor phosphatic pebbles. At Oppdalssåta (inner part of Reindalen) the bed is poorly cemented and only 30 cm thick.

The Marhøgda Bed. – Resting on the Brentskardhaugen Bed an oolitic, glauconitic to chamositic sand/siltstone is commonly found on Spitsbergen (Fig. 8). This 0.3 to 1.5 m thick unit was named the Marhøgda Bed by Bäckström & Nagy (1985). The type section of the unit is located at Marhøgda, at the southern shore of Sassenfjorden, where it is from 1.2 to 1.5 m thick.

This glauconitic/chamositic marker bed is also found at Fonnhetta, Drønbreen and Fleksurfjellet. In these areas the grey to greenish bed is characterized by dispersed oolitic glauconite/chamositic grains and some similar sized phosphate pebbles in a sandy matrix. The composition of the oolites varies to some extent, however, with chamosite found in siderite cemented beds and with glauconite associated with dolomite



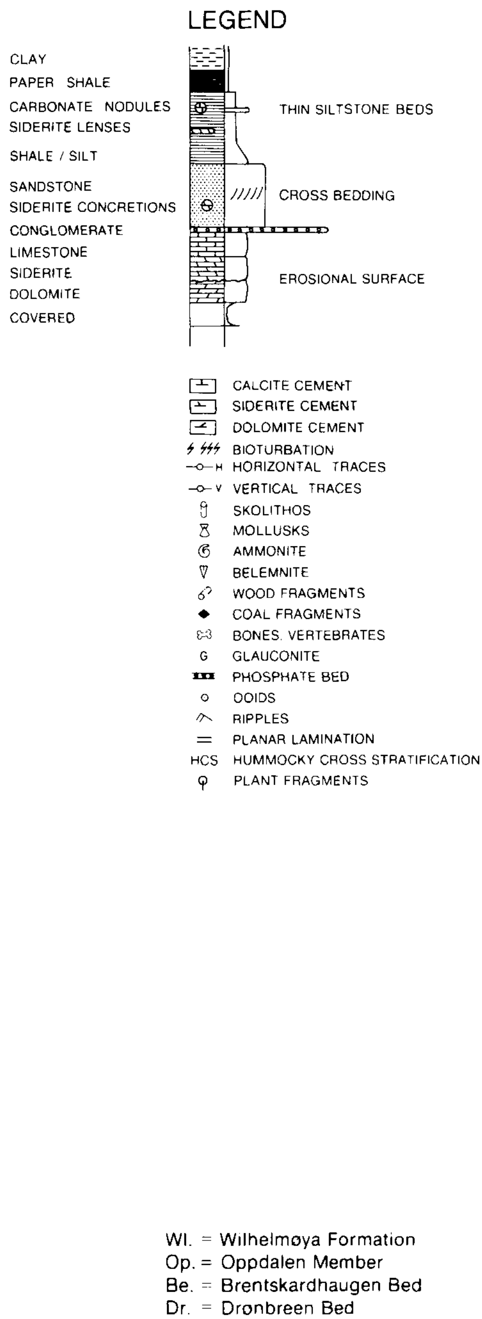


Fig. 6. Columnar section showing the Agardhfjellet Formation and lower part of the Rurikfjellet Formation at Lardyfjellet, Kjellströmdalen (78° 3.8′N, 17° 48.8′E).

Fig. 7. The Brentskardhaugen Bed at the front of Drønbreen, the inner part of Adventdalen. Outcrop surface formed by well-developed bedding plane is seen.

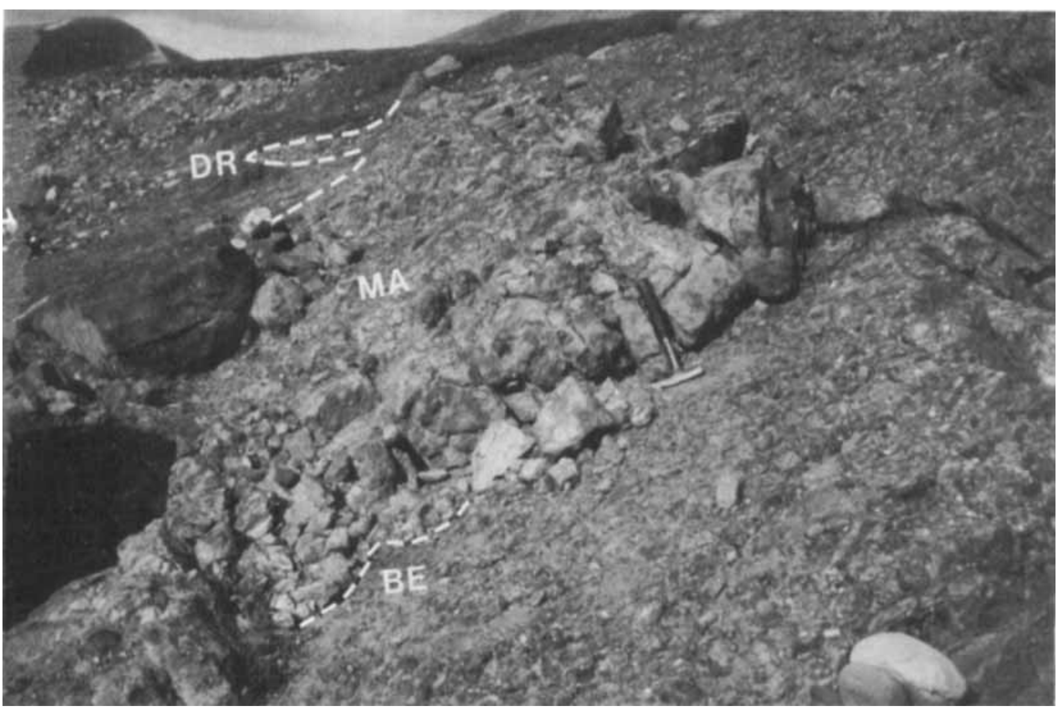


Fig. 8. The Marhøgda Bed at the front of Drønbreen, inner Adventdalen (BE-Breentskardhaugen Bed, MA-Marhøgda Bed, DR-Drønbreen Bed).

cemented units. A similar oolitic sandstone is also developed at Juvdalskampen. Rozycki (1959) mentions an iron-rich oolite bed directly overlying the phosphate conglomerate in the Ingebrigtsen-bukta area, southern side of Van Keulenfjorden.

In the inner part of Reindalen, at Oppdalsåta, the Marhøgda Bed is recognized as a 30 cm thick carbonate cemented glauconitic sandstone bed. In the inner part of Kjellstrømdalen, at Vråbreen, the unit is 0.8 m thick, and consists of loose, partly carbonate-cemented, glauconitic/chamositic sand. The loose sandy appearance may be a result of weathering and suggests the sediment to be more firmly cemented deeper in the section.

The Drønbreen Bed. – The Marhøgda Bed is overlaid by an upward-fining unit of poorly sorted, clay-rich fine sand and silt with up to 30 cm thick beds of siderite (Fig. 9). Due to its extensive exposures west of Drønbreen we have named the unit after this glacier. The unit represents a Bathonian to Callovian transgressive phase. It comprises a 10 to 60 m thick sequence of loosely cemented sediments which separate the Marhøgda Bed from the typically black, commonly papery shales of the overlying Lardyfjellet Member. The type section of this bed is situated at the head of Adventdalen, about 1 km northeast of the front of Drønbreen.

The bed is generally structureless, probably due to a high degree of bioturbation. In the lower part of the unit, at Janusfjellet, it is possible that hummocky cross-stratification was observed. The unit shows a gradually upward-fining development from the glauconitic sandstones of the Marhøgda Bed to the black shales of the Lardyfjellet Member.

The Drønbreen Bed thins to some extent from the northwestern margin of the basin and eastwards. This thickness reduction matches the sedimentary transport directions measured in Reindalen, where the main transport directions are towards S-SE, with a minor component towards E-NE and W-NW. The thickness of the bed at seven localities is as follows:

Janusfjellet	25 m
Syltoppen, Bohemanflya	60 m
Myklegardfjellet	40 m
Fleksurfjellet area	30–35 m

Fig. 9. The Drønbreen Bed consisting of siltstones and shales, and containing a well-developed carbonate bed displaced by a small fault. Exposure at the front of Drønbreen, Adventdalen.

Fig. 10. The black, finely laminated paper shales of the Agardhfjellet Formation, Oppdalsåta.

Oppdalsåta/Slottsmøya area	45–50 m
Lardyfjellet/Vråbreen	15 m
Knorringfjellet area	10–20 m

The Drønbreen Bed is relatively rich in fossils, mainly ammonites, belemnites and bivalves (*Buchia*). Its foraminiferal faunas consist of agglutinated assemblages with relatively high species diversity.

The Lardyfjellet and Slottsmøya Members

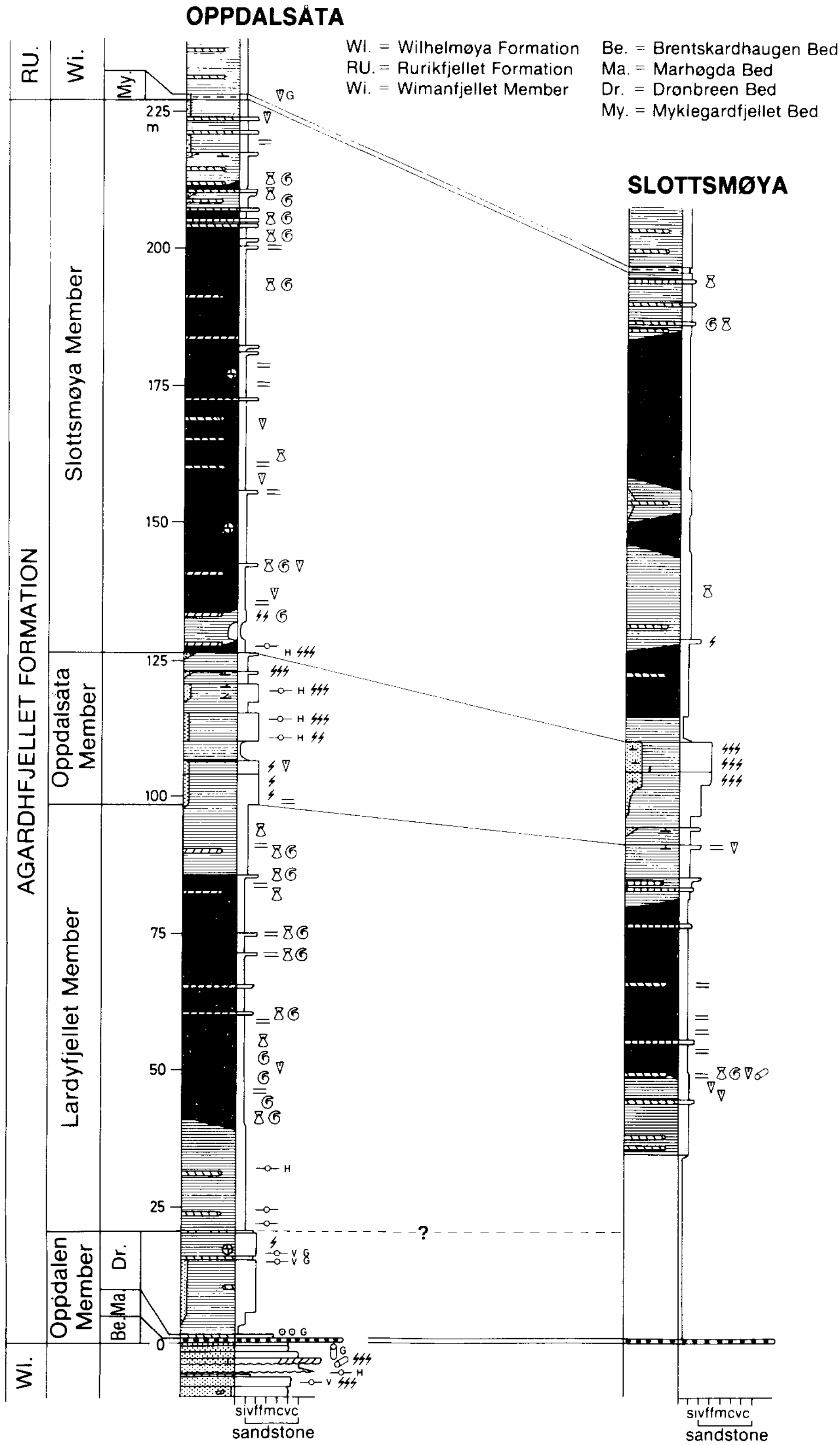
The main part of the Agardhfjellet Formation consists of dark-grey to black shales and paper shales, with common carbonate concretionary beds (Fig. 10). This shale sequence comprises a lower Lardyfjellet Member and an upper Slottsmøya Member, separated by the silty to sandy development of the Oppdalsåta Member (Figs. 2 and 11).

The paper shales of the Agardhfjellet Formation are dark, rich in organic material and have a fine papery fissility, most probably following the well-developed lamination of the sediment. However, shales with more blocky to prismatic fracture also occur. The varying degree of fissility most probably reflects the degree of bioturbation, the amount of organic material and the changing contents of coarse-grained (silty-sandy) components. The paper shales are characterized by a low silt and sand content. The observable degree of bioturbation is still generally low in the coarse intervals of the Agardhfjellet Formation, and no bioturbation has been seen in the paper shales. The paper shale sequences are developed in the Callovian, Kimmeridgian and Volgian parts of the succession.

The intervals consisting of grey shale are moderately rich in fossils such as bivalves (*Buchia*), ammonites and belemnites, while the paper shale beds normally are more or less depleted in comparison to the more blocky fracturing, siltier parts. The shales also contain well-preserved plesiosaur remains.

The Lardyfjellet Member consists almost exclusively of black paper shales, and the highest concentrations of organic carbon are found in

Fig. 11. Columnar sections showing the Agardhfjellet Formation at Oppdalsåta (78° 4.6′N, 17°23.7′E) and Slottsmøya, Reindalen (78°3.5′N, 17°21.2′E). Legend for symbols is given in Figure 6.


OPPDALSÅTA
SLOTTSMØYA
Wl. = Wilhelmøya Formation
RU. = Rurikfjellet Formation
Wi. = Wimanfjellet Member
Be. = Brentskardhaugen Bed
Ma. = Marhøgda Bed
Dr. = Drønbreen Bed
My. = Myklegardfjellet Bed
RU.
Wi.
My.
AGARDHFJELLET FORMATION
Slottsmøya Member
Oppdalsåta Member
Lardyfjellet Member
Oppdalen Member
Dr.
Ma.
Be.
Wl.
225 m
200
175
150
125
100
75
50
25
0
?
sivffmcvc
sandstone
sivffmcvc
sandstone

this unit. The type section of the member is the northwestern corner of Lardyfjellet on the southern side of Kjellstrømdalen where the thickness of the member is 35 m. The member shows higher natural gamma activity and uranium enrichments compared to the Slottsmøya Member. The concretions found in the Lardyfjellet Member are made up of dolomite, while those in Slottsmøya Member are sideritic.

The Slottsmøya Member consists mainly of grey shales commonly found with locally-developed occurrences of black, paper shales. In the upper part of this member coarsening-upward shale-silt-sand sequences are commonly developed at the *Dorsoplanites* horizons. The type locality of this member is the northern slope of Slottsmøya, at the junction between Reindalen and Lundstrømdalen, where the thickness of the member is 90 m.

The concretions occurring in the shales of the Agardhfjellet Formations are normally red to yellowish in colour. Close to the boundary towards the Rurikfjellet Formation, light-yellow 10–30 cm thick concretionary beds dominate.

A transect across central Spitsbergen shows the thickness of the shales in the Agardhfjellet Formation to increase relatively to the sandstones towards the east. The dominance of paper shales is also shown to increase in the same direction (Fig. 5). These shales are suggested to have acted as decollement zones for Tertiary movements (Haremo et al. 1990), indicating that some of the thickness variations are results of tectonic thickening.

The Oppdalsåta Member

The Oppdalsåta Member (Figs. 2 and 11) is characterized by the appearance of more silty and sandy developments than the beds above and below. At Slottsmøya (Figs. 3 and 4) fine sand dominates, but in the region as a whole the grain size is somewhat finer. At Sassenfjorden and Agardhfjellet sandy developments of the Agardhfjellet Formation are referred to this member (Nagy et al. 1990). It should be noted, however, that lack of detailed observations provides only sparse information concerning the development of the Oppdalsåta Member. In the western outcrop belt at Jurakammen and Keil-

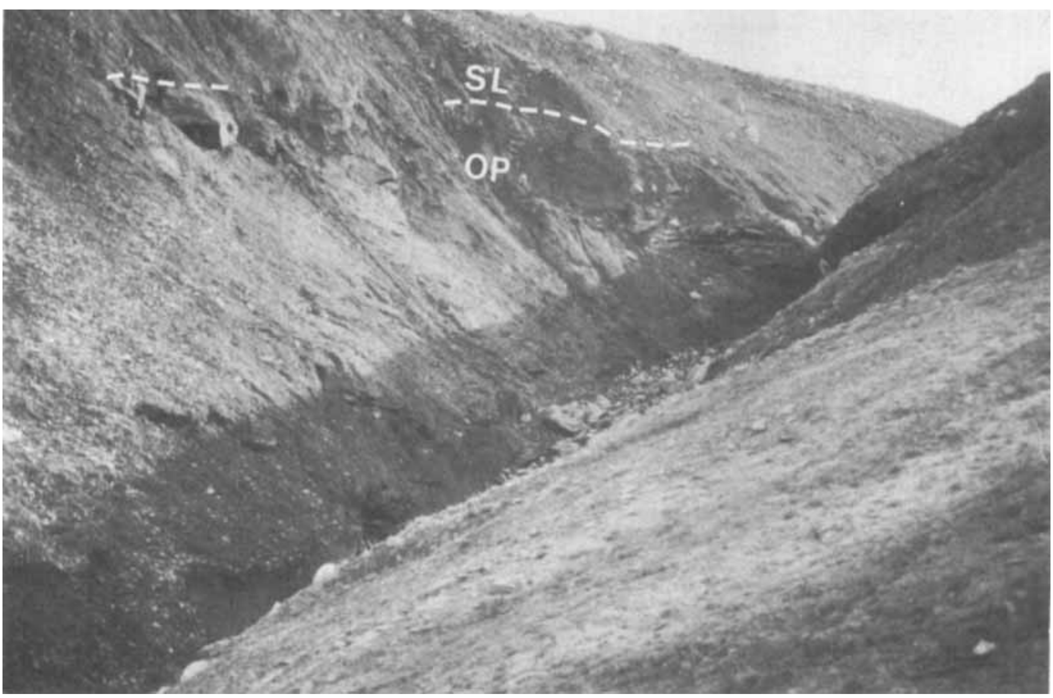


Fig. 12. The uppermost coarse-grained part of the Oppdalsåta Member at Glitrefjellet, Reindalen (OP-Oppdalsåta Member, SL-Slottsmøya Member).

haufjellet (Figs. 3 and 4), for example, only shales have been noted at this stratigraphical level. The possibility for presence of some sandier beds equivalent to this member should nevertheless not be completely excluded. At Keilhaufjellet only a 2 m thick sand bed is thought to represent a probable correlative unit. The type locality of the member is the western slope of Oppdalsåta in Oppdalen, where the thickness of the member is 41 m.

The silty to sandy (very fine sand) sediments of the Oppdalsåta Member compose several upward-coarsening units (Fig. 12). In the Sassenfjorden area (Janusfjellet, Wimanfjellet, Knorringfjellet), three sequences show coarsening-upward developments into siltstone (Fig. 5). The beds in that area are heavily bioturbated and rich in fossils. Two sequences are each 20 m thick and one is 60 m thick.

In the western outcrop belt, at Festningen and Ahlstrandodden (Van Keulenfjorden) (Figs. 2, 3 and 4), two upward-fining sequences are assigned to the Oppdalsåta Member; these are from 10 to 20 m thick. At Bohemanflya/Syltoppen an approximately 30 m thick highly bioturbated, poorly sorted organic rich sandstone unit is observed. The section at Bohemanflya contains in addition several coarsening-upward sequences throughout the Agardhfjellet Formation, reflecting a possibly more marginal position in the depositional basin than the more south-easterly localities.

In central parts of Spitsbergen some distinct sedimentological variations are seen in the Oppdalsåta Member. At Juvdalskampen, Fleksurfjellet E, and Lardyfjellet (Figs. 3 and 4) silty, heavily bioturbated sediments dominate a 30 m thick interval, while at Fleksurfjellet W and Arctowskifjellet one or two coarsening-upward sequences are found. Some possible hummocky cross-stratification, appearance of glauconite, and various degrees of bioturbation characterize these beds. At Arctowskifjellet some coarsening-upward sequences are observed terminating in 1 to 2 m thick beds of siltstone and very fine sandstone at some horizons showing parallel bedding. Although the development of the Oppdalsåta Member in central Spitsbergen is variable, it is always recognizable by the presence of sediments coarser than the shales above and below. At Slottsmøya, Oppdalsåta, Fonnhetta and Glitrefjellet NW, the development of the Oppdalsåta Member is characterized by three upward-coarsening units, with 4 to 10 m thick heavily bioturbated siltstones at the top. At Glitrefjellet and Slottsmøya two upward-fining sequences are also observed which are 5 m in thickness each and display some modest degree of bioturbation.

The silt and sand beds of the Oppdalsåta Member are generally rich in fossils. The most common groups are bivalves, ammonites and belemnites.

Subdivision of the Rurikfjellet Formation

The Myklegardfjellet Bed

This distinct clay unit is an important marker horizon, easily observable at the boundary between the Agardhfjellet and Rurikfjellet formations. It was originally defined by Birkenmajer (1980) with type locality at Myklegardfjellet near Agardhbukta, where the bed is from 0.5 to 10 m thick.

Although the Myklegardfjellet Bed shows variable thickness, it has been found at all localities where the formation boundary was studied by our field parties on the eastern-central part of Spitsbergen (Fig. 5). The observed thickness variation of the unit might partially be influenced by soil creep along the hillsides. On the northern slope of Arctowskifjellet (Fig. 14), the Myklegardfjellet Bed forms a thick horizon totalling 2 m. It contains two clay-rich zones, the lower 15 cm and the upper 30 cm thick separated by grey shales. The two zones are made up of from 5 to 10 cm plastic clay beds with yellow, reddish to grey colours, and they are separated by grey claystones/shales.

At Lardyfjellet the bed is found as a 40 cm thick, white-yellow and green clay unit reflecting various oxidation stages of iron. The reddish brown colours are seen along the bounding surfaces of the clay bed, probably indicating oxidation along these contact horizons.

At Glitrefjellet (Fig. 4) the Myklegardfjellet Bed is developed as a 0.5 m thick zone with partly plastic-yellow to light-grey clays. Glauconite occurs in varying amounts. Enrichments of glauconite are also observed in the clay beds at Tronfjellet, where 70 cm of glauconitic, silty clays and siltstones with two 10 cm thick plastic clay layers are developed. Both at Oppdalsåta and Slottsmøya, grey to yellow and green plastic clays make up the Myklegardfjellet Bed.

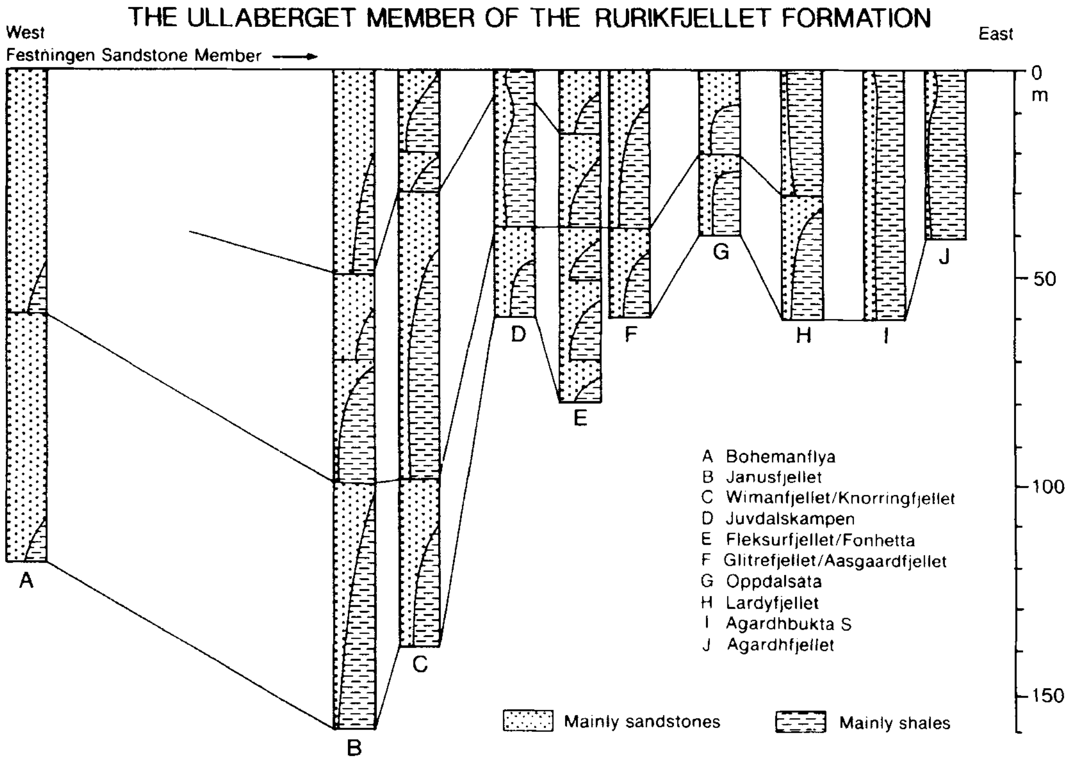


Fig. 13. The regional stratigraphical development of the Ullaberget Member of the Rurikfjellet Formation.

A few belemnites have been found in this clay unit at Arctowskifjellet and Glitrefjellet. Samples analysed for foraminifera from the plastic clays of Arctowskifjellet contained agglutinated specimens, but in considerably smaller amounts than the adjacent grey shales. On the contrary, the plastic clays at Janusfjellet where somewhat enriched in foraminifera compared to the adjacent shales.

The Wimanfjellet Member

In central and eastern Spitsbergen the Myklegardfjellet Bed defines the base of the Rurikfjellet Formation. Above this thin clay unit, the formation is made up of grey shales and partly silty shales composing the Wimanfjellet Member (Figs. 15 and 16). The shales show prismatic fracture and varying degrees of bioturbation. The lowermost, least silty beds are only moderately bioturbated in comparison to the more silty and sandy beds higher up in the member. The carbonates of the Wimanfjellet Member are characteristically made up of mostly reddish, sideritic lenticular concretions up to a meter in diameter. The upper part of the member contains cannon ball-shaped and ovoidal nodules of siderite and calcite (Dypvik 1978). Together with these concretions, thin cigar-like nodules are also commonly seen.

The Wimanfjellet Member contains rather moderate amounts of fossils: bivalves, belemnites and more rarely, ammonites. The fossil content here is clearly lower than in the shales of the Agardhfjellet Formation, where the highest amounts were found just below the Rurikfjellet Formation boundary.

The Ullaberget Member

The sandstone-siltstone-shale sequence developed in the upper part of the Rurikfjellet Formation has been defined as the Ullaberget Series by Rozycki (1959) in western outcrop areas (outer Van Keulenfjorden and Torell Land), and the unit was redefined as the Ullaberget Member by

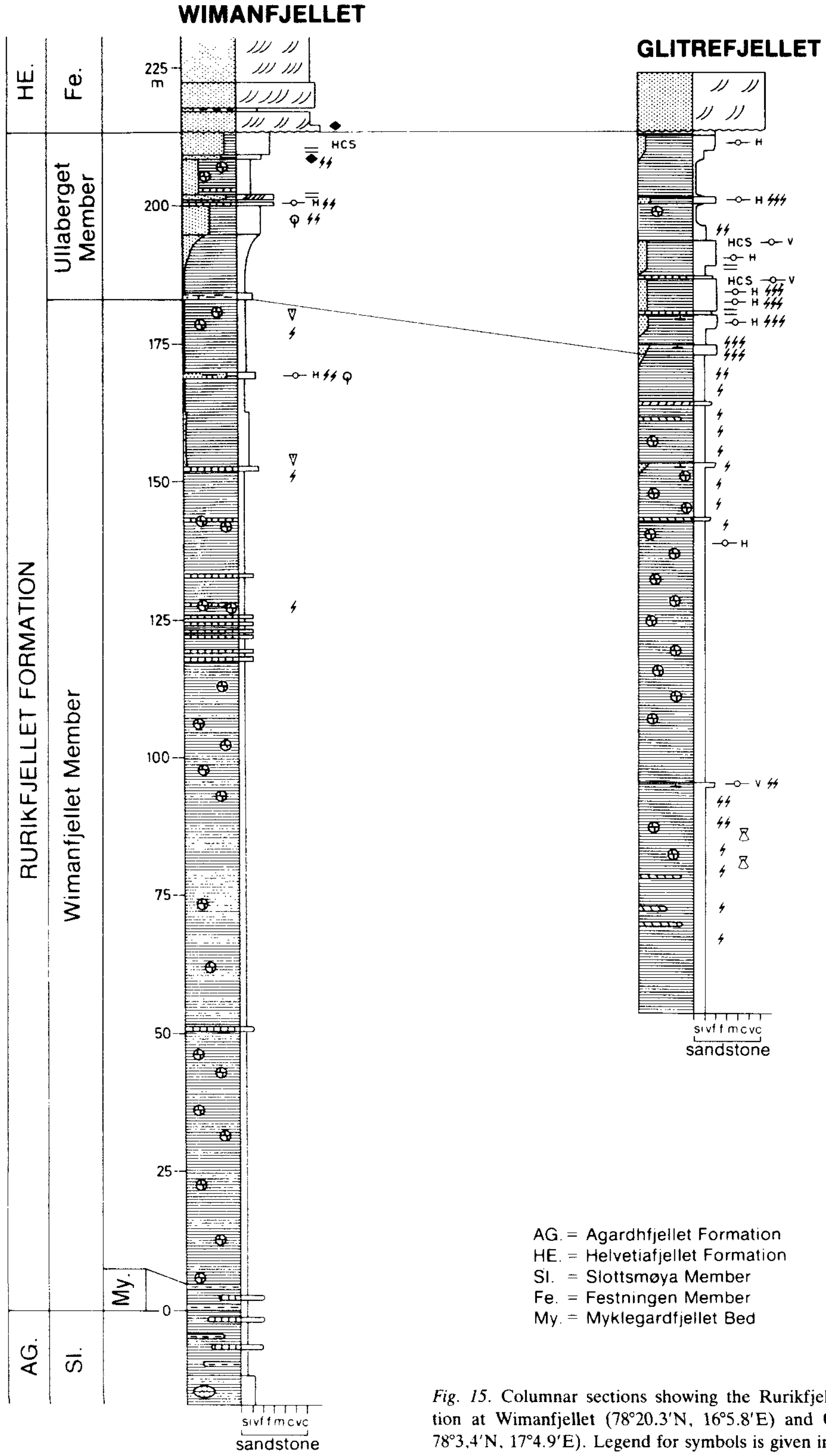
Fig. 14. The upper clay units of the Myklegardfjellet Bed at Arctowskifjellet, Adventdalen.

Birkenmajer (1975). In addition to the type area (Ullaberget in Van Keulenfjorden), the member is also recognized in Sørkapp Land and in central and eastern Spitsbergen, although it shows large variability in thickness and lithological development compared with its type locality.

In the areas investigated by us the Ullaberget Member consists generally of very fine sands, with some interbedded fine sands, silts and shales (Figs. 15 and 17). Fine sands dominate in the Keilhaufjellet, Glitrefjellet and Aasgaardfjellet sections (Figs. 3 and 4), but the overall variations in grain size are minor. Regionally, the thickness and the sand content of the Ullaberget Member decreases towards the east (Fig. 13). The sections at Keilhaufjellet and in Hornsund are made up of four coarsening-upward sequences (Edwards 1976; Mørk 1978) with thicknesses varying between 15 and 35 m, totalling 85 m. Similar upward-coarsening sequences are reported from Bohemanflya (Hvoslef 1984; Øxnevad 1986) and Festningen near the west coast. These sections generally contain from 50 to 60 m thick upward-coarsening developments, including several minor coarsening-upward intervals, interbedded with some minor fining-upward horizons. The member contains well-developed hummocky cross-stratification, cross-bedding and some bioturbation. At Bohemanflya some of the sandstones in the upper part of the section are coarse grained. The hummocky cross-stratified beds at Bohemanflya are succeeded by parallel laminated, in part heavily bioturbated sandstones. At Jurakammen, north of Hornsund (Fig. 3) one upward-coarsening sequence is indicated (Rozycki 1959).

In the Isfjorden area the Ullaberget Member has been studied at Festningen, Bohemanflya, Janusfjellet, Wimanfjellet and Knorringfjellet. In this region the member is commonly made up of 4 coarsening upward sequences, varying in thickness from 10 to 30 m. The total member thickness is 85 m and the unit shows a gradually upward-increasing sand content. The lower three coarsening-upward sequences are characterized by bioturbation, ripple lamination, and parallel lamination, while the uppermost sequence contains hummocky cross-stratification and shows a reduced degree of bioturbation.

In the Adventdalen area, sections have been



AG. = Agardhfjellet Formation
HE. = Helvetiafjellet Formation
Sl. = Slottsmøya Member
Fe. = Festningen Member
My. = Myklegardfjellet Bed

Fig. 15. Columnar sections showing the Rurikfjellet Formation at Wimanfjellet (78°20.3'N, 16°5.8'E) and Glitrefjellet 78°3.4'N, 17°4.9'E). Legend for symbols is given in Fig. 6.

Fig. 16. The Wimanfjellet Member of dark silty shales with 'cannonball'-like carbonate concretions, Reindalen.

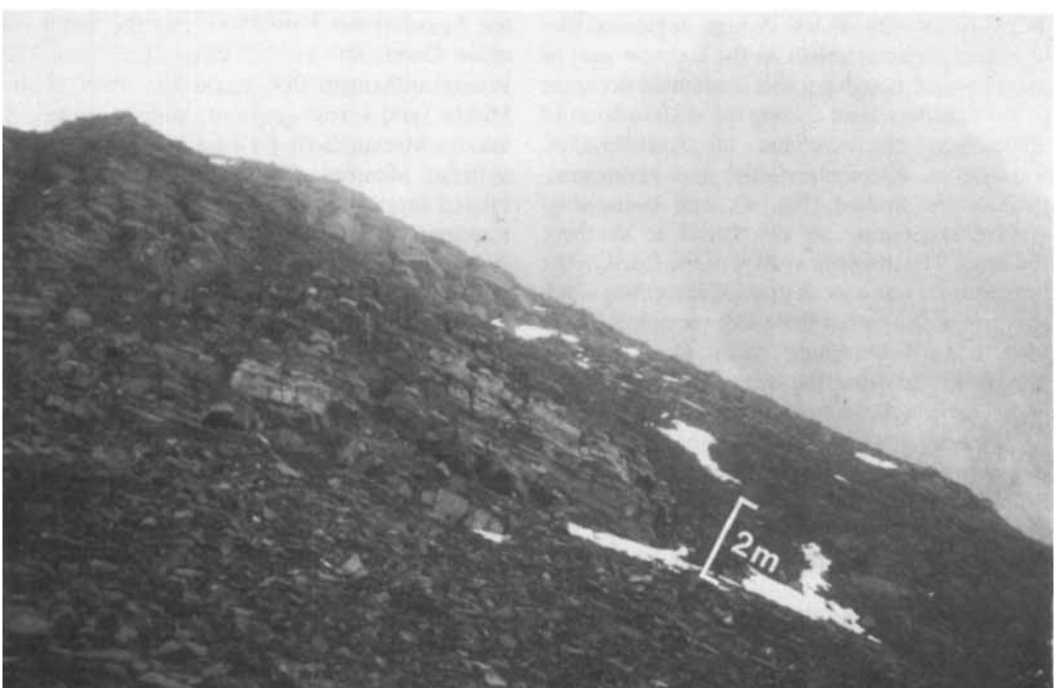


Fig. 17. The Ullaberget Member at Oppdalsåta, Reindalen. In the background the sandstones of the Festningen Member, Helvetiafjellet Formation, can be seen.

studied at Juvdalskampen, Roulettegga and Drønbreen (Fig. 4). In this area, the member is approximately 30 m thick and forms a single upward-coarsening sequence. Further south at Fleksurfjellet and Tronfjellet the upward-coarsening member consists internally of three 5 to 10 m thick sandstone dominated intervals. In the uppermost beds hummocky cross-lamination is well-developed. In addition black-coloured feeding tunnels (*Muensteria*) are found. Bioturbated units dominate below the hummocky stratified beds.

Around the inner part of Reindalen, the Ullaberget Member was studied at Slottsmøya, Oppdalsåta, Glitrefjellet, Aasgaardfjellet and Bergmøya (Fig. 4). At these localities the member comprises from two to three coarsening-upward sequences, varying in thickness from 10 to 20 m with a high degree of bioturbation and *Muensteria* tunnels in the upper part. The upward-coarsening units terminate in 2 to 4 m thick sandstones, which also in this area contain well-developed hummocky cross-stratification. Below the hummocky cross-stratified sandstone, zones of alternating silt and sand with abundant bioturbation are found.

Further towards the east the Lardyfjellet section was studied. This section, however, shows only 30 m of silty shales. A high degree of bioturbation is characteristic in the topmost part of these beds, although parallel lamination occurs in parts of the sequence. Along the eastern coast of Spitsbergen the sections at Agardhfjellet, Rurikfjellet, Klementievfjellet and Myklegardfjellet were studied (Fig. 4), and coarsening-upward sequences are also found at all these localities. The uppermost 20 m of the Rurikfjellet Formation shows a weak upward-increasing sand-silt content in a rather shale-like sequence. Three such upward-coarsening units appear to be present as indicated by means of mineralogical and geochemical analyses (Dypvik 1980).

The sediments forming the Ullaberget Member display a general transport direction towards S-SE, a feature also found at Bohemanflya (Hvoslef 1984) and in Reindalen. Øxnevad (1986) presented multiple transport directions in the Ullaberget Member at Bohemanflya, showing transport towards S, SW and S-E.

The Ullaberget Member is poor in fossils compared to the beds below, but it contains a high degree of bioturbation. In several sections saurian bone fragments have been observed, while also other fossils including ammonites, belemnites, gastropods, *Buchia* and plant remains have been seen.

Summary and conclusions

The stratigraphical revision of the Janusfjellet Subgroup presented here is generally based on new field information obtained during the last few years. The demand for a more elaborate stratigraphy became clear during increased field activity which has taken place in Spitsbergen in the last decade. The stratigraphical subdivision proposed by Parker (1967) provided an adequate basis for this study.

The emended stratigraphical scheme presented here (Fig. 2) is primarily based on observations made in central and eastern Spitsbergen. Based on reconnaissance work in other parts of Spitsbergen, we expect that it will be applicable with some modifications also to the western outcrop belt and the northeastern areas of Spitsbergen. An updated correlation with these areas requires, however, new and detailed field information.

Important items of the revised scheme are the inclusion of the Brentskardhaugen Bed in the Oppdalen Member composing the lower part of the Agardhfjellet Formation, and the definition of the Oppdalsåta and Ullaberget members. The Brentskardhaugen Bed marks the onset of the Middle Jurassic transgression, continuing directly into the Marhøgda Bed, Drønbreen Bed and Lardyfjellet Member. This solution ties together related depositional units formed during a major transgressive event in the lower part of the Agardhfjellet Formation, with the directly succeeding organic-rich shales above.

The Oppdalsåta and the Ullaberget Members are characterized by increased sand and silt content in the Janusfjellet Subgroup. As described earlier in this presentation the lithology of these formations varies from sandstone to silty-shale, but they reveal marked differences with regard to sedimentary structures. The Oppdalsåta sands are interpreted as shelf sand ridges. The deposition of the Ullaberget sands is attributed to the progradation of the Festningen delta system.

We prefer to retain the Janusfjellet Subgroup (Upper Bathonian-Hauterivian) as a single major stratigraphical unit, as proposed by Parker (1967). It makes room for a more elaborate stratigraphical framework applicable in future studies involving detailed field work. Main features of the two formations composing the subgroup are given below.

The Agardhfjellet Formation

The thickness of this unit varies from 65 m at Juvdalskampen (less than 40 m at Roulettegga) to 290 m in Van Keulenfjorden area (Rozycki 1959). The Brentskardhaugen Bed, a phosphorite conglomerate, forms the base of the unit, towards the light coloured sandstones of the underlying Wilhelmøya Formation. The upper part of the formation terminates at the lower boundary of the light-grey to yellow clays of the Myklegardfjellet Bed. The Agardhfjellet Formation is divided into four members: the Oppdalen, Lardyfjellet, Oppdalsåta and Slottsmøya.

The Oppdalen Member, a sandy and silty unit, consists of the Brentskardhaugen Bed, the glauconitic sandstones of the Marhøgda Bed, which are succeeded by the upward fining sandy siltstones of the Drønbreen Bed.

The Lardyfjellet Member, consisting of black paper shales with scattered carbonate concretions, overlies the Oppdalen Member. The top of the Lardyfjellet Member is drawn at the first appearance of silt-sand beds and disappearance of black shales.

The Oppdalsåta Member found on top of the Lardyfjellet Member commonly consists of several upward-coarsening sands and sandy shale units. The last sand bed marks the top of this member.

The Slottsmøya Member, resting on the Oppdalsåta Member, consists of black paper shales sometimes with faint developments of coarsening-upward sequences in the upper part. The unit terminates in the Myklegardfjellet Bed.

The Rurikfjellet Formation

The thickness of the Rurikfjellet Formation varies from 40 m at Juvdalskampen to 290 m in the Van Keulenfjorden area (Rozycki 1959). The lower boundary of the formation is marked by the clays of the Myklegardfjellet Bed, while the uppermost beds are found below the cross-bedded sandstones of the Festningen Member. The Rurikfjellet Formation is divided into the Wimanfjellet and the Ullaberget Members.

The Wimanfjellet Member contains at its base the light-grey to yellow soft clays of the Myklegardfjellet Bed. The rest of the member is made up of grey, silty shales to dark-grey shales. The first appearing sand bed marks the boundary to the overlying Ullaberget Member, which in addition to silty/sandy shales contains several sandstone beds commonly with cross-bedding and bioturbation. The boundary between the two members is commonly found near the uppermost 'cannon ball' concretionary beds.

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