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The Jurassic-Cretaceous boundary in Jameson Land, East Greenland

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An almost complete sequence of Upper Jurassic-lowermost Cretaceous shales and sandstones occurs in Jameson Land. In latest Volgian or earliest Ryazanian time the succession was folded into a shallow syncline. The synclinal trough was transgressed by the sea from the south in Ryazanian time and filled with clastic sediments. Successively younger rocks rest with tectonic overstep on the gently folded sequence. Ammonites characteristic of the *Chetaites chetae* Zone (uppermost Volgian) occur 200 metres below the unconformity, whereas the oldest fossils found in the filling of the synclinal trough are characteristic of the *Surites spasskensis* Zone (Middle Ryazanian). Presumably the Jurassic-Cretaceous boundary is situated in the upper part of the folded sequence and not at the unconformity.

In Jameson-Land ist eine fast vollständige Folge von Ton- und Sandsteinen des Oberjura und der Unterkreide vorhanden. Zur Zeit der jüngsten Wolga- oder der frühesten Ryazan-Stufe wurde die Schichtfolge zu einer flachen Synkline gefaltet. Dieser Synklinal-Trog wurde im Ryazan vom Süden aus vom Meer erobert und mit klastischen Sedimenten angefüllt. Jüngere Schichten liegen mit "tectonic overstep" auf der schwach gefalteten Abfolge. Für die Zone des *Chetaites chetae* (hohe Wolga-Stufe) typische Ammoniten sind 200 m unterhalb der Diskordanz beobachtet worden. Demgegenüber gehören die ältesten in der Synklinalfüllung auftretenden Fossilien in die Zone des *Surites spasskensis* (Mittel-Ryazan). Vermutlich liegt die Jura-Kreide-Grenze im höheren Abschnitt der gefalteten Folge und nicht an der Diskordanz.

La Terre de Jameson offre une séquence quasi complète de schistes et de grès d'âge jurassique supérieur à crétacé essentiellement inférieur. Au Volgien terminal ou au Ryazanien basal, ces couches furent plissées dans un synclinal peu profond. La dépression synclinale fut recouverte au Ryazanien par une transgression marine en provenance du Sud et fut comblée par des dépôts clastiques. Des sédiments de plus en plus récents reposent en discontinuité tectonique sur cette séquence modérément plissée. Des Ammonites caractéristiques de la zone à *Chetaites chetae* (Volgien terminal) ont été récoltées 200 mètres environ sous la discordance, alors que les fossiles les plus anciens recueillis dans le remplissage de la dépression synclinale caractérisent la zone à *Surites spasskensis* (Ryazanien moyen). La limite Jurassique-Crétacé se situe probablement à la partie supérieure de la séquence plissée et non au niveau de la discordance.

1. Introduction

Sediments of Lower and Middle Jurassic age exposed along the southeastern coast of Jameson Land have been known for a long time (see Rosenkrantz 1934 and Callomon 1961). However, the Upper Oxfordian and ?Lower Kimmeridgian age of the immediately overlying beds was known only from a few ammonites described by Spath (1935 pp. 35, 78; pl. 13 fig. 5; pl. 15 fig. 3) while Lower Cretaceous sediments exposed in a small area on the south coast of Jameson Land were described by Aldinger in 1935. The faunas collected by Aldinger were described by Spath (1947).

Until 1968 the interior of southern Jameson Land was, however, completely unknown. In the years from 1968 to 1971 the whole of Jameson Land was mapped under the auspices of the Geological Survey of Greenland. In 1970 and 1971 the author mapped the Upper Jurassic and Lower Cretaceous sediments of southeastern Jameson Land (Surlyk and Birkelund 1972). A surprisingly complete Upper Jurassic sequence was found and the Lower Cretaceous succession established by Aldinger (1935) was completely revised.

Surlyk *et al.* (in press) established a formal lithostratigraphy for the whole sequence comprising in total 7 formations spanning in time from the Rhaeto-Liassic Kap Stewart Formation to the Ryazanian Hesteelv Formation. A review of the stratigraphical scheme is given by Surlyk and Birkelund (1972).

2. Geological setting

Throughout Jurassic time the present Jameson Land was covered by the sea, and marine shales and sandstones were deposited with a dominance of sandy facies towards the north and shaly facies towards the south. The subsidence was greatest towards the north where a very complete sequence is found (Surlyk and Birkelund 1972, fig. 9) whereas in southern Jameson Land the sequence includes several major gaps. The general dip of the beds is towards the south-southwest and consequently the youngest sediments are found along the southern and southwestern coast of Jameson Land. In Upper Jurassic time the following formations were deposited: the sandy Olympen Formation of Upper Callovian-Middle Oxfordian age (found only in northern Jameson Land), the shaly Hareelv Formation of Upper Oxfordian-Middle Kimmeridgian age (southernmost occurrences probably include younger horizons) and the sandy Raukelv Formation of Middle Kimmeridgian-Upper Volgian (lowermost Ryazanian ?) age. The Ryazanian Hesteelv Formation overlies the Raukelv Formation and, to the southeast and south, the Hareelv Formation with angular unconformity.

The boundary relations of the Hareelv, Raukelv and Hesteelv Formations are rather complicated and of great importance for the understanding of the Jurassic-Cretaceous boundary in Jameson Land. The formations are therefore described in some detail here.

The Danish lithostratigraphical terms as well as some topographical names are translated below to ease reading of the paper. According to normal stratigraphical practice the names should, however, be used in their Danish form.

Ø = island
Elv = river
Fjeld = mountain
Bjerg = mountain

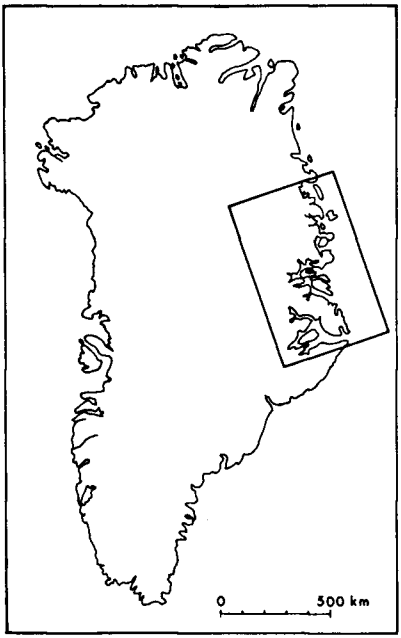

Fig. 1. Map of Greenland showing the position of the area covered by Fig. 2.

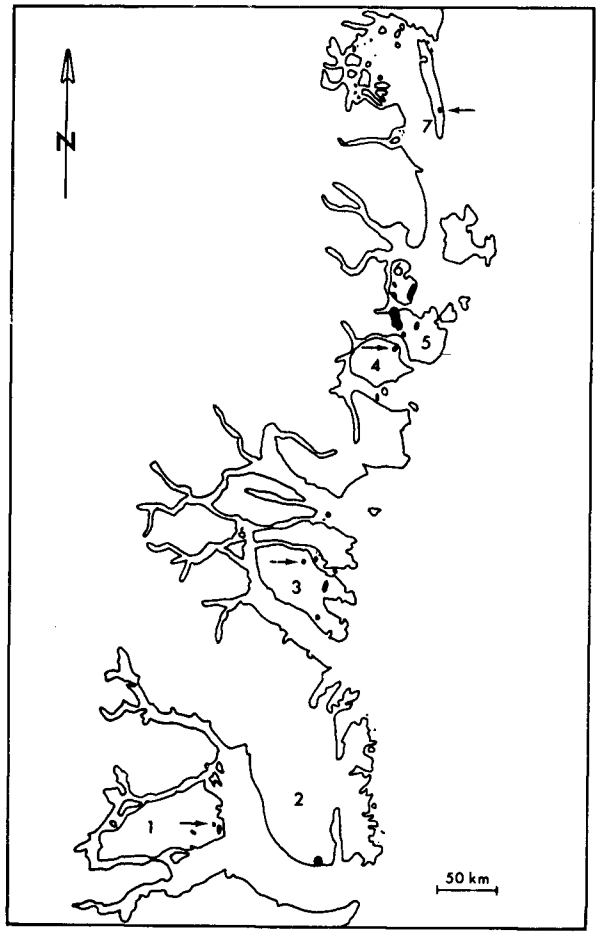

Fig. 2. Map of central East Greenland. Distribution of Ryazanian and Valanginian rocks shown in black. Arrows indicate the smaller outcrops. 1: Milne Land. 2: Jameson Land. 3: Traill Ø. 4: Clavering Ø. 5: Wollaston Forland. 6: Kuhn Ø. 7: Store Koldewey Ø. Based on Donovan (1957 fig. 12), Håkansson *et al.* (1971) and the author's observations.

Hareëlv Formation = Hare River Formation
Raukelv Formation = Rauk River Formation ("rauk" is Scandinavian for a characteristic form of exposure of rocks).
Hesteëlv Formation = Horse River Formation
Crinoid Bjerg Member = Crinoid Mountain Member.
Muslingeëlv Member = Mussel River Member

2a. The Hareelv Formation

The formation was established by Surlyk *et al.* (in press; see also Surlyk and Birkelund 1972). The formation is about 200 metres thick and overlies the Middle Jurassic Vardekløft Formation (Callomon 1961; Surlyk *et al.*, in press). It is composed of black and grey shales with large, irregular lenses and layers of yellow

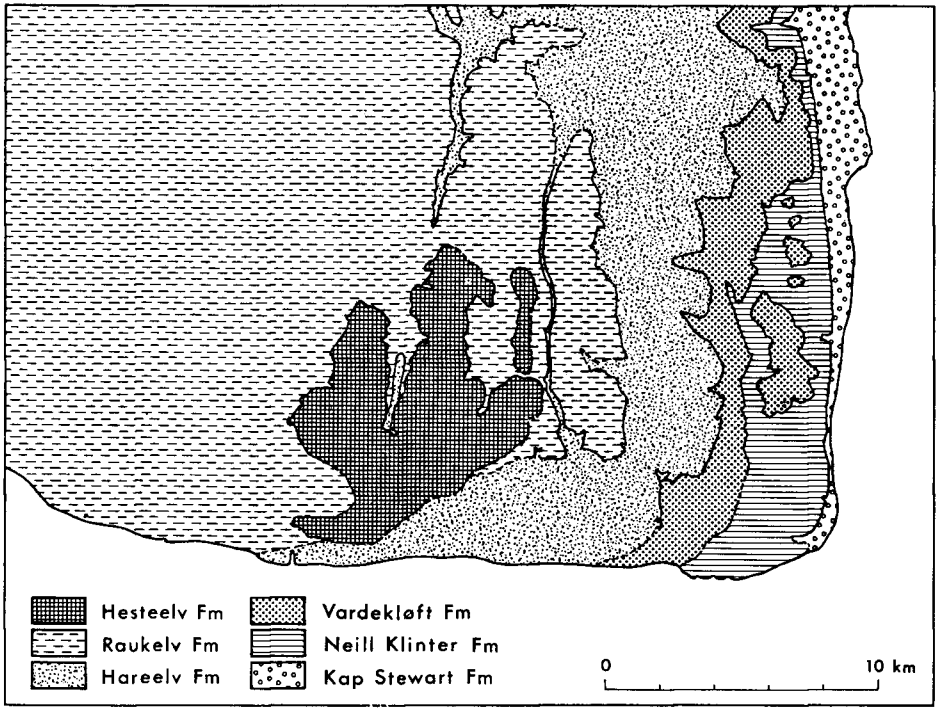

Fig. 3. Geological map of south Jameson Land. Stippled line between formations indicates that the boundary is inferred. The limits of the northeastern exposure of the Hesteelv Formation are rather uncertain as several dolerite sills and dykes disturb the bedding here. The Kap Stewart Formation is of Rhaetic-Liassic age, the Neill Klinter Formation of Pliensbachian-Toarcian, the Vardekløft Formation of Bajocian?-Middle Callovian, the Hareelv Formation of Upper Oxfordian-Lower (Middle?) Volgian, the Raukelv Formation of Middle-Upper Volgian (lowermost Ryazanian?), and the Hesteelv Formation of Ryazanian age.

sandstone. The shales are micaceous and often contain thin beds of loose, light sandstone and occasional calcareous or ferruginous concretions. Normally the shales are fine-grained but at some horizons sandier, lighter grey shales occur. The bedding planes are sometimes covered with a thin layer of mica. The shales often shows intense bioturbation by deposit feeding animals, but well-defined trace-fossils are rare except for occasional meandering trails. The shales are marine as they contain ammonites, bivalves and scattered inarticulate brachiopods throughout.

The boundaries between the shales and the sandstones are always knife-sharp. The sandstone lenses are of a very irregular shape. They may attain a length of several hundred metres and a thickness of 100 metres. The sandstones are well-sorted, medium-grained and rich in mica and sometimes in glauconite. Large, angular pieces of black shale are often incorporated in the basal parts of the sandstones. The lateral contact between the sandstone and the shale is normally curved in cross-section and ribbed longitudinally, and flame structures are developed on the surface of the sandstone body.

The shales are penetrated by numerous yellow sandstone dykes and sills. The sills are often transgressive and may continue into dykes. The thickness of the dykes varies from a few millimetres to about 20 centimetres. The shales only rarely show

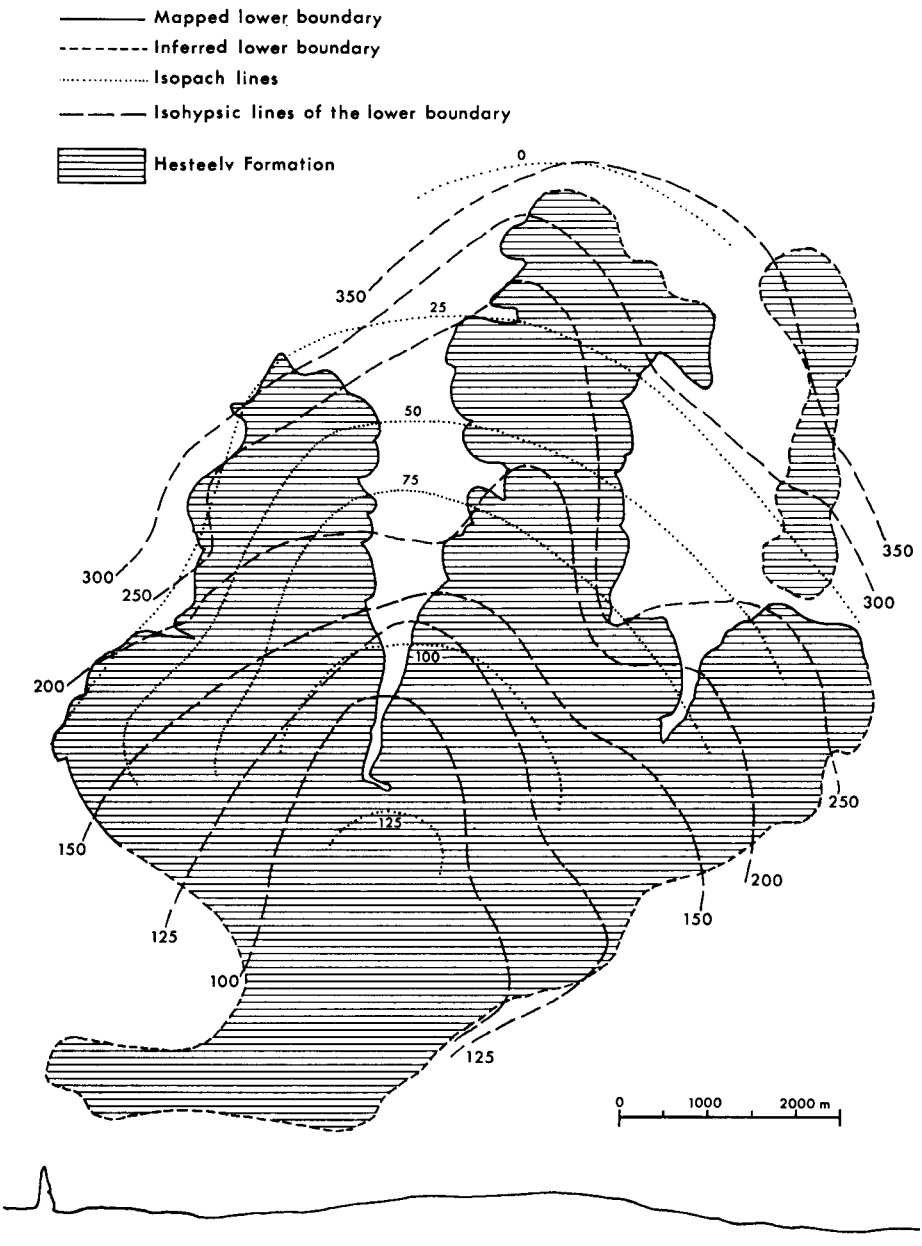

Fig. 4. Isopach map of the Hesteelv Formation with structure contour map of the lower boundary of the formation superimposed. All numbers are in metres.

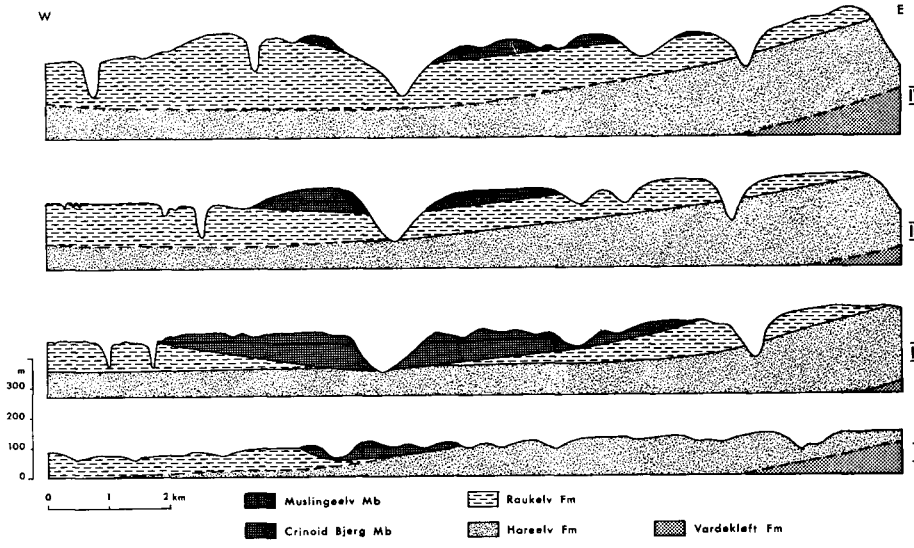

Fig. 5. West-east sections through the Hesteelv Formation in south Jameson Land. Positions of sections I-IV are indicated on Fig. 6. The Hesteelv Formation is divided into a lower Crinoid Bjerg Member and an upper Muslingeelv Member. The two members have the same shading but are separated by a heavy line on the sections.

disturbance at the contact with the dykes. The density of dykes and sills is greatest in the vicinity of the large sandstone lenses.

Inorganic sedimentary structures and trace-fossils are very rare in the massive sandstone. However, the tops of many of these almost structureless sandstone lenses often show trough cross-bedding.

Silicified wood and charcoal are very common in the sandstones and often form the cores of concretions in the shales. In some of the harder glauconitic sandstone lenses rare ammonites and small bivalves (e.g. smooth and costate pectinids) are found, but normally the massive sandstones are completely free of fossils.

The depositional environment of this formation would appear to have been of a rather unusual kind. The rocks are marine throughout and there is no evidence to indicate place of deposition in relation to the coast. The large sandstone lenses have the same shape as normal channel sands. They were, however, deposited under marine conditions and at a time when the shales were at least relatively hardened—judging from the angular shape of the shaly pieces incorporated at the bottom of many of the "channel sands". These features, combined with the existence of numerous sandstone dykes and sills of undoubtedly intrusive nature, suggest the following depositional regime. Along a coast a sequence of clastic sediments was deposited with near-shore sands gradually passing into black mud off-shore. Triggered by some unknown mechanism, presumably earthquakes, the sand moved seaward as slumping masses and eroded deep channels in the more-or-less hardened fine-grained deposits.

Deposition of the sand-flows was followed by intrusion of sandstone dykes and sills and the sand settled with expulsion of water. By erosion and rotation of the

lateral parts of the sand bodies the large-scale longitudinal side-ridges were developed and flame structures were formed. The rotational nature of these large ridges can be seen from their shape and their repeated occurrence, one above the other, and from the orientation of the mica flakes. The cross-bedding found at the top of the "channels sands" was probably formed by reworking of the exposed part of the sand bodies after the sand had settled in the eroded channels.

The Hareelv Formation is found in the southern half of Jameson Land (Fig. 3; see also map in Surlyk and Birkelund 1972). Only in the southwestern part is it covered by younger deposits.

In the basal shales of the formation a rich fauna of Upper Oxfordian ammonites is found (*Decipia* and *Amoeboceras*) (Callomon 1961; Surlyk *et al.*, in press). Higher parts have yielded amoeboceratids, *Rasenia* and ?*Aulacostephanus,* indicating the presence of the whole of the Lower Kimmeridgian (Surlyk *et al.*, in press). Sparse finds of ?*Subdichotomoceras* above may indicate a Middle Kimmeridgian age for the upper part of the sequence (Surlyk *et al.*, in press). Only a very few badly preserved ammonites have been collected in southernmost Jameson Land, where the formation is directly overlain by the Ryazanian Hesteelv Formation, and the extent of the hiatus cannot be established with certainty.

2b. The Raukelv Formation

Upwards the shales and "channel sands" of the Hareelv Formation pass more-or-less gradually into a sequence of very coarse, light-coloured sandstones, about 300 metres thick, designated as the Raukelv Formation by Surlyk *et al.* (in press).

Aldinger (1935) described a sequence of large-scale cross-bedded sandstones from the area around the river Raukelv as the top member of the Lower Cretaceous sediments (i.e. what is now the Hesteelv Formation). These sandstones are now known to underlie the Hesteelv Formation and constitute the top beds of the Raukelv Formation. They are of Upper Volgian-?very early Ryazanian age and dip beneath the sediments of the Hesteelv Formation (Fig. 5).

The Raukelv Formation consists of cyclically alternating, massive or large-scale cross-bedded sandstone units and shaly siltstones. The sandstone horizons vary in thickness from 10–50 metres and form conspicuous marker beds.

The sandstones are white or yellow, but commonly weather to brown or dark-red colours. They are composed almost solely of quartz grains, and in many of the massive and cross-bedded layers glauconite plays an important role. The degree of sorting is very poor, the grain-size is mainly in the coarse sand or gravel fraction. Large quartz pebbles are very common.

The massive beds are sometimes divided into large irregular sheets with a thickness of 0·1–0·3 metres. These sheets may represent very flat cross-bedding. In the basal part of the formation platy, red-brown sandstone with parting lineation or small-scale linguoid ripples often occurs.

Palaeocurrent directions in the cross-bedded sandstones are very uniform, often varying within only a few degrees in an area of several square kilometres (Fig. 9). The main transport direction is towards the southeast. Viewed from the air the foresets can be seen to form large fans (Fig. 9).

The foresets are tangential or, more rarely, sigmoidal (Fig. 8). They normally show graded bedding with gravel at the base passing within a few centimetres into medium-grained sand. The form sets are tabular, commonly with erosional surfaces, and vary in thickness from 0·3–10 metres.

A characteristic cyclicity is often observed. The modal cyclothem commences

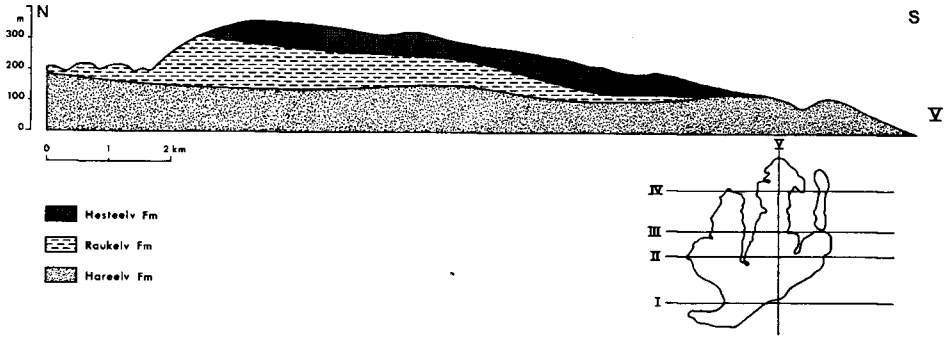

Fig. 6. North-south section through the Hesteelv Formation in south Jameson Land. Inset a map of the distribution of the formation showing the position of the section and the 4 sections on Fig. 5.

with one or two large-scale cross-stratified sandstones each 5 to 10 metres thick. The top surface is erosional, penetrated by numerous vertical burrows and covered with a thin ferruginous crust. This is followed by a massive, poorly-sorted sand- or gravelstone, 5–10 metres thick, sometimes with ammonites, bivalves and crinoids, and again with an erosional, burrowed, iron-impregnated top surface. It is overlain by silty or fine-sandy intensely bioturbated shale with rare ammonites and bivalves.

Numerous variations on this theme are seen, but the main features—cross-bedded sandstone, followed by massive sandstone, followed by shale—play a very important role throughout the formation.

Many of the sandstones contain brown ferruginous concretions, which vary in size from 1 centimetre to 1 metre and in shape from perfectly ball-shaped to completely irregular masses.

Petrified tree-trunks with a diameter up to 0·5 metre are common in some horizons. In the massive, coarse sandstones and gravelstones, ammonites, bivalves, and crinoids are often present in great numbers. Pavements of large, smooth pectinids with the convex side up or shell-beds with no preferred orientation of the fossils are seen at several places. In the cross-bedded sandstones only very few body-fossils (rare ammonites and oysters) have been observed, but vertical burrows such as mantled U-tubes and *Monocraterion* are characteristic of the sediment.

Thin horizons of brownish, silty or sandy shale occur between the sandstones. They normally weather out as large, concretionary, ellipsoidal bodies. The shales contain rare ammonites and bivalves and occasionally large plant fragments. They are intensely bioturbated and contain a wealth of trace-fossils.

In the western part of the area one of the shale horizons thickens considerably (to about 70 metres) and assumes a grey-black colour.

The Raukelv Formation is found in the southernmost part of Jameson Land and forms extensive plateaus. Only in the extreme southernmost part of the area is the formation covered by the Ryazanian Hesteelv Formation.

In the basal part of the formation perisphinctids of ?Middle Kimmeridgian age are found. Higher beds contain successive faunas of *Pavlovia, Dorsoplanites, Epipallasiceras* and *Laugeites* of Upper Kimmeridgian (Middle Volgian) age and *Subcraspedites* and *Chetaites* of Upper Volgian age (Surlyk *et al.* in press).

The specimens of *Chetaites* are found several hundred metres below the unconformity between the Raukelv Formation and the Ryazanian Hesteelv Formation. Between the *Chetaites* horizon and the unconformity a few hitherto undetermined

ammonites have been found (one was described but not figured by Spath 1947, pp. 51–52).

Stratigraphical sequences of the ammonites and therefore the biostratigraphical zonation of the Raukelv Formation are not yet perfectly understood. All the fossils were collected bed-by-bed in measured sections with exact altitude and localization indicated. However, owing to the low topography and especially to the nature of the rocks—thick massive or large-scale cross-bedded sandstones—it is often very difficult to combine and correlate the individual sections with certainty. Furthermore, the upper part of the Raukelv Formation possibly includes several minor unconformities. Thus a flexure trending east-west with a southerly dip seems to have been formed before the deposition of the upper 200 metres or so of the Raukelv Formation i.e., immediately below the layers with ammonites close to *Chetaites chetae*. The supposed flexure runs through the northernmost exposure of the Hesteelv Formation (Fig. 3). Another flexure is seen in the section on Figure 6, and is also revealed in the changing dip of the axis of the synclinal trough in which the Hesteelv Formation was deposited (Fig. 4).

These structures are difficult to see on the ground and are mainly interpreted from aerial photographs. Recent erosion often follows the giant foresets of the large-scale cross-beds resulting in a kind of exposure which, when viewed from a distance, gives a perfect illusion of a monoclinal fold.

Contrary to the pessimistic prophecies of Donovan (1957 p. 58)—"Further work in the area is desirable, but might not be very rewarding"—it must be stated that the whole interior of southern Jameson Land from the northernmost occurrence of the Raukelv Formation and southwards (Fig. 3) is extremely well exposed. More detailed field work in the future will doubtless yield much supplementary information on the succession of the critical ammonite faunas of the Jurassic-Cretaceous boundary.

2c. The Hesteelv Formation

In late Volgian or very early Ryazanian time the Jurassic sequence was folded into a shallow syncline with an axis dipping a few degrees towards the south. After a short break in sedimentation the synclinal trough was transgressed from the south in Ryazanian time. The whole succession deposited in the synclinal trough comprises the Hesteelv Formation, established by Surlyk *et al.* (in press).

In the southern part of the trough the formation is developed as uniform black shales. Upwards and towards the margins the shales become more sandy and are characteristically developed as light-brownish, irregularly silty and fine-sandy shales. The lower dark shales are almost totally free of carbonate. Upwards the carbonate content in the shales increases to about 55%. The degree of sorting is medium to poor.

The lower half of the shaly sequence (designated as the Crinoid Bjerg Member by Surlyk *et al.*, in press) weathers to a greyish colour, whereas the upper half weathers light-yellow-brown. Thin yellow layers of loose sandstone occur. The shales are very micaceous and often contain numerous small pieces of reworked dark-grey shale. They weather out into huge ellipsoidal concretionary bodies and contain light-brown calcareous concretions sometimes with barytes-filled cracks. The bedding-planes are often covered with finely comminuted plant debris. Large pieces of wood occur at many horizons and some have been bored by bivalves. The shales often show intense bioturbation and well-defined trace-fossils are found at many levels. The shales grade upwards into grey-brown, fine-grained sandstones with parting lineation or linguoid ripples.

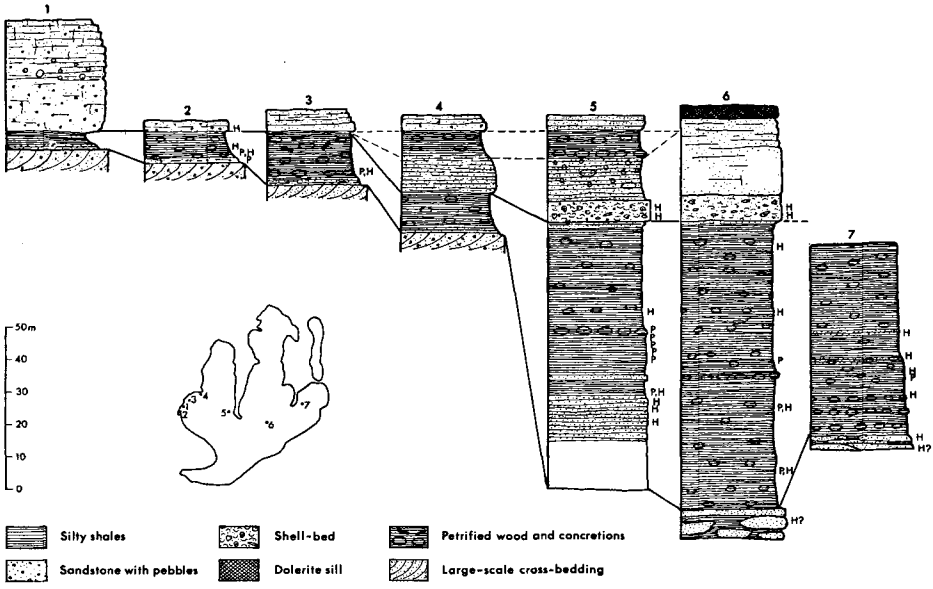

Fig. 7. Sections and litho-units of the Ryazanian Hesteelv Formation. The lower solid line indicates the boundary between the Raukelv Formation—or in sections 5, 6 and 7 the Hareelv Formation—and the Crinoid Bjerg Member. The upper solid line indicates the boundary between the Crinoid Bjerg Member and the Muslingeelv Member. The stippled lines enclose the upper shaly unit of the Muslingeelv Member. The positions of the sections are shown on the inset map. H = *Hectoroceras kochi*. P = *Praetollia maynci*. H? in section 6 indicates that the determination is doubtful. H? in section 7 indicates that the specimen was not collected *in situ*.

Ammonites are common in most horizons but are normally flattened or crushed. However, in the calcareous horizons their preservation is better and they are here accompanied by bivalves which are often found preserved in life position.

The member is found in the major part of the distributional area of the formation, but has wedged out at the northern and easternmost localities (Fig. 5).

The shaly Crinoid Bjerg Member is overlain with a rather sharp contact by a characteristic, sandy shell-bed, which can be traced as a marker horizon in the central part of the area. The matrix between the shells is a hard, grey calcareous sandstone or gravelstone often containing larger quartz pebbles. The fossil assemblage is dominated by large, thick-shelled bivalves with subordinate ammonites and belemnites (Fig. 10). The bivalves are in most cases found with the shell preserved. At some localities (e.g. the type locality of the formation; section 6 on Fig. 7) the shells are mainly orientated parallel with the bedding. The number of fossils decreases upwards but this is to some extent merely a matter of preservation, for a clear transition can be seen from a fauna with shells preserved, through beds with fossils preserved as casts, to beds where the fossils are only recognisable as thin curved, white lines. The shell-bed is followed by massive or cross-bedded light sandstones and in the central part of the area by a thin sequence of brownish, micaceous shale of the same type as the shales characteristic of the Crinoid Bjerg Member (sections 4 and 5 on Fig. 7). These shales are overlain by massive or large-scale cross-bedded sandstones with vertical burrows. The surfaces of the sets are erosional, penetrated by burrows, corroded and covered by a thin ferruginous crust. Perfectly spherical concretions varying in size from a few millimetres to 0·5 metre are very

common in many of the sandy horizons. The whole sequence from the shell-bed and upwards comprises the Muslingeelv Member (designated by Surlyk *et al.*, in press).

The Crinoid Bjerg Member contains the ammonites *Hectoroceras kochi* Spath and *Praetollia maynci* Spath. In the shell-bed *H. kochi* is the only ammonite found with some rare exceptions. In the highest sandstones *H. kochi* is found together with a few specimens of *Surites*, probably close to *S. poreckoensis* Sazonov (see Surlyk *et al.*, in press, pl. 4, fig. 4). Consequently the whole fauna is of Lower Cretaceous, Ryazanian age.

In an isolated occurrence on the summit of the tectonically disturbed J. P. Kochs Fjeld a few ammonites of presumed Valanginian age were found (see Surlyk *et al.*, in press, pl. 4, fig. 5).

2d. Dating the unconformity

About 200 metres below the unconformity separating the Raukelv Formation from the Hesteelv Formation there occurs a rich assemblage of ammonites which includes forms close to *Chetaites chetae* Shulgina (Surlyk *et al.*, in press, pl. 3, figs 3, 4). Approximately 100 metres higher in the succession several ammonites were found which apparently belong to a new, undescribed genus. From about the same level but further westwards an assemblage of *Buchia* and ammonites was collected. One of the ammonite species might well be a predecessor of *Hectoroceras*. It is more sharply keeled along the venter and the general rib pattern is the same but the ribs are straighter than those of *Hectoroceras*. It is associated with several smaller ammonites some of which may be related to *Praetollia*. The general character of the assemblage is thus suggestive of a Ryazanian age.

Many badly preserved ammonites occur in the top beds of the Raukelv Formation. One collected by Säve-Söderbergh in 1933 was described but not figured by Spath (1947 pp. 51–52). Spath was much confused by the ammonite as he thought it came from the top beds of the Ryazanian Hesteelv Formation. We now know that this part of the sequence in fact constitutes the top beds of the underlying Raukelv Formation (see p. 87). I have collected many specimens of badly preserved ammonites from the same locality. A reliable generic determination is not possible, but they may be related to *Praetollia*.

Hectoroceras kochi occurs together with *Praetollia maynci* and probably another species of *Praetollia* in the basal beds of the Hesteelv Formation immediately above the unconformity. After this paper was submitted for publication the author's collections were examined by Dr. J. A. Jeletzky. It became apparent that the latter species of *Praetollia* (Pl. 1c) is conspecific with or very closely related to *Praetollia antiqua* Jeletzky (described as a new species by Dr. Jeletzky in this volume). Furthermore a single specimen (only living chamber preserved) of "*Subcraspedites* (= *Borealites*)" aff. *suprasubditus* (Pl. 1 d, e, f) and a single specimen of *Buchia okensis* (Pl. 1a, b) were found higher in the succession, in the shell-bed of the Hesteelv Formation. The two latter species are both diagnostic of Jeletzky's lowest Berriasian zone in Canada (Jeletzky, this volume).

Praetollia antiqua was previously known only from Canada by about 9 specimens from a single bed 8·5 metres below the lowest bed containing *Buchia okensis* and "*Subcraspedites* (= *Borealites*)" aff. *suprasubditus*. Their relative stratigraphical position in Canada and in Jameson Land is thus almost identical.

Based on its occurrence together with *Buchia terebratuloides* Lahusen f. typ., *B. t.* var. *obliqua* Tullberg and *B. terebratuloides* var. *subuncitoides* Bodylevsky, *Praetollia antiqua* is placed in the late Upper Tithonian in Canada (Jeletzky, this

volume: but see also Casey and Rawson, this volume).

In Jameson Land *P. antiqua* is found together with *H. kochi* and *P. maynci* and therefore placed in the Ryazanian Zone of *Hectoroceras kochi* (see Table 1).

Several explanations might be put forward to explain this discrepancy in stratigraphical occurrence:

(1) The Jurassic-Cretaceous boundary falls within the *Hectoroceras kochi* Zone and both *Praetollia maynci* and *H. kochi* cross the boundary.

(2) *Praetollia antiqua* crosses the Jurassic-Cretaceous boundary.

(3) The long distance correlations by means of species of *Buchia* placing *P. antiqua* in the topmost Tithonian are not valid.

I am of the opinion that (1) can be excluded as all Russian and West European workers seem to agree that *H. kochi* is placed well up in the Berriasian or Ryazanian (see Table 1).

As *P. antiqua* is found in only one single bed in Canada its range is unknown and (2) might be correct. Thus its Canadian occurrence would correspond to the lower part of its range and the Greenland occurrence to the upper part.

A correlation from Canada to Jameson Land on the basis of species of *Buchia* is very difficult, but the majority of the *Buchia* species found in the upper part of the Raukelv Formation, i.e. below the unconformity and below *P. antiqua*, seem to show Cretaceous affinities (Jeletzky, personal communication 1972).

Dr. Jeletzky's identification of the three above mentioned species in East Greenland is of extreme importance for the correlation between Europe, Greenland and Canada. As the faunal successions in East Greenland fit well with those of England and Siberia it is to be hoped that additional ammonite discoveries in Canada will solve the problems of the position of the Jurassic-Cretaceous boundary in that region, as long distance correlations by means of *Buchia* seem to meet with great difficulties.

In summary, ammonites diagnostic of the highest Volgian zone in Russia, viz. the *Chetaites chetae* Zone, are represented 200 metres below the unconformity in Jameson Land. They are followed by assemblages of undescribed and often badly preserved craspeditid ammonites presumably related to *Subcraspedites, Hectoroceras* and *Praetollia*. Separated by the unconformity follows an ammonite assemblage diagnostic of the second Ryazanian zone in Russia, the *Hectoroceras kochi* Zone. Thus there is still no fossil evidence for the lowest Ryazanian zone—the *Riasanites rjasanensis* Zone.

Plate 1.

1a, b. *Buchia okensis* (Pavlov). x 0·66. GGU No. 138190, MMH No. 12821. Muslingeelv Member (the shell bed). Ryazanian. Eastern bank of Muslingeelv, 2·5 km south of section 5 (Fig. 7).

2. *Praetollia* cf. *antiqua* Jeletzky. x 0·66. GGU No. 138146, MMH No. 12822. Lateral view. Crinoid Bjerg Member. Rayazanian. Associated in the same piece of rock with *Hectoroceras kochi* Spath. Eastern bank of Muslingeelv at river level, 1·7 km. south of section 5 (Fig. 7).

3a-c. "*Subcraspedites*" (=*Borealites*) aff. *suprasubditus* (Bogoslovsky). x 0·66. GGU No. 138191. MMH No. 12823. Muslingeelv Member (the shell bed). Ryazanian. Eastern bank of Muslingeelv, 2·5 km south of section 5 (Fig. 7).

a. Peripheral view. x 0·66. Impression of *Hectoroceras kochi* on the left side of the specimen.

b. Lateral view. x 0·66.

c. Lateral view. x 0·66. Impression of *H. kochi* on the lower left part of the specimen.

All three specimens were determined by Dr. J. A. Jeletzky. The specimens are housed in the Mineralogical Museum, Copenhagen. Photos by J. Aagaard.

Plate 1

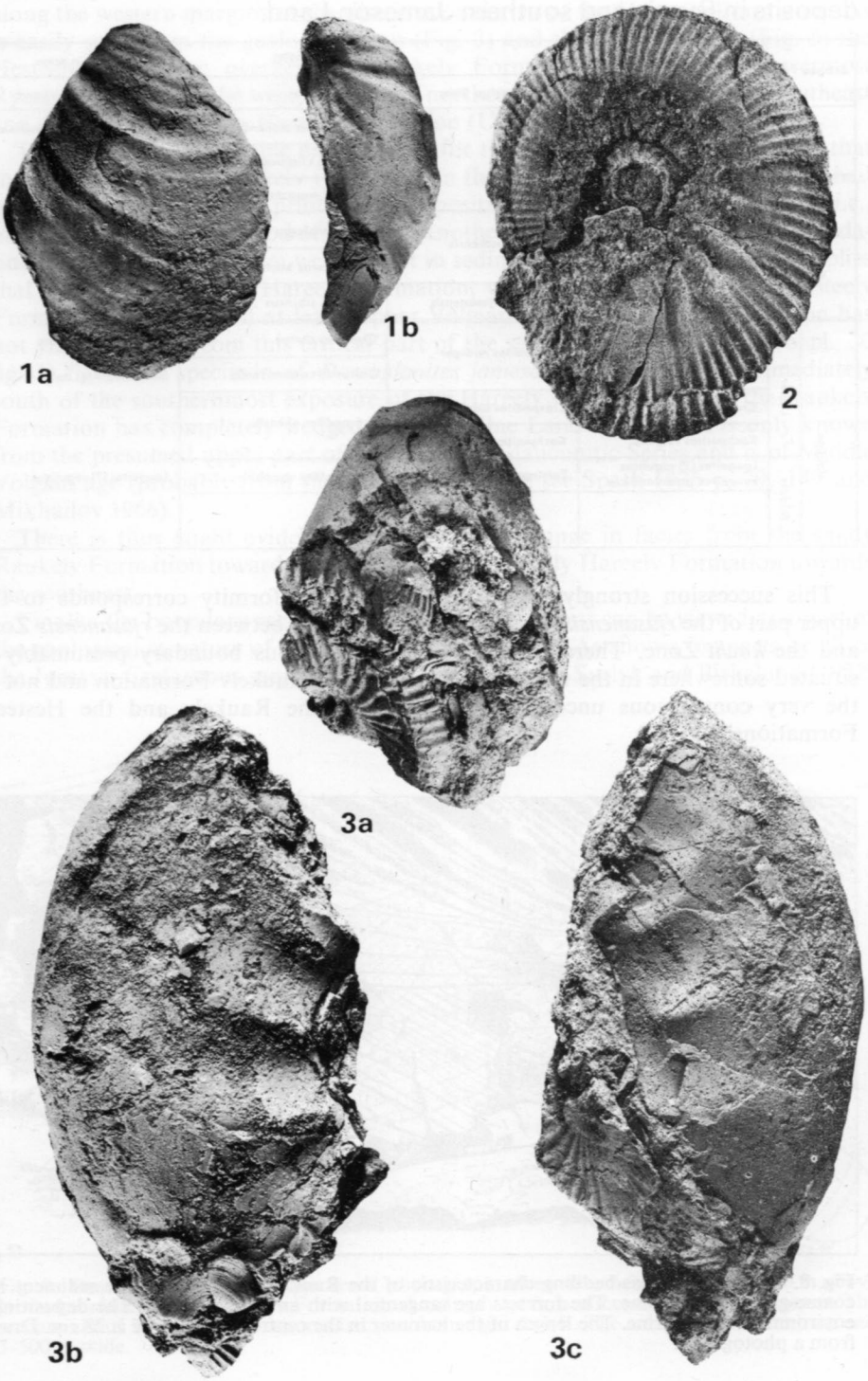

Table 1. Correlation of the Middle Volgian-lowermost Valanginian deposits in Russia and southern Jameson Land.

Stages		Sachs et al., 1968		Basov et al., 1970	Surlyk et al., in press
		North Ural	Basin of Volga River	Bay of Anabar	Southern Jameson Land
Valanginian				Polyptychites stubendorffi	cf. Polyptychites mokschensis
				Neotollia klimovskiensis	
Ryazanian		Tollia payeri		Bojarkia mesazhnikowi	
		Surites analogus Hectoroceras kochi	Surites spasskensis	Surites analogus	Surites aff. poreckaensis Hectoroceras kochi
				Hectoroceras kochi	Hectoroceras kochi Hectoroceras kochi Praetollia maynci
		?	Riasanites rjasanensis	Chetaites sibiricus	
Volgian	Upper	?	Craspedites nodiger	Chetaites chetae	Aff. Chetaites chetae
				Craspedites taimyrensis	Subcraspedites sp.
		Craspedites subditus	Craspedites subditus	Craspedites okensis	
		Kachpurites fulgens	Kachpurites fulgens		
	Middle	Laugeites (?) vogulicus Laugeites groenlandicus	Epivirgatites nikitini	Epivirgatites variabilis	Laugeites (?) vogulicus

This succession strongly suggests that the unconformity corresponds to the upper part of the *rjasanensis* Zone or to the boundary between the *rjasanensis* Zone and the *kochi* Zone. Therefore the Jurassic-Cretaceous boundary presumably is situated somewhere in the upper 200 metres of the Raukelv Formation and not at the very conspicuous unconformity separating the Raukelv and the Hesteelv Formations (Fig. 11).

Fig. 8. Large-scale cross-bedding characteristic of the Raukelv Formation. The sediment is a coarse-grained sandstone. The foresets are tangential with an erosional top. The depositional environment was marine. The length of the hammer in the centre of the figure is 28 cm. Drawn from a photograph.

It must be remembered, however, that the sequence described above is only found along the western margins of the distributional area of the Hesteelv Formation. As is easily seen from the geological map (Fig. 3) and the cross-sections (Fig. 5) the Hesteelv Formation overlies the Raukelv Formation (M. Volgian-?lowermost Ryazanian) towards the west, north and northeast, whereas towards the southeast and south it overlies the Hareelv Formation (U. Oxfordian-L. Volgian).

There are several possible explanations for this. Thus it might be suggested that the sediments of the Raukelv Formation in the southeastern part of the area had been removed by erosion prior to the deposition of the Hesteelv Formation, i.e., immediately after the period of folding. Another possibility is that there is a gradational change in facies from west to east in sediments of the same age. This implies that the top beds of the Hareelv Formation, where it is overlain by the Hesteelv Formation, should be of at least Upper Volgian age. The Hareelv Formation has not yielded fossils from this critical part of the sequence, but Spath (1936 pl. 30 fig. 1) figured a specimen of *Dorsoplanites jamesoni* collected loose immediately south of the southernmost exposure of the Hareelv Formation. Here the Raukelv Formation has completely wedged out. In Milne Land this species is only known from the presumed upper part of the so-called Glauconitic Series and is of Middle Volgian age (probably from the zone of *P. albani,* see Spath 1936 p. 79, 149 and Mikhailov 1966).

There is thus slight evidence in favour of a change in facies from the sandy Raukelv Formation towards the northwest to the shaly Hareelv Formation towards the southeast.

Finally, the boundary relations of the three formations can be viewed as a part of the geological structure of Jameson Land as a whole. As shown for parts or all of the Jurassic-Cretaceous sequence by Callomon (1961), Surlyk and Birkelund (1972)

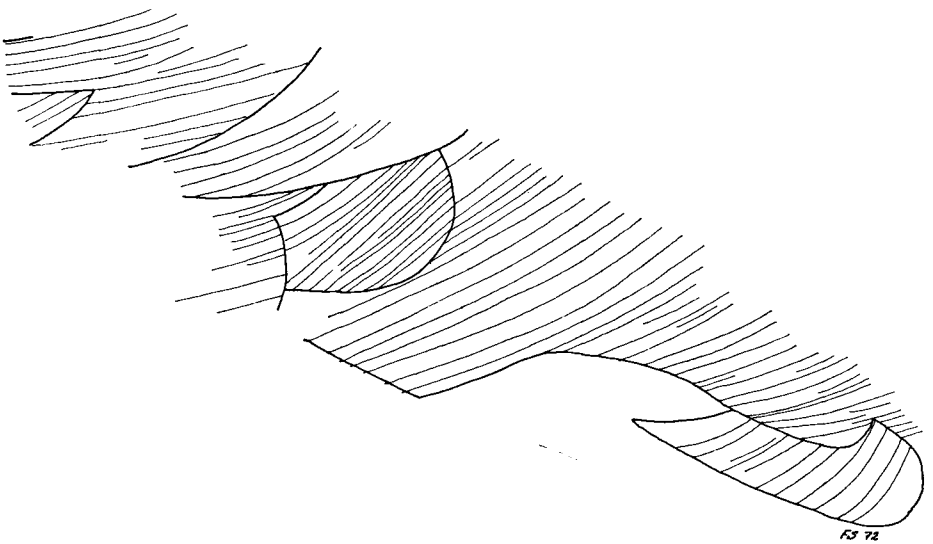

Fig. 9. Drawing (from an oblique aerial photograph taken at a height of about 300 m above ground surface) of the Raukelv Formation showing huge fans of cross-bedded sandstones. The sets are about 2 m thick. Transport direction from right to left. The area is several km long and 3–500 m wide.

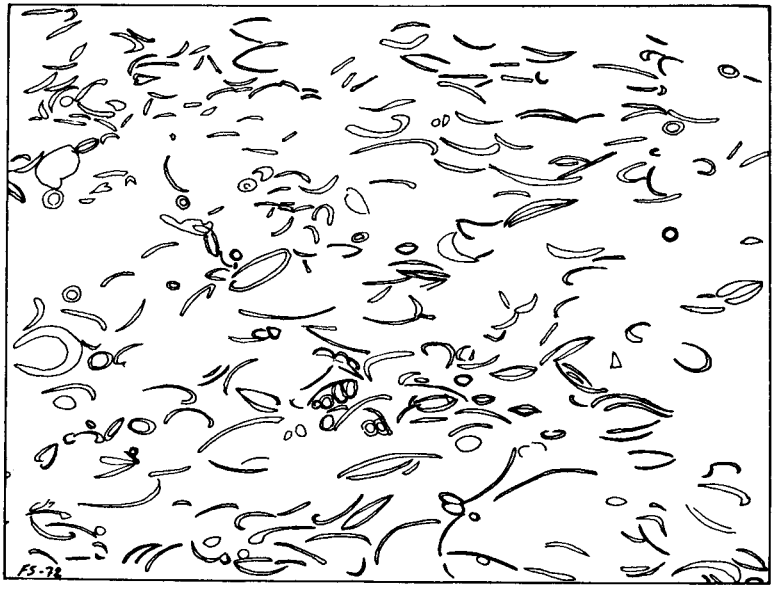

Fig. 10. Detail of Muslingeelv Member, Hesteelv Formation. The rock consists of large bivalves, ammonites, belemnites and other fossils in a matrix of calcareous sandstone. The dimensions of the figured area are 60 x 44 cm. Drawn from a photograph.

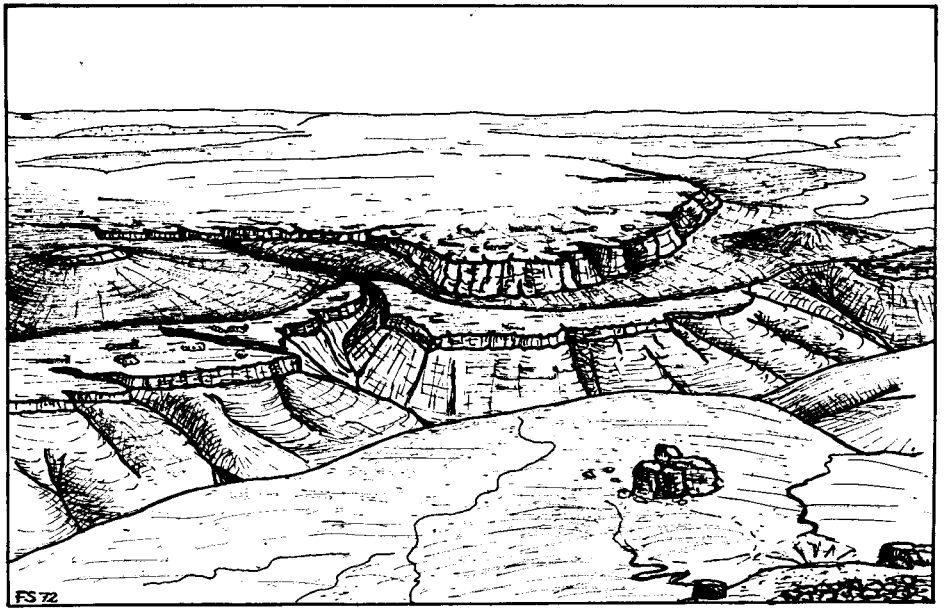

Fig. 11. Drawn from an aerial photograph of southernmost Jameson Land, looking southeast. Centrally in the figure the angular unconformity between the Hesteelv Formation and the Raukelv Formation is clearly seen. Note the overstep of the 35 m thick, massive sandstone of the Muslingeelv Member on to the lower sandstones of the Raukelv Formation and the corresponding thinning of the intervening shales of the Crinoid Bjerg Member. The central part of the figure corresponds to the western part of section II (Fig. 5) and to section 1 on Fig. 7.

The "Lingula Bed" contains *Laugeites groenlandicus* (Spath) of upper Middle Volgian age (see Table 1). Only 15 metres higher *Tollia groenlandica* (Spath) and *Tollia bidevexa* (Bogoslovsky) occur (Donovan 1964). According to Donovan (1964) *T. bidevexa* and *T. tolli* Pavlov are probably synonyms and the assemblage is therefore of Upper Ryazanian age (see Table 1).

The whole Upper Volgian and the three lowest Ryazanian zones are therefore missing in the Milne Land succession. Above the horizons with the two species of *Tollia* no ammonites have yet been found.

3b. Northern Wollaston Forland

At the mountains Niesen and Rigi, sections through Volgian, Ryazanian and Valanginian rocks were described by Maync (1949). The Ryazanian part of the fauna collected by Maync was dealt with by Spath (1952). In 1952, 1956 and 1957 the area was visited by several field parties and the results were summarized by Donovan (1964).

It was revealed that a correct combination of the data of the different geologists was very difficult as they probably did not examine exactly the same sections and as there may be discrepancies between their altitude measurements. Furthermore, the Volgian part of Maync's section (1947 fig. 19) has only slight resemblance with the same section figured again by Maync (1949 fig. 30) or with Donovan's description (1964 p. 11).

I have tried in the following to give combined succession recalculated to Donovan's altitudes (1964 p. 11).

The exposure starts at an altitude of 27 metres, beginning with grey pebbly sands which pass up into alternating yellow sand and grey or black shales. At 115 metres this sequence is followed by whitish sands with bands of sandstone. Several prominent conglomerate horizons occur up to about 250 metres. Upwards follow calcareous grey and reddish sandstones which at about 500 metres gradually pass into sandy limestones.

Laugeites? *parvus* Donovan and *Laugeites intermedius*? Donovan occur at 90 metres. They are found together with *Laugeites groenlandicus* in western Kuhn Is. and are therefore presumably of upper Middle Volgian age (see Table 1).

At 255 metres the *Praetollia maynci* assemblage which was described by Spath (1952) and at 268 and 270 metres the *Hectoroceras* sp. nov. figured by Spath (1947 pl. 3, fig. 2) were collected.

At 300–305 metres there occurred *Tollia payeri*? (Toula), *Surites tzikwinianus* (Bogoslovsky), *Surites spasskensis* (Nikitin) and *Surites* sp. ind. (Donovan 1964).

At 360–370 metres *Praetollia maynci*?, *Surites* sp. ind. and *Tollia payeri*? were present and at 400 metres a questionable *Tollia payeri* (Spath 1952 pl. 4 fig. 8 and Donovan 1964 p. 30).

Finally, typical Valanginian *Polyptychites* start at 414 metres. The succession from 255 metres to about 400 metres is of Middle to Upper Ryazanian age. There is thus no evidence for the presence of any of the Upper Volgian zones or of the *Rjasanites rjasanensis* Zone. Nevertheless, the part of the section between 90 metres and 255 metres has not yielded any ammonites and it is therefore possible that renewed work in the area will give evidence of a more complete zonal record.

3c. Western Kuhn Island

Close to the coast, low sections through conglomerates, sands, sandstones and dark grey shales are found in the stream valleys. According to Donovan (1964 p.12)

the dip of the rocks exposed in the valley sides is in many cases nearly the same as the gradient of the stream, and consequently it is very difficult or impossible to place the isolated exposures in stratigraphical order. The most common ammonite is *Laugeites* and Donovan (1964) reported the following species: *L.* aff. *groenlandicus*, *L. intermedius*, *L. parvus*, *L.* n. sp. and *L. jamesoni*. The four first-mentioned species are all found together (locality 10 of Donovan 1964) and the assemblage can be dated to the upper Middle Volgian on the basis of *L.* aff. *groenlandicus*.

Maync found one specimen of *Subcraspedites* aff. *preplicomphalus* associated in the same piece of rock with *Laugeites parvus*, but Spath (1952) assumed that these specimens were derived as he considered *Laugeites* a Jurassic and *Subcraspedites* a Cretaceous ammonite. Maync (1949 p. 28) emphasized that from a lithological point of view there was nothing to indicate a non-sequence and the reworking of Jurassic fossils. Casey (1962) and Donovan (1964), for palaeontological reasons, also showed that Spath's theory was unnecessary.

The sole indication of possible Ryazanian rocks in western Kuhn Is. is a single impression of a *Praetollia*? from Donovan's locality 6.

3d. Eastern Kuhn Island

As mentioned by Donovan (1964 p. 13) an exposure of Upper Ryazanian rocks must exist somewhere on the east coast of Kuhn Is. since *Tollia payeri* was collected here by a German expedition (1870–71). The locality has not been re-discovered.

4. Conclusions

The most complete and best exposed Volgian-Ryazanian sequence in East Greenland is the section from southern Jameson Land described in the present paper. The highest Jurassic zone identified is the *Craspedites nodiger* Zone (with its upper Subzone of *Chetaites chetae*) and 200 metres higher this is followed by the Middle Ryazanian Zone of *Surites spasskensis*. Thus the only zone not identified is the lowest Cretaceous Zone of *Riasanites rjasanensis*. However, this zone may yet be present within the 200 metres of undated sandstones. It is to be hoped that future collecting will demonstrate its presence.

The Upper Volgian has not been found in the Niesen succession on northern Wollaston Forland but there is an undated sequence of 165 metres above Middle Volgian and below Middle Ryazanian.

In Milne Land the Middle Volgian is followed within 15 metres by Upper Ryazanian, while on western Kuhn Is. the discovery of *Subcraspedites* aff. *preplicomphalus* may indicate the existence of low Upper Volgian and *Praetollia*? of Ryazanian. In eastern Kuhn Is. Upper Ryazanian occurs but the locality is unknown.

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