

The Jurassic and Cretaceous Sequence in Spitsbergen

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ABSTRACT

The Jurassic and Cretaceous sequence of Spitsbergen, Svalbard archipelago, is described and a revised lithostratigraphical scheme, of four formations, is proposed. The main episode of tectonic activity, together with dolerite intrusion, was in late Jurassic-early Cretaceous times and is represented by a non-sequence and local unconformity between the two lower formations. The faunal succession is also discussed.

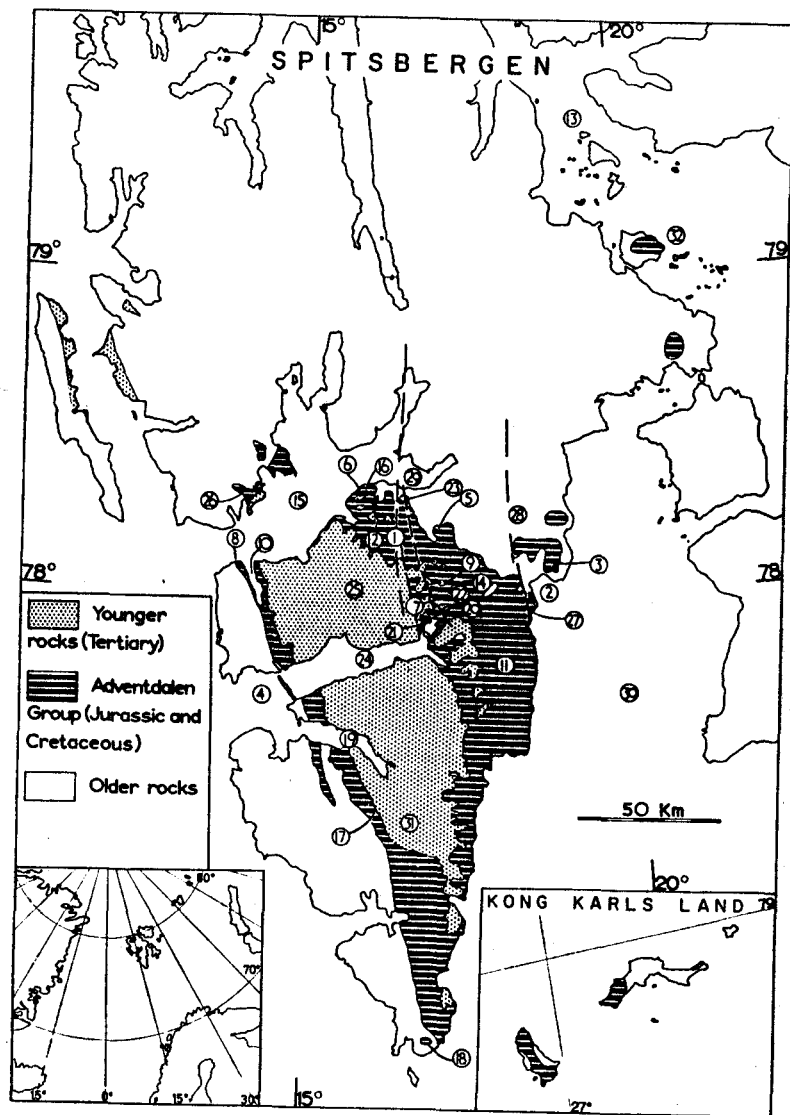
I. INTRODUCTION

THE Jurassic and Cretaceous rocks of Spitsbergen are exposed as an elliptical outcrop around the main Tertiary syncline (Text-fig. 1). Along the west coast the rocks have been folded and thrust in a deformation belt of Tertiary age but in the north and east are gently dipping and little deformed, apart from local activity along fault belts.

Jurassic fossils were first collected from Spitsbergen by Lovén in 1837 from Grønfjorden, and subsequent expeditions, led principally by Nordenskiöld and Nathorst, established the presence of Jurassic and "Neocomian" strata along the south side of Isfjorden, in Bellsund, at Agardhbukta on the east coast, and on Kong Karls Land, the group of islands which lie some 150 km east of Vestspitsbergen. The results of these early expeditions were summarized by Nathorst (1910).

Subsequent palaeontological work was based mainly on material from the Festningen section (Hoel and Orvin, 1937; Sokolov and Bodylevsky, 1931; Frebold and Stoll, 1937) but much information on other localities and collections was given in a series of papers by Frebold (1929 *a-c*, 1930, 1931) who also discussed the palaeogeography and correlation of the Arctic Jurassic and Cretaceous rocks. Useful summaries of the Jurassic-Cretaceous sequence were given by Frebold in his two reviews of Spitsbergen geology (1935, 1951) and Arkell (1956) has, in particular, discussed the Jurassic faunas. In addition, results from the Russian geological investigations of 1962-64 have recently been published (Sokolov, 1965) and two papers by Pchelina (1965 *a, b*) provide detailed descriptions of the Mesozoic successions in the Isfjorden and Van Keulenfjorden regions.

Recent work by the Cambridge expeditions has produced additional stratigraphical and palaeontological information, mostly from central Spitsbergen, on the Jurassic-Cretaceous sequence and this is discussed here in conjunction with a revised lithostratigraphical scheme. This scheme essentially follows that of Nathorst (1910; see also Table 1), but further divisions are proposed and type sections specified. Reference must also be made to the forthcoming Norsk Polarinstitut 1 : 100,000



TEXT-FIG. 1.

geological map of Adventdalen and I am indebted to Mr. H. Major of Norsk Polarinstitutt for discussion and information on the stratigraphical scheme appearing with this map.

II. STRATIGRAPHICAL SUCCESSION

The whole Spitsbergen Mesozoic succession is of fairly constant thickness, having a maximum development of about 2,400 metres. The main Lower and Middle Triassic marine shale sequence is overlain by the non-marine sandstones and shales of the Kapp Toscana Formation (Buchan, Challinor, Harland, and Parker, 1965). For the strata between the top of the Kapp Toscana Formation and the base of the Tertiary, four formations are proposed, these together being termed the Adventdalen Group. The lower Agardhfjellet and Rurikfjellet Formations are a marine shale sequence, together equivalent to the Aucella Shale of Nathorst (1910) and other authors, extending from the uppermost Bathonian/lowermost Callovian to the Hauterivian. For this interval, the term Janusfjellet sub-group (following Norsk Polarinstitutt and other unpublished usage) is informally proposed. The two formations are separated by a non-sequence and local unconformity, the break occurring between the Lower Volgian and the Valanginian. Above is a series of continental deposits (Helvetiafjellet Formation) consisting of coarse quartz clastics, thin coal seams, and carbonaceous shales, and these are assigned to the Barremian. The highest Mesozoic strata seen beneath the Tertiary unconformity are shallow water marine shales and flaggy sandstones of Aptian and Albian age (Carolinefjellet Formation).

The relationship of these proposed terms to previous stratigraphical nomenclature is shown in Table I. Further details of the new units are given in the appendix and representative sections are illustrated in Text-figs. 2, 3, and 4.

TEXT-FIG. 1.—Outcrop and place-name map. Place-names numbered as follows:

- | | |
|----------------------|------------------------|
| (1) Adventdalen | (17) Jurakammen |
| (2) Agardhbukta | (18) Keilhaufjellet |
| (3) Agardhfjellet | (19) Van Keulenfjorden |
| (4) Bellsund | (20) Kjellströmdalen |
| (5) Brentskardhaugen | (21) Langstakken |
| (6) Carolinefjellet | (22) Lundströmdalen |
| (7) Dalkjegla | (23) Marmierfjellet |
| (8) Festningen | (24) Van Mijenfjorden |
| (9) Glitrefjellet | (25) Nordenskiöld Land |
| (10) Grønfjorden | (26) Ramfjellet |
| (11) Heer Land | (27) Rurikfjellet |
| (12) Helvetiafjellet | (28) Sabine Land |
| (13) Hinlopenstretet | (29) Sassenfjorden |
| (14) Innkjegla | (30) Storfjorden |
| (15) Isfjorden | (31) Torell Land |
| (16) Janusfjellet | (32) Wilhelmøya |

TABLE I.—STRATIGRAPHICAL SCHEME SHOWING RELATIONSHIP TO PUBLISHED STRATIGRAPHICAL NAMES.

W. Nordenskiöld Land	Kjellströmdalen	Torell Land	Sabine Land & E. Nordenskiöld Land	
NATHORST 1897, 1910, 1913	HAGERMAN 1925	ROZYCKI 1959	Proposed scheme	
HOEL and ORVIN 1937	Upper Lamina sandstone Cretaceous shale Lower Lamina sandstone	<i>Ditrupe</i> Shale Series		Member
Dentalienschiechten			Longstrakten Innkjegia Dalkjegia	
Sandsteinreihe	<i>Ginkgo</i> -Schichten	Shore sandstone	Adventdalen	Gittretjellet
	<i>Pityophyllum</i> -Schichten Süsswasserachicht mit <i>Lipolaria palmaris</i> LUNDGR. <i>Elatides</i> -Schichten			
Aucellenschichten	Festungsandstein	Festningen sandstone		Festningen
	(Black shales with spherical nodules) (Dark grey soft shaly rock with clay ironstone) (Black shales)	<i>Aucella</i> shale	Ullaberget Series Tirolarpasset Series Ingabrigtsenbukta Series Lias conglomerate	Rurikfjellet Agardhfjellet
	(conglomerate)		Janusfjellet sub-group	Kapp Toscana
				de Geardalen: Brentskardhaugen bed

(a) *Kapp Toscana Formation*

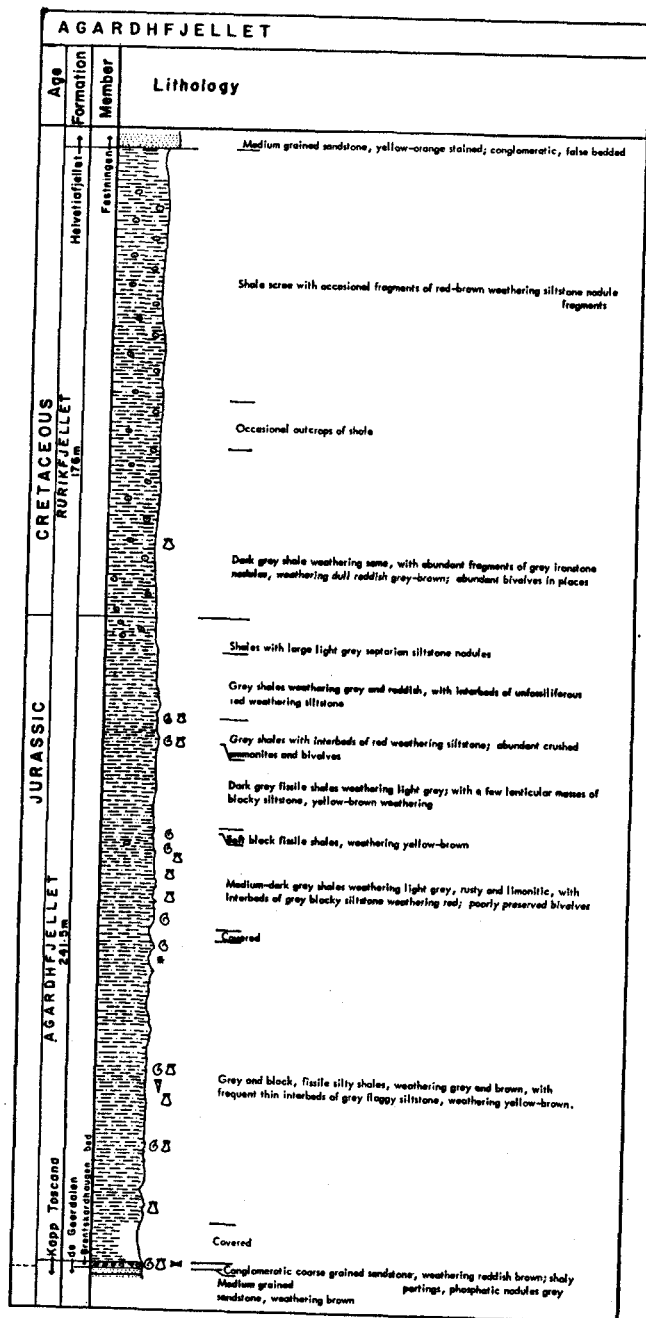
The Triassic-Jurassic boundary is not represented by any lithological or palaeontological marker horizon. Plant remains from the sandstones of the Kapp Toscana Formation indicate a Rhaetian age but by analogy with East Greenland, where a flora of Rhaeto-Liassic age is recorded (Harris, 1937), the upper part of the Kapp Toscana Formation could be of lower Jurassic age (see discussion in Rozycki (1959, p. 66), and in Buchan *et al.* (1965)). At the top of the Kapp Toscana Formation is the so-called "Lias conglomerate" which contains the first undoubted Jurassic fossils; hence this conglomerate has frequently been separated from the Kapp Toscana Formation. It is a thin remanié deposit and consists largely of reworked Kapp Toscana Formation material together with phosphatic nodules containing fossils of Toarcian age. Lithologically it is part of the Kapp Toscana Formation, the sharp lithological junction and topographical break occurring at the top of the conglomerate. It is therefore proposed to include the "Lias conglomerate" within the Kapp Toscana Formation, as an upper Brentskardhaugen Bed, rather than with the overlying shale sequence as suggested by Buchan *et al.* (1965).

(b) *Janusfjellet sub-group*

The *Agardhfjellet* Formation (Text-fig. 2) is a shale sequence, dark grey to black in colour, with interbeds of grey siltstone. These interbeds weather yellow-brown over most of the unit but in the lowest 20 m and in the upper 40-50 m weather to a brick red colour. This variation in weathering colour is gradational but provides a useful broad subdivision.

The *Rurikfjellet* Formation (Text-fig. 2) is again a shale sequence, black in colour, with dark brown and black clay ironstone nodules, weathering brown-red and orange.

The junction between these two formations is a sharp lithological change from the shale/siltstone sequence below to the shale/nodule sequence above, each having distinctive weathering colours. There is also a distinct break in slope at the junction. The two units have different geomorphological features, gullies being developed on the lower unit but not on the upper, and the upper limit of gullying provides a close approximation to the junction. Locally septaria may be developed below the junction and in the Agardhbukta area a yellowish clay, interpreted as weathered doleritic material, occurs along the junction. This lithological break most probably also represents an Upper Volgian non-sequence (see below) and locally the Rurikfjellet Formation is unconformable on the Agardhfjellet Formation and older strata, and on intruded dolerites.



TEXT-FIG. 2.—Agardhfjellet section.

Fossils are relatively abundant, although poorly preserved, within these two formations. *Buchia* (formerly termed *Aucella*) occurs throughout but the ammonites are found mostly in distinct horizons (Text-fig. 6).

The Agardhfjellet Formation has a fairly constant thickness of between 240 and 260 m except where modified by the two fault belts of the central area (Text-fig. 1). Over these fault belts the Agardhfjellet Formation is either much thinner or has been completely removed by erosion, this being related to the late Jurassic movements along the belts (Text-fig. 5 and Parker, 1966). The submarine features resulting from these movements persisted into Cretaceous time and gave rise to localized variation in the thickness of the overlying Rurikfjellet Formation along the belts. Apart from this, the Rurikfjellet Formation is of fairly constant thickness (160–180 m) over central Spitsbergen but the area to the west shows a much thicker sequence.

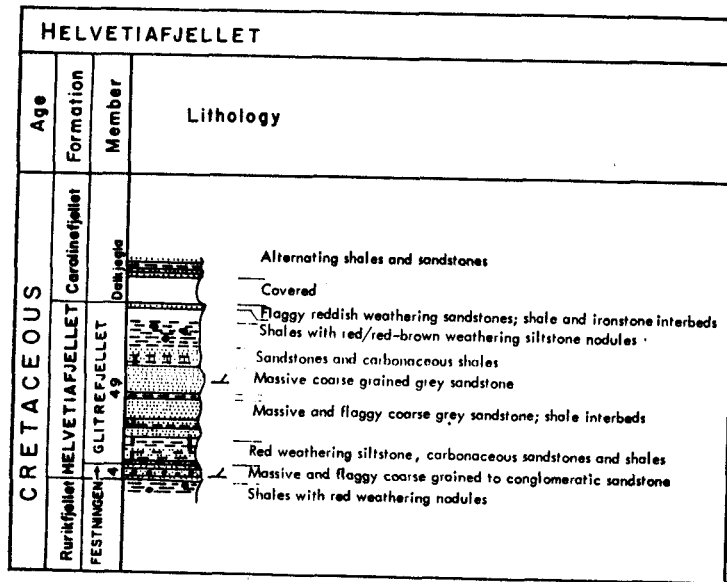
In the west coast area the Jurassic and Cretaceous rocks occur as a narrow strip in the Tertiary deformation belt. Here the Agardhfjellet and Rurikfjellet Formations especially are deformed by thrusting, having acted as décollement horizons. Consequently it is difficult to obtain reliable thicknesses for these two formations but three sections lying to the east of the main deformation (Ranfjellet, Jurakammen, and Keilhaufjellet) give thicknesses of about 250 m for the Agardhfjellet Formation and between 300 and 340 m for the Rurikfjellet Formation.

From his study of the succession in Torell Land, Rozycki (1959) proposed three divisions for the Aucella Shale interval: (in ascending order) Ingebrigtsenbukta Series, Tirolarpasset Series and Ullaberget Series. The lower two are principally shales and are separated by a conglomerate representing, according to Rozycki, the Portlandian transgression. The Ullaberget Series is characterized by arenaceous strata and the lower two also have characteristic lithologies. In the Ingebrigtsenbukta Series there is an absence of ferruginous rocks, except at the base, and the siltstone interbeds weather to a light yellow colour, whereas in the Tirolarpasset Series the siltstones are more iron-rich and weather to yellow-brown and reddish colours. In the Jurakammen section, described by Rozycki, this lithological change apparently occurs distinctly at the conglomerate. Elsewhere in Spitsbergen, as noted above, no conglomerate is found but a similar, although gradual, weathering colour change is seen in the upper part of the Agardhfjellet Formation. Thus, although a distinct lithological break is represented in the south-west of Spitsbergen (Torell Land), it is not found over the rest of Spitsbergen. The upper arenaceous Ullaberget Series of Rozycki also appears to be a local development confined to the western coastal areas as it is not found to the east over the major part of the Jurassic-Cretaceous outcrop examined. It is best developed in the area around Isfjorden (Ranfjellet, Janusfjellet,

and Festningen) but is not seen to any extent further south, except on Keilhaufjellet.

(c) *Helvetiafjellet Formation*

The Helvetiafjellet Formation (Text-fig. 3) is a sequence of continental deposits, consisting of coarse quartz clastics, thin coal seams and carbonaceous shales. It is divided into two members: a lower Festningen Sandstone Member, consisting of the massive Festningen



TEXT-FIG. 3.—Helvetiafjellet section.

sandstone; and an upper Glitrefjellet Member, consisting of the remaining strata.

The Helvetiafjellet Formation is represented over the whole of Spitsbergen and, although there is much local variation, shows an overall thickening to the south and south-east. In the Isfjorden region the lower Festningen Sandstone Member is generally thin but the Glitrefjellet Member above contains many massive sandstone units, whereas to the south and east the Festningen Member is a massive unit 20–30 m thick and the overlying strata are principally argillaceous. Current directions measured in the Helvetiafjellet area indicate a general pattern of derivation from the west and north-west.

The formation has yielded plant remains and freshwater molluscs from six horizons at the Festningen section (28a–30), including the

Elatides, *Lioplax*, *Pityophyllum*, and *Ginkgo* layers (Nathorst, 1910; Hoel and Orvin, 1937); the extensive flora was listed by Nathorst (1910).

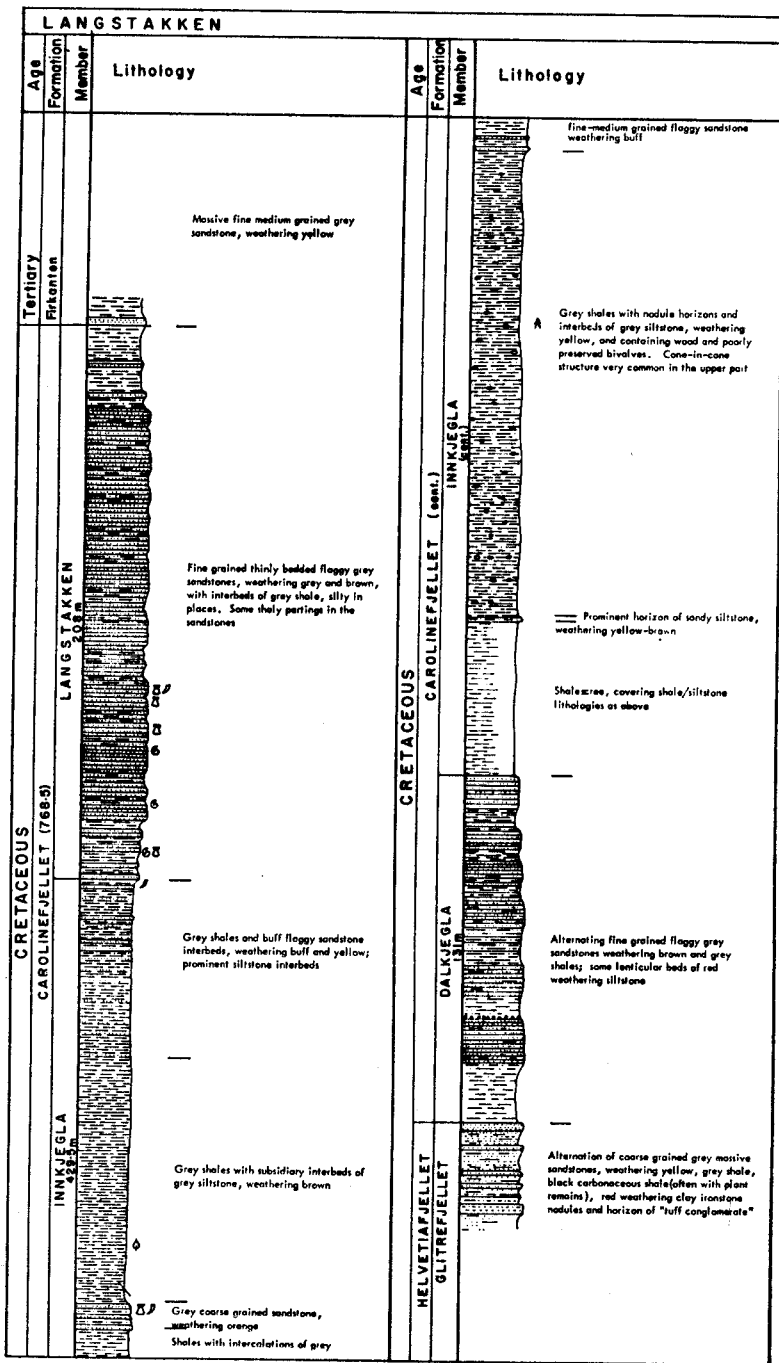
The Festningen Sandstone Member is a hard light grey sandstone, weathering grey but also yellowish and orange, very variable in grain size, from medium grained to a coarse breccia; conglomeratic beds and lenses are frequent. The pebbles in the conglomerates represent a variety of lithological types including recognizable fragments of nodules from the Agardhfjellet and Rurikfjellet Formations, chert (most probably from the Permian Kapp Starostin Formation), quartzitic sandstones of possible Middle Carboniferous age, and weathered feldspars and marble fragments suggesting derivation from the Caledonian Hecla Hoek sequence.

The Glitrefjellet Member is a complex unit of lithologies of Coal Measure type, consisting of coarse grey sandstones, cross bedded and ripple marked, with abundant plant remains and carbonaceous streaks, together with carbonaceous shales, clay ironstone horizons and thin seams of poor quality coal. Material of volcanic origin is present in several thin beds, the first being noted by Hagerman (1925) as a “tuff conglomerate”, containing rounded grains of quartz and altered isotropic fragments showing a trachytic texture of included feldspar laths. Large pieces of lithified wood are also common.

(d) *Carolinefjellet Formation*

The Carolinefjellet Formation (Text-fig. 4) marks a return to marine conditions but fossils are not common and where found are poorly preserved; worm tubes referred to the genus *Ditrupa* (and formerly recorded as *Dentalium*) are found throughout.

The top of the succession is limited by the Tertiary unconformity and thus the original development of the highest Mesozoic rocks is not known. The thickest sequence of the Carolinefjellet Formation is preserved in the area around Van Mijenfjorden and Van Keulenfjorden. In Kjellströmdalen, at the head of Van Mijenfjorden, the formation is about 750 m thick and three members are defined from this area. The lower part of the succession consists of flaggy sandstones and interbedded shales (“Lower Lamina sandstone”) followed by a thick shale sequence with nodular siltstones and occasional sandy intercalations (“Cretaceous Shale”) and the upper part is a return to interbedded sandstones and shales (“Upper Lamina sandstone”). These lithological divisions, which were first proposed by Hagerman (1925), are further described below and in the appendix. The names of the members (Dalkjegla, Innkjegla and Langstakken respectively) are from localities in Kjellströmdalen and Lundströmdalen where they are very well exposed, this being the area from which Hagerman originally described this part of the succession.



TEXT-FIG. 4.—Langstakken section.

Around Van Keulenfjorden, the total thickness is again about 750 m but here the Innkjegla Member (Cretaceous Shale) is much thinner compared with the Kjellströmdalen section and there is a thick shale development at the top of the Langstakken Member (Upper Lamina sandstone). This shale, which contains the highest Cretaceous fauna so far recorded (see below), most probably represents a highest, fourth member of the Carolinefjellet Formation, preserved only in that region; however, little field information is available and so no formal definition is given in this account.

Over the south of Spitsbergen the sequence is somewhat thinner (about 500 m) but on the few sections described (e.g. Rozycki, 1959; Birkenmajer and Narebski, 1963; Nagy, 1966; Birkenmajer, 1966) the three main divisions of the Carolinefjellet Formation are still recognized. To the north of Van Mijenfjorden the Tertiary unconformity cuts progressively down through the Carolinefjellet Formation. Around Isfjorden no Langstakken Member is preserved and there is less than one half the thickness of the Innkjegla Member, compared with its development in Kjellströmdalen, preserved beneath the Tertiary. The limited fossil evidence suggests that the junction between the Dalkjegla and Innkjegla Members may be diachronous when traced north, the shale-sandstone facies, represented by the Dalkjegla Member, having persisted for longer in the north.

In the Kjellströmdalen region, the lower Dalkjegla Sandstone Member is a cliff-forming unit, consisting of flaggy thinly bedded sandstones, fine to medium grained, grey and brown in colour, weathering grey-green, with interbedded grey shales, weathering grey.

The succeeding Innkjegla Shale Member is a sequence of grey shales, weathering grey, with interbeds and nodules of yellow weathering grey siltstone in the lower part and with intercalations of grey flaggy fine to medium grained sandstone, weathering orange and buff. These sandstones generally occur at the base of the upper third of the member and above them the shales are without interbeds or nodules of siltstone. The siltstones below the sandstone intercalations often contain wood and poorly preserved bivalves; mud flake conglomerates are very common and cone-in-cone and algal structures have also been noted.

The upper Langstakken Member is more or less identical in lithology with the Dalkjegla Member and again consists of alternating shales and flaggy thin-bedded grey sandstones, weathering grey-green. At the base of the unit there is an equal alternation of shale and sandstones in units about 10–15 m thick but higher up the sandstones are much thicker and the shales correspondingly thinner.

Birkenmajer (1966) has described the sedimentary structures of the Dalkjegla Member and concluded that the strata were deposited in a shallow-water marine environment, strongly influenced by tidal action.

The overlying Innkjegla Member suggests a more placid, although still shallow, environment but there was a return to the initial conditions for the deposition of the sandstones and shales of the Langstakken Member.

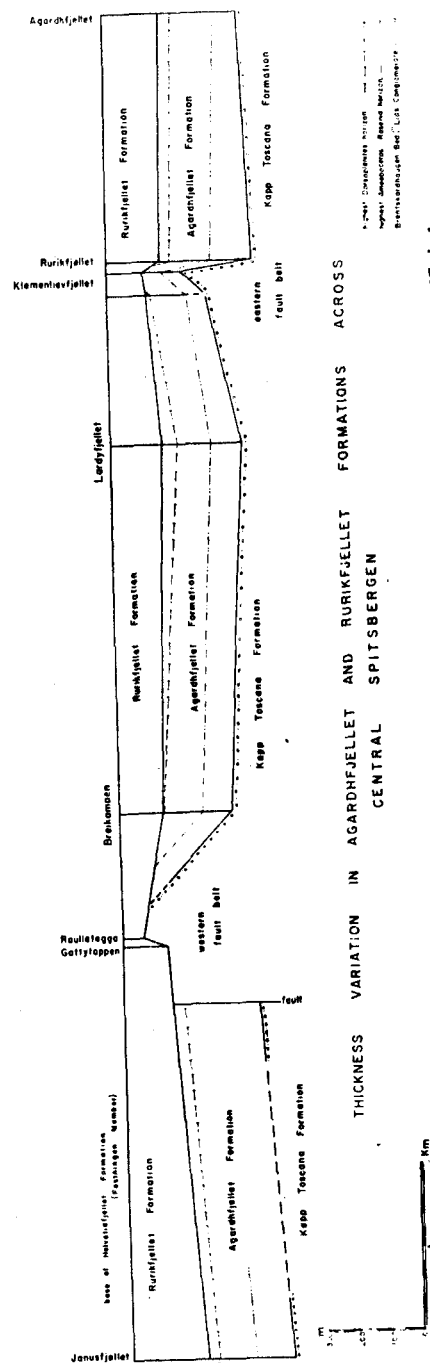
III. MESOZOIC IGNEOUS ACTIVITY

A prominent feature of the Mesozoic rocks of Spitsbergen is the extensive sheet intrusion of dolerite. The principal areas of intrusion are Hinlopenstretet, Storfjorden and Isfjorden. Around Hinlopenstretet the sills intrude Hecla Hoek, Carboniferous, Permian, and Triassic rocks while in the Storfjorden and Isfjorden regions they are confined mainly to rocks of Triassic age. A comprehensive account of the Spitsbergen dolerites is given by Tyrrell and Sandford (1933); in addition Birkenmajer and Narebski (1963) and Burov and Livshitz (1965) have discussed further the petrology of the dolerites, and the general question of their age was again considered by Orvin (1940), Harland (1961), Gayer, Gee, Harland, Miller, Spall, Wallis, and Winsnes (1966), and Parker (1966).

The bulk of the Spitsbergen dolerite intrusions are of the normal medium- to fine-grained type of Tyrrell and Sandford (1933). They are essentially plagioclase-pyroxene rocks with randomly orientated laths of labradoritic plagioclase in ophitic relationship with clinopyroxene. The degree of alteration varies but the thinner sills and the margins of the larger sills, especially when intruded into shales, are largely replaced by carbonate material forming a bleached and softened rock, termed by Tyrrell and Sandford "white trap".

The sills are known to intrude rocks ranging in age from pre-Down-tonian (Hecla Hoek) to Upper Jurassic and on the basis of this evidence, together with De Geer's report (1923) of basaltic lavas overlain by unbaked Lower Cretaceous sediments on Wilhelmøya, Tyrrell and Sandford (1933) dated the dolerites as between Jurassic and Cretaceous. The recent investigations in central Spitsbergen have resulted in confirmatory evidence for this view from two localities. At Marmierfjellet, south of Sassenfjorden, the Valanginian Rurikfjellet Formation overlies and truncates dolerite dykes intruded into the Middle Triassic Botneheia Formation (Parker, 1966) and at Agardhfjellet, on the east coast, dolerites intruded into the Lower Volgian part of the Agardhfjellet Formation are again overlain by the Rurikfjellet Formation. The few radiometric determinations made on the dolerites are not inconsistent with this age (Gayer *et al.*, 1966).

On Kong Karls Land, to the east of the main island of Spitsbergen, the dolerites and associated basalts are younger, being interbedded with and overlying continental deposits of post-Valanginian age and most probably equivalent to the Helvetiafjellet Formation (Nathorst, 1910).



TEXT-FIG. 5.—Lateral variation of the Agardhfjellet and Rurikfjellet Formations across central Spitsbergen.

The only evidence for this later activity on Spitsbergen itself is in the volcanic horizons, mentioned above, which occur in the upper part of the Helvetiafjellet Formation. The source of this material is not known, there being no evidence of any dykes or sills in the immediately underlying sediments. Derivation by weathering from the late Jurassic-early Cretaceous dolerites would be possible but the trachytic and glassy fragments found within these horizons are unlike anything seen or described from the intrusive dolerites. Also, the occurrence of the volcanic fragments in definite horizons and not disseminated throughout the rock suggests that the fragments were not derived from the weathering of a pre-existing volcanic mass but rather that contemporaneous volcanic material was added to the sediment being laid down.

IV. FAUNAL SUCCESSION (Text-fig. 6)

The lowest undoubted Jurassic fossils come from the Brentskardhaugen Bed ("Lias conglomerate") of the Kapp Toscana Formation, phosphatic nodules in this conglomerate yielding a fauna of bivalves, belemnites, and ammonites, the latter indicating a Middle and Upper Toarcian age (see Frebald, 1929 *a, c*; 1930).

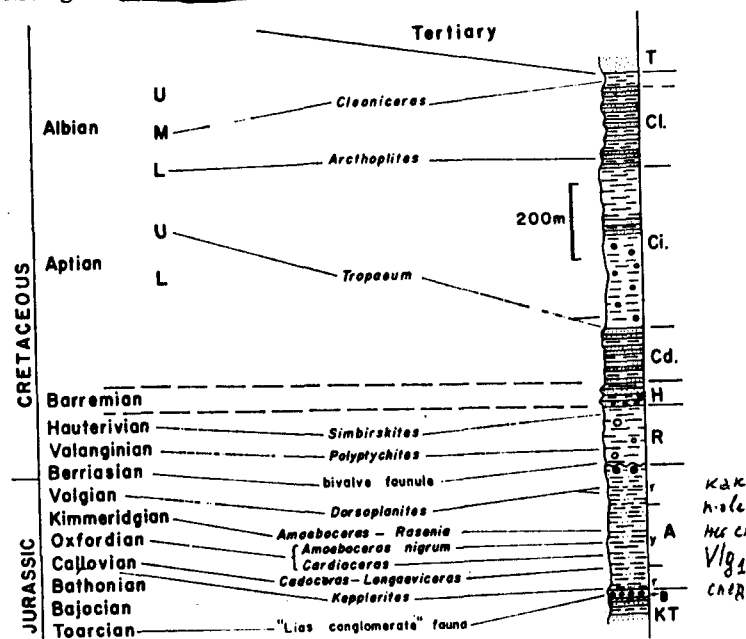
The lowest fauna of the Agardhfjellet Formation is that of *Kepplerites* and is found in some sections immediately above the Brentskardhaugen Bed. It is of uppermost Bathonian-basal Callovian age and equivalent to the *variable* or *tychonis* zone of East Greenland (Callomon, 1959). Upper Callovian is represented by a fauna of *Cadoceras*, *Longaeviceras*, and *Quenstedtoceras* recorded from Festningen by Sokolov and Bodylevsky (1931) and by Frebald and Stoll (1937) and from Torell Land by Rozycki (1959).

Lower Oxfordian had not previously been recorded from Spitsbergen but in 1961 an ammonite fauna was collected from the Agardhfjellet Formation on Keilhaufjellet, in Sørkapp Land, by J. L. Cutbill of the Cambridge expedition. These ammonites, which were found 73 m above the top of the Brentskardhaugen Bed and 76 m below the *Amoeboceras-Rasenia* fauna, have been identified as *Cardioceras* sp. and Dr. J. H. Callomon has suggested (personal communication) that they represent the *cordatum* sub-zone of the *cordatum* zone. Upper Oxfordian is represented by *Amoeboceras (Prionodoceras) nigrum* SPATH from Festningen and Bellsund, which was referred to the *bimammatum* zone by Arkell (1956).

The succeeding *Amoeboceras-Rasenia* fauna is very widely distributed and occurs principally in three fossiliferous horizons contained within some 20 m of strata, although scattered records are known from above and below. The horizons all contain a more or less identical fauna, which is probably equivalent to Spath's γ horizon from East Greenland

(1935), this now being referred to the *mutabilis* zone (J. H. Callomon, personal communication).

The *dorsoplanus* zone of the Lower Volgian is represented by abundant *Dorsoplanites* spp., this fauna being found over the whole of Spitsbergen at the top of the Agardhfjellet Formation. The highest



TEXT-FIG. 6.—Faunal succession.

- T Tertiary
 Cl Carolinefjellet Formation, Langstakken Member
 Ci Carolinefjellet Formation, Innkjegla Member
 Cd Carolinefjellet Formation, Dalkjegla Member
 H Helvetiafjellet Formation
 R Rurikfjellet Formation
 A Agardhfjellet Formation
 KT Kapp Toscana Formation
 B Kapp Toscana Formation, Brentskardhaugen Bed
 r, y red and yellow weathering divisions within the Agardhfjellet Formation (see text).

horizon, containing *Dorsoplanites*, which is the highest fossiliferous horizon in the Agardhfjellet Formation; has sometimes been taken as the Jurassic-Cretaceous boundary. However, this horizon is overlain by strata lithologically identical to those below, although unfossiliferous, up to the base of the Rurikfjellet Formation, usually 20 m above, where the distinct lithological break occurs. Above the break the first fossiliferous horizon at Festningen contains a Ryazanian bivalve fauna and

thus the lithological junction between the Agardhfjellet and Rurikfjellet Formations appears to represent an Upper Volgian non sequence and can be taken as the Jurassic-Cretaceous boundary.

The records of the Berriasian ammonite *Subcraspedites* are now largely discounted (see Spath, 1952) and the main ammonite fauna in the Rurikfjellet Formation is that of *Polyptychites*, *Dichotomites*, and possibly *Thorsteinssonoceras*, of Valanginian age (Frebald, 1928, 1929 *b*; Sokolov and Bodylevsky, 1931; Frebold and Stoll, 1937; Jeletzky, 1965). However, recent finds of the ammonites *Simbirskites* and *Speetonoceras* from the top of the Rurikfjellet Formation (Pchelina, 1965 *a, b*; and in the Cambridge collections) have extended the formation's stratigraphical range upwards into the Upper Hauterivian.

The non-marine Helvetiafjellet Formation has yielded plant remains and fresh-water molluscs from six horizons at Festningen (Nathorst, 1910; Hoel and Orvin, 1937). These beds can only be dated indirectly as Barremian from the age of the fossiliferous marine strata above and below, although Maync (1949) has suggested an Aptian age for the flora.

In the Carolinefjellet Formation three main ammonite faunas appear to be represented. These are of *Tropaeum arcticum* STOLLEY of Upper Aptian age (Frebald and Stoll, 1937), *Archthoplites jachromensis* NIKITIN of probable Lower Albian age (Donovan, 1957) and *Cleoniceras* of Middle Albian age (Pchelina, 1965 *b*). In the Kjellströmdalen region the lower two are found in the lower part of the Innkjegla Member of the Carolinefjellet Formation and at the base of the Langstakken Member, while the upper is as yet only recorded from the "Upper Shale Member" in the Van Keulenfjorden region.

V. ACKNOWLEDGMENTS

This paper results from field work carried out by the Cambridge Spitsbergen Expeditions over the years 1961-1965 and I thank Mr W. B. Harland for organization of the expeditions and for help and advice during these studies. Funds for the expeditions were made available to Mr Harland by the Department of Scientific and Industrial Research (later the Science Research Council) as part of his investigation into the stratigraphy and structure of Spitsbergen. All those expedition members whose work and discussion have contributed to this paper are mentioned in the various expedition reports (Harland, 1962, 1963, 1964, 1965; Harland and Wallis, 1966). I also thank Shell International Petroleum Company Limited for the award of a Research Studentship; Dr J. H. Callomon for advice on ammonite zonation; Mr H. Major for discussion and information, as mentioned previously; and Miss A. B. Reynolds for the final drafting of the figures.

VI. APPENDIX

BRENTSKARDHAUGEN BED: upper division of the De Geerdalen Member

of the Kapp Toscana Formation (Buchan *et al.*, 1965); name from Brentskardhaugen, Adventdalen, Nordenskiöld Land. Type section: Adventdalen, river gorge exposure 1.5 km south-west of 530 m height on Brentskardhaugen; thickness of unit in type section 1.5 m. Dominant lithology: conglomeratic sandstone with phosphatic nodules; fossils include *Harpoceras*, *Dactylioceras*, *Catacoeloceras* and *Pseudolioceras*; age—Middle and Upper Toarcian.

ADVENTDALEN GROUP: consists of the Agardhfjellet, Rurikfjellet, Helvetiafjellet and Carolinefjellet Formations.

JANUSFJELLET SUB-GROUP: consists of the Agardhfjellet and Rurikfjellet Formations. Name from Janusfjellet, Nordenskiöld Land (H. Major, *in lit.*).

AGARDHFJELLET FORMATION: name from Agardhfjellet, Sabine Land. Type section: Agardhfjellet (Text-fig. 2); thickness of unit in type section 241.5 m; also illustrated by Hoel and Orvin (1937) and by Hagerman (1925). Dominant lithology: shale with siltstone interbeds; fossils include *Buchia* throughout and horizons containing *Kepplerites*, *Cadoceras* and *Longaeviceras*, *Cardioceras*, *Amoeboceras* and *Rasenia*, and *Dorsoplanites*; age—uppermost Bathonian to Lower Volgian.

RURIKFJELLET FORMATION: name from Rurikfjellet, Heer Land. Type section: Agardhfjellet (Text-fig. 2); thickness of unit in type section 176 m; also illustrated by Hoel and Orvin (1937) and by Hagerman (1925). Dominant lithology: shale with clay ironstone and siltstone nodules; fossils include *Buchia* and horizons containing *Polyptychites*, *Dichotomites* and *Simbirskites*; age—Valanginian to Hauterivian.

HELVETIAFJELLET FORMATION: divided into a lower Festningen Sandstone Member and an upper Glitrefjellet Member; name from Helvetiafjellet, Nordenskiöld Land (H. Major, *in lit.*). Type section: Helvetiafjellet (Text-fig. 3); thickness of unit in type section 53 m; also illustrated by Hoel and Orvin (1937) and by Hagerman (1925). Dominant lithology: coarse sandstones with carbonaceous shales and thin coal seams; cliff forming in lower part; fossils include fresh water molluscs and an extensive flora; age—Barremian.

FESTNINGEN SANDSTONE MEMBER: name from Festningen, Nordenskiöld Land (Nathorst, 1913; Hagerman, 1925). Type section: Festningen (Hoel and Orvin, 1937); thickness of unit in type section 29.5 m; also illustrated in Text-fig. 3 and by Hagerman (1925). Dominant lithology: massive quartzitic sandstone.

GLITREFJELLET MEMBER: name from Glitrefjellet, Nordenskiöld Land. Type section: Glitrefjellet; thickness of unit in type section 69 m; illustrated in Text-fig. 3 and by Hoel and Orvin (1937) and by Hagerman (1925).

CAROLINEFJELLET FORMATION: divided into a lower Dalkjegla Sandstone Member, a middle Innkjegla Shale Member, and an upper Langstakken Sandstone Member; a further upper shale member is not formally defined here; name from Carolinefjellet, Nordenskiöld Land (H. Major, *in lit.*). Type section: Carolinefjellet; thickness of unit in type section 270 m; illustrated in Text-fig. 4 and by Hoel and Orvin (1937) and by Hagerman (1925). Fossils sparse but include *Ditrupea* throughout and horizons containing *Tropaeum* and *Archthoplites*; age—Aptian and Albian.

DALKJEGLA SANDSTONE MEMBER: name from Dalkjegla, Nordenskiöld Land. Type section: Langstakken, Nordenskiöld Land (Text-fig. 4); thickness of unit in type section 131 m; also illustrated by Hoel and Orvin (1937) and by Hagerman (1925). Dominant lithology: alternating sandstones and shales; cliff forming.

INNKJEGLA SHALE MEMBER: name from Innkjegla, Nordenskiöld Land. Type section: Langstakken, Nordenskiöld Land (Text-fig. 4); thickness of unit in type section 429.5 m; also illustrated by Hoel and Orvin (1937) and by Hagerman (1925). Dominant lithology: shale with siltstone interbeds, nodules and sandstone intercalations.

LANGSTAKKEN SANDSTONE MEMBER: name from Langstakken, Nordenskiöld Land. Type section: Langstakken (Text-fig. 4); thickness of unit in

type section 208 m; also illustrated by Hagerman (1925). Dominant lithology: alternating sandstones and shales; cliff forming.

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