

**GEOLOGICAL
SURVEY
OF
CANADA**

**DEPARTMENT OF ENERGY,
MINES AND RESOURCES**

PAPER 72-37

**DESCRIPTION, PALYNOLOGY AND PALEOECOLOGY OF THE
HASSEL FORMATION (CRETACEOUS) ON EASTERN
ELLEF RINGNES ISLAND, DISTRICT OF FRANKLIN**

(Report, 2 figures and 2 plates)

W.S. Hopkins, Jr. and H.R. Balkwill

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ABSTRACT

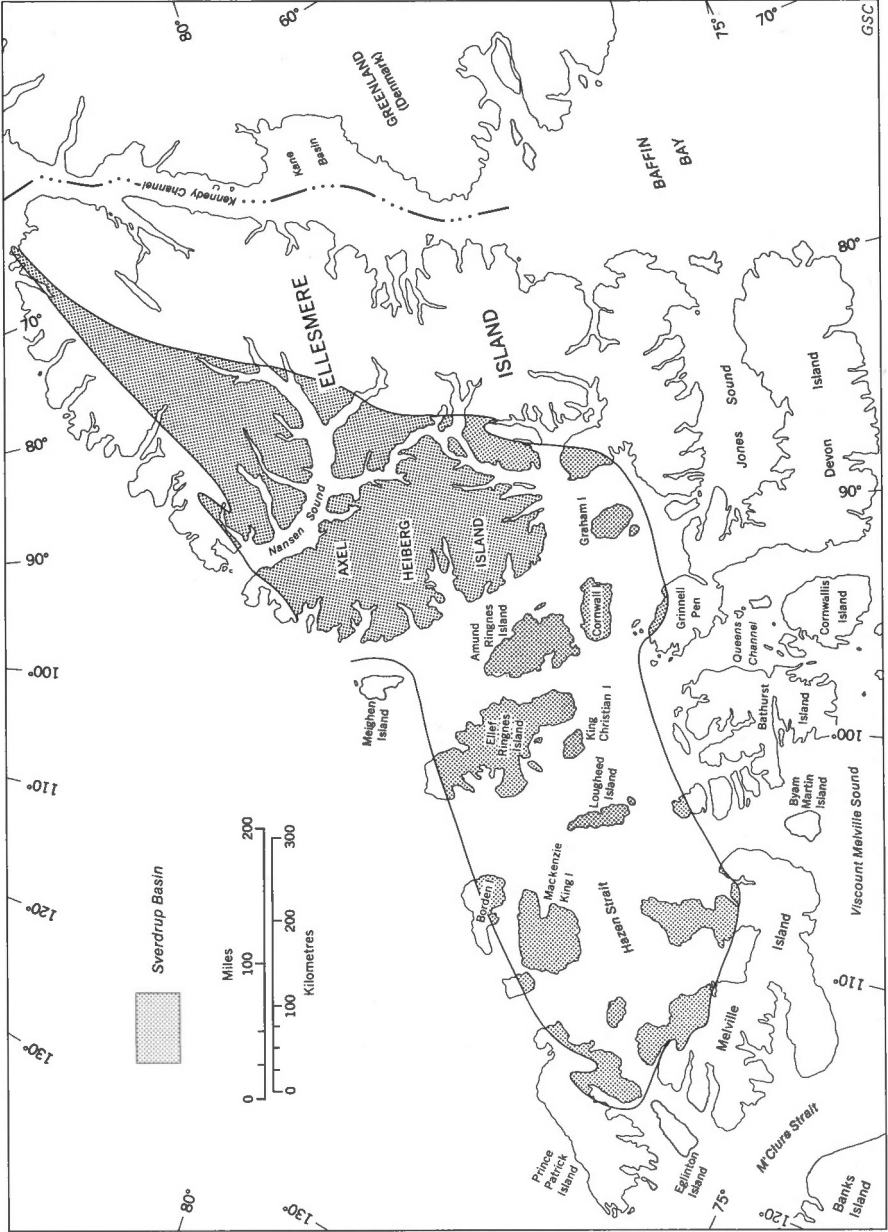
Sedimentary structures and palyno-assemblages indicate that the sandstones of the lower part of the Hassel Formation of eastern Ellef Ringnes Island were deposited in an upper shore-face marine environment; sandstone, siltstone, shale and coal, comprising the middle and upper parts of the formation, have structures and features indicative of fluvial deposition.

Thin, lenticular carbonaceous shale beds at Hoodoo Dome and Cape Cairo were analysed for their spore and pollen content. The microfloras indicate a late Albian and/or early Cenomanian age, which is consistent with regional paleontological and structural evidence. Humid, warm temperate conditions during Hassel deposition are suggested by the microflora.

RÉSUMÉ

Les structures sédimentaires et les palyno-assemblages montrent que les grès de la partie inférieure de la formation d'Hassel dans la partie est de l'île Ellef Ringnes ont été déposés dans un environnement marin d'avant-côte supérieure; le grès, le siltstone, le schiste argileux et le charbon que contiennent les parties moyennes et supérieures de la formation ont des structures et des traits distinctifs qui indiquent une sédimentation en milieu fluvial.

Des lits de schiste argileux carbonneux minces et lenticulaires à Hoodoo Dome et à Cape Cairo ont été étudiés pour les spores et le pollen qu'ils contiennent. Les microflores indiquent une origine datant de l'Albien supérieur et/ou du Cénomaniens inférieur, ce qui est conforme aux indications paléontologiques et structurales régionales. La micro-flore indique qu'une température humide et chaude régnait au cours de la phase de sédimentation d'Hassel.



Text-figure 1. Map showing the Sverdrup Basin, Canadian Arctic Archipelago (after Thorsteinsson and Tozer, 1970, p. 550)

DESCRIPTION, PALYNOLOGY AND PALEOECOLOGY OF THE HASSEL FORMATION (CRETACEOUS) ON EASTERN ELLEF RINGNES ISLAND, DISTRICT OF FRANKLIN

INTRODUCTION

REGIONAL SETTING

The Hassel Formation is one of several thick, quartz-sandstone dominated rock units of Mesozoic age that lie between marine, dark shales in the Sverdrup Basin region of the Canadian Arctic Archipelago (Text-fig. 1). Heywood (1957, p. 13) named the formation for about 1,800 feet of very poorly indurated quartz-sandstone near Isachsen Dome in the central part of Ellef Ringnes Island (Text-fig. 2), although he did not designate or measure a type section. From Ellef Ringnes Island, where the Hassel sandstones crop out in several broad synclines, commonly adjacent to piercement domes, the formation extends eastward to Ellesmere Island and westward to Eglinton Island (Plauchut, 1971).

According to Thorsteinsson and Tozer (1970), the Hassel Formation in the central part of the Sverdrup Basin lies conformably on marine, silty shales of the Christopher Formation, and is overlain by marine, dark shales of the Kanguk Formation. Gould and DeMille (1964) and Stott (1969) reported considerable local variation in the thickness of the formation, from a minimum of about 300 feet to a maximum of about 1,800 feet. They considered this to be a depositional consequence of doming initiated by diapiric intrusion of evaporites, but it has not been demonstrated clearly whether intervals within the formation thicken preferentially to peripheral sinks and rim synclines between domes, or whether there are unconformities within or at the top of the formation on the flanks of domes.

Few fossils have been found in the Hassel Formation. Plauchut (1971, p. 674) reported early late Albian ammonites from a lens of marine shale on Banks Island that he correlated with the Hassel Formation, and Thorsteinsson and Tozer (1970, p. 583) reported that microplankton, tentatively dated as Cenomanian, have been described from Graham and Ellef Ringnes Islands. The youngest paleontologically dated beds of the Christopher Formation on Ellef Ringnes Island (about 400 feet below the top of the formation) are late middle Albian (Jeletzky *in* Stott, 1969, p. 26, and Jeletzky, pers. com., 1972). The lowermost dated Kanguk beds on Ellef Ringnes Island are from the middle part of the formation, and are Santonian to lower Campanian (Stott, 1969, p. 27), although Greiner (1963, p. 411) and Thorsteinsson and Tozer (1970) reported Kanguk strata as old as Cenomanian on Graham Island.

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Non-paleontological evidence for the age of the Hassel Formation on Ellef Ringnes Island is derived from the presence of diabase sills and dikes. The igneous intrusions cut the middle part of the Hassel Formation and underlying rocks; samples of diabase from sills in the northwestern part of the island yielded radiometric ages of 102 m.y. to 110 m.y. (Larochelle, *et al.*, 1965). This agrees with an Early Cretaceous (Albian) age for Hassel strata at and below the level of intrusion.

ACKNOWLEDGMENTS

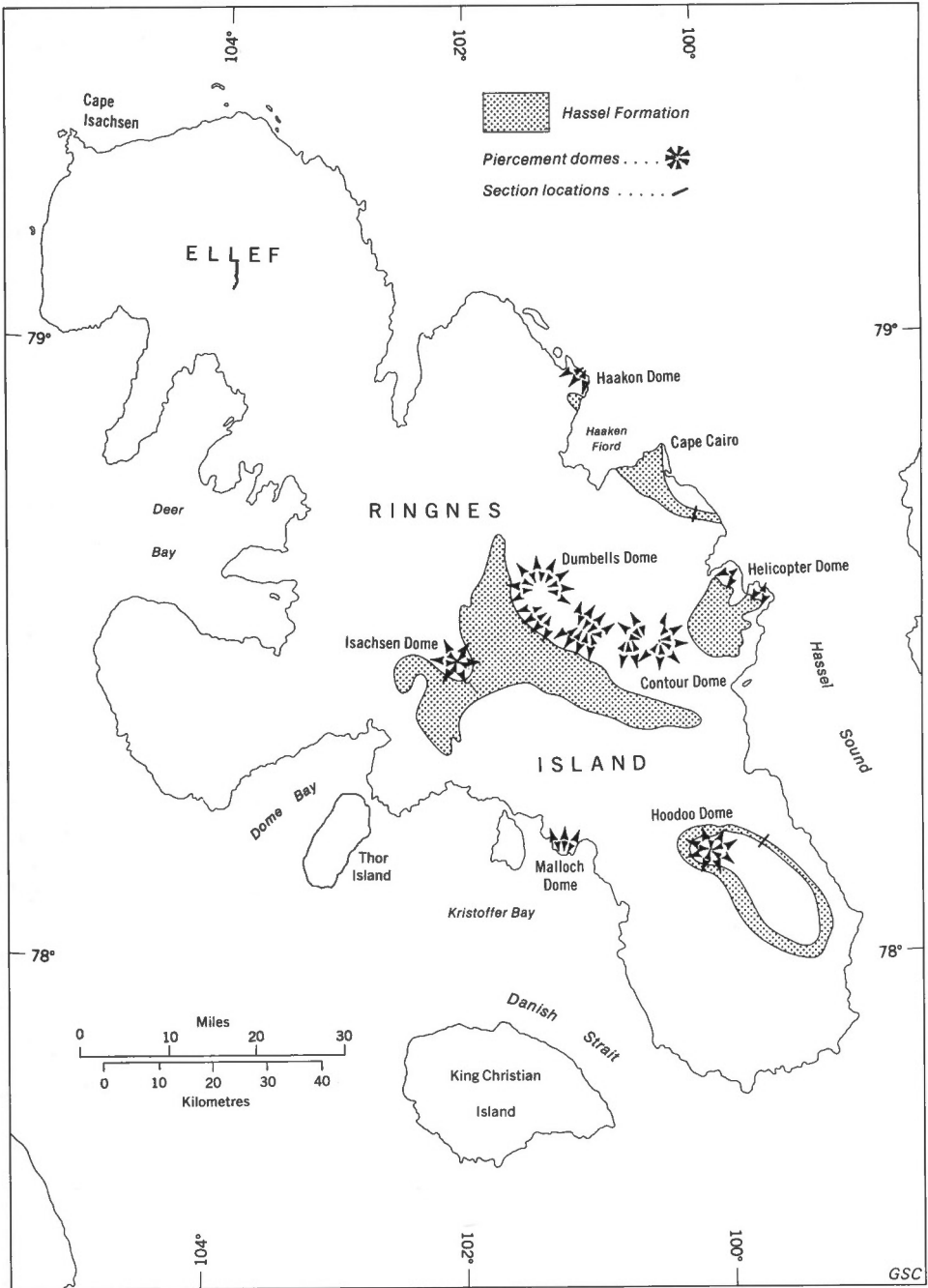
The writers thank W.W. Brideaux and D.W. Gibson (Geological Survey of Canada, Calgary) and G.E. Rouse (Botany Department, University of British Columbia) for reading the original manuscript and offering many helpful suggestions. Helen McDonald ably prepared the samples for examination and the photographs for reproduction.

LITHOLOGY OF THE HASSEL FORMATION AT HOODOO DOME AND CAPE CAIRO, EASTERN ELLEF RINGNES ISLAND

From graphic measurements, the Hassel Formation is estimated to be about 600 feet thick on the eastern flank of Hoodoo Dome. This includes about 300 feet of brown and buff sandstone that Stott (1969), on the basis of air-photo interpretation, mapped as being within the uppermost part of the Christopher Formation; however, ground observations indicate that the sandstone is more appropriately included in the Hassel Formation than in the shale-dominated Christopher Formation. Lower Hassel strata consist of medium brown to yellow-brown, quartzose, partly feldspathic sandstones that lie abruptly, but apparently conformably, on dark grey, slightly to moderately silty and sandy, moderately indurated Christopher shale. Lowermost Hassel beds are parallel-laminated, and also have large lenticular sets, up to 2 feet thick, of very low-angle cross-strata¹. Several tens of feet above the base, partings and very thin beds of black, carbonaceous shale become increasingly abundant. About 150 feet above the base, a bed of red-brown, silty mudstone, with embedded quartz granules, marks a distinctive break in lithology: above this bed there is an interval of fine- to medium-grained, yellow-buff, friable sandstone, with large high-angle cross-strata, cross-laminated sandstone and siltstone with abundant carbonized plant stem impressions, and carbonaceous shale.

The upper 300 feet of the formation consist principally of thick to very thick beds of fine- to coarse-grained, very poorly indurated, quartzose and partly feldspathic sandstone. The quartz grains are frosted and well-rounded, and are well-sorted within individual beds. Very light buff, quartz sandstone, thin black carbonaceous shale, and a few very thin beds of coal constitute the uppermost strata. Hassel sandstone is overlain abruptly by dark grey and green-grey, papery, silty shales of the Kanguk Formation; the Hassel strata are not truncated perceptibly at the contact.

¹Terminology of McKee and Weir, 1953



Text-figure 2. Map showing distribution of the Hassel Formation, Ellef Ringnes Island (after Stott, 1968)

From graphic measurements, the Hassel Formation near Cape Cairo is estimated to be about 1,400 feet thick, including the 300 feet of brownish sandstone, mentioned previously, that Stott (1969) mapped within the Christopher Formation. The contacts with the Christopher and Kanguk Formations are poorly exposed, but appear to be conformable. Lowermost Hassel beds consist of fine-grained, yellowish brown, very poorly cemented (clay and calcareous cement) quartzose and partly feldspathic sandstone, with thin to thick parallel beds, and some large sets of low-angle cross-strata up to 4 feet thick. Some of the sandstones contain conspicuous (5 to 10 per cent) dark green glauconite grains, most of which are ovoidal and not diagnostic of a particular origin, but some of which are 'glauconitized' foraminifers (identified as Haplophragmoides sp. and Trochamina sp. by W.V. Sliter, Geological Survey of Canada), and others which are elongated, finely grooved forms suggestive of fecal origin. Two diabase sills, each about 40 feet thick, have intruded the lower third of the formation.

The upper two-thirds of the formation at Cape Cairo are distinctly lighter colored than the lower third. Light yellow-buff, fine- to coarse-grained, poorly cemented to non-cemented, quartzose-feldspathic sandstone comprises the predominant lithology; the sandstones commonly have large, high-angle cross-stratification. Intercalated with the sandstones are cyclical repetitions of red-brown, cross-laminated siltstone, black carbonaceous shale, and very thin beds of coal. Sandstone beds near the top of the formation contain some ovoid glauconite pellets and large sets of low-angle cross-strata.

ENVIRONMENT OF HASSEL DEPOSITION

From a brief investigation of lithology and sedimentary structures, it appears that deposition of the Hassel Formation in the region of eastern Ellef Ringnes Island was dominated by a deltaic regime: marine shales of the upper Christopher Formation (possibly pro-delta and delta slope facies) are overlain transitionally by lower Hassel sandstones, consisting of glauconitic, foraminiferal sandstone, with parallel laminations and low-angle cross-strata (marine, delta platform deposits). Fluvial deposition by shifting distributary channels may be represented by fining-upward, cyclical repetitions of: granule lenses, and medium- and coarse-grained sandstones with large sets of high-angle cross-strata (channel and point bar deposits); cross-laminated, fine-grained sandstones and siltstones, and carbonaceous shale (overbank floodplain deposits); and thin coal beds (interdistributary marshes).

Sandstone-free Kanguk shale overlies the uppermost Hassel sandstones; this indicates abrupt (and possibly rapid) marine transgression of the Hassel fluvial system.

AGE DETERMINATION OF THE HASSEL FORMATION

In determining an age based on palynology, it must be emphasized that no palynological sections from the Sverdrup Basin have been published. Consequently, it is necessary to examine Cretaceous palynological and paleobotanical studies from other parts of the world. Over the years, it has become apparent that pre-Turonian pollen assemblages are generally cosmopolitan, while post-Turonian assemblages show increasing provincialism (Doyle, 1969). As a result, more meaningful long-

range correlations are possible in pre-Turonian microfloras but, in younger rocks, this sort of correlation becomes difficult or impossible. However, as will be mentioned later, latitudinal variation does occur, even in pre-Turonian floras and, unless this is considered, serious miscorrelations may be made.

Bearing in mind the general homogeneity of pre-Turonian floras, let us look at several characteristics of the Hassel microflora.

1) The absence of characteristic Early Cretaceous spore genera such as Trilobosporites, Pilososporites and Concavissimisporites is striking. One specimen of Trilobosporites was found, but its differential preservation suggests it has been reworked into the assemblage. These three genera occur sporadically through the underlying Christopher Formation (Hopkins, 1971a), which is considered middle Albian (Thorsteinsson and Tozer, 1970; Plauchut, 1971), and are quite abundant in the older Isachsen Formation (Hopkins, 1971b), the upper beds of which are probably near the Aptian-Albian boundary.

2) The Schizaeaceae (Cicatricosisporites, Appendicisporites) are very rare in the Hassel, while in the underlying Christopher they are locally dominant. In the Sverdrup Basin, the Schizaeaceae gradually diminish in frequency upward from the base of the Christopher until they disappear in the Upper Cretaceous (personal observation).

3) Pollen of both the extinct pteridosperm Vitreisporites and the extinct conifer Classopollis are present, the former being abundant locally while the latter is represented only by several grains. Vitreisporites is found infrequently in Cenomanian rocks in other parts of the world, while Classopollis diminishes in upper Albian and Cenomanian rocks and is found rarely in post-Cenomanian deposits (Brenner, 1967). Bisaccate conifer pollen is abundant locally in the Hassel Formation whereas, in later Cretaceous rocks of the central Sverdrup Basin, it is relatively less abundant. This is consistent with megafossil evidence from northern Alaska where conifers reach their maximum abundance in upper Albian and Cenomanian strata, then diminish in numbers. Presumably, they were steadily replaced by the rapidly evolving angiosperms. Evidence from palynology and paleobotany would suggest, therefore, an Albian or Cenomanian age for the Hassel microflora.

More concrete age evidence is added by consideration of the presence of comparatively rare, but omnipresent, small tricolpate pollen grains, obviously of angiosperm origin. The earliest probable angiosperm pollen grain is the monocolpate genus Clavatipollenites, which makes its first appearance in the Hauterivian or Barremian (Couper, 1964; Doyle, 1969). It is particularly abundant in Aptian and lower Albian strata and, although its upper limit is not quite certain, it probably occurs in the Cenomanian. This genus was not recognized in the Hassel Formation. In most parts of the world, the undoubted tricolpate grains (i.e. angiosperms) made their appearance about the Aptian-Albian boundary, although a few rare grains have been described from older deposits (see discussion in Doyle, 1969 and Muller, 1970). Through the early and middle Albian, they remain very simple, undifferentiated and rare. Not until late Albian do they begin to become more characteristic and abundant, with increasing morphological diversity. A small number of tricolpate grains are present in the Hassel Formation. They are generally small and simple, but with varying size and ornamentation.

The Patapsco Formation of Maryland and Delaware is considered to be middle and upper Albian, possibly extending into the Cenomanian (Brenner, 1963; Doyle, 1969). This formation is characterized by the decline in the number of Classopollis and spores of the Schizaeacea but, more importantly, it records the first appearance of small reticulate tricolpate pollen grains (Brenner, 1967; Doyle, 1969). Generally, then, in the upper Albian tricolpate pollen are characteristic of microfloral assemblages and show a low frequency of diversity. In upper Cenomanian rocks, angiosperm pollen are locally dominant and include advanced forms such as tricolporates and triporates (Brenner, 1963; Groot, Penny and Groot, 1961; Groot and Groot, 1962; Doyle, 1969). The general appearance of the Hassel microflora, although much less diverse than that of Maryland and Delaware, combined with the state of morphologic development of the angiosperm pollen, suggests that the Hassel is essentially equivalent with zone II, subzone B of the Patapsco Formation (i.e. upper Albian) as described by Brenner (1963). Similarities are also apparent between the Albian-Cenomanian microfloras of Portugal (Groot and Groot, 1962) and the microflora of the Hassel Formation.

Although it is difficult to compare macrofloras with microfloras, the Kungok macroflora of northern Alaska (Smiley, 1966) appears to be similar to the floral assemblage interpreted for the Hassel on palynological grounds. This Alaskan late Albian flora is characterized by abundant and varied ferns, ginkgophytes (not recognized in the Hassel), cycadophytes and conifers. Angiosperms are rare. Arnold and Lowther (1955) also mentioned a gymnosperm-fern flora in the upper Albian Killik tongue of the Chandler Formation of northern Alaska. Smiley (1967) noted that ferns are dominant and varied in the upper Albian-lower Cenomanian strata, but are uncommon and few in number in younger rocks. The abundance of conifers and ferns plus the presence of a few angiosperms suggest a similar flora to that of the Hassel interpreted by palynological evidence. In summary, it appears that the Hassel microflora is of late Albian or early Cenomanian age.

However, one further modification must be considered. Smiley (1966, 1967, 1969a, 1969b) studied plant megafossils in northern Alaska, Stanley (1967) used palynology in northern Alaska, and Pokrovskaya (1966) used palynology in the northern U.S.S.R.; they noted that angiosperms are absent or rare until the Cenomanian. Stanley (1967) did not find any angiosperm pollen in rocks older than Cenomanian. His microflora from the Umiat section of northern Alaska, which is considered Cenomanian, is very similar to that of the Hassel Formation, including a very high proportion of sphagnum spores. Assuming these ages are correct, there may have been latitudinal or ecologic factors that slightly retarded the spread of angiosperms northward (see Axelrod, 1952, 1959). Therefore, although the Hassel microflora compares closely with late Albian floras in other parts of the northern hemisphere, especially in development of angiosperm pollen, the retardation in northward spreading of angiosperms could allow an age as young as Cenomanian for the Hassel flora. Consequently, we have concluded that the Hassel Formation on eastern Ellef Ringnes Island is latest Albian and/or early Cenomanian in age. This would be in keeping with the tentative Cenomanian age indicated by microplankton (see Thorsteinsson and Tozer, 1970).

PALEOECOLOGY

Paleobotanical and palynologic conclusions of paleoecology are based on two assumptions: 1) that closely related plant groups had ecological requirements in the past that were analogous to their modern counterparts; and 2) that the floras were in equilibrium with their environment. On the whole, these assumptions seem to be valid, and support is available from Pleistocene studies "to indicate that, under changing climatic condition, plants are much more apt to migrate to a favorable locale than adapt to their current position" (Andrews, 1961, p. 193). Thus, although plant evolution has occurred since the Albian, available evidence suggests that groups of plants (though there are certainly individual exceptions) have not appreciably altered their climatic requirements. Hence, fossil plants, if they can be related to modern forms, should give evidence as to the paleo-environment.

A brief review of the distribution and ecological requirements of the extant related taxa includes plants that range from temperate to tropical, with the majority being warm temperate to subtropical. Most appear to require moist soil and comparatively humid conditions. Exceptions to these temperature-moisture requirements are the Pinaceae and some of the Taxodiaceae which are largely temperate, and Ephedra which today is a xerophytic plant.

Observations on the lithology and sedimentary structures of the Hassel Formation, combined with the general conclusions on paleoclimate as deduced from the microflora, suggest that, on eastern Ellef Ringnes Island, the depositional environment was that of a coastal lowland. During early and late Hassel deposition, environment was dominated by marine deltaic and shore processes resulting in marine sandstones. During middle Hassel deposition, the environment was dominated by fluvial processes, resulting in channel, point bar and overbank deposits. The lowland probably was covered with small ephemeral lakes and sloughs, providing suitable habitats for abundant Sphagnum and possibly early angiosperms. Higher ground surrounding the ponds, lagoons and sloughs could support a flora composed of ferns, seed ferns, certain conifers such as the Taxodiaceae, and quite probably primitive angiosperms. Drier areas of the coastal plain, such as sandy ridges or dunes, could support more xerophytic plants such as Ephedra, the cycads, the gleicheniaceae ferns and perhaps some of the Selaginellaceae. The comparatively limited occurrence of bisaccate conifer pollen (considering that present-day bisaccate conifer pollen is produced in enormous quantities) suggests a more distant source, probably in uplands from which the detritus was being removed. Climatically, these lowlands were probably warm-temperate, possibly even subtropical. Inland, and probably somewhat topographically higher, the climate may have been temperate to warm temperate. These climatic conclusions are consistent with paleobotanical evidence from other areas of the world which suggest that the climate warmed to a maximum (humid warm temperate in the Arctic) then very gradually cooled through the Late Cretaceous (Smiley, 1969b). A number of megafossil floras from Labrador, Greenland and northern Alaska indicate a warm temperate climate during the Cretaceous and early Tertiary (Andrews, 1961; Smiley, 1966). A warm-temperate climate implies a mean annual temperature of about 60°F; at the present the mean annual temperature of the Isachsen western station, on the northeast coast of Ellef Ringnes Island, is -2.1°F (Meteorological Branch, 1970). The mean annual temperature of this area, therefore, appears to have fallen 60 or more degrees since the Albian.

Other aspects of the environment of the late Albian-early Cenomanian in the polar areas invite speculation. The indication that the Albian-Cenomanian climate was

much warmer and more humid than at present, and the fact that this is presently a truly polar region, lying only 12° from the North Pole, present a dilemma. Firstly, if this area was polar in the Albian, it was obviously necessary for these plants to be adjusted to long winter nights and long summer days. They must have been adapted to a prolonged growing season of long days with little or no night, except at the beginning and end of the season. The growing season would have been perhaps 6 or 7 (or more?) months, with a sun that was always low on the horizon and where radiation was reduced by a thick blanket of atmosphere. However, it should also be acknowledged that the total hours of daylight in the Arctic, per year, is considerably higher than at the equator (Weyer, 1956). The plants would have had to be adjusted to a totally different photoperiod and more hours of daylight per year, but to a much lower light intensity than their modern counterparts. Dormancy would seem to have been mandatory four or five months of the year. The sun disappears for at least 24 hours everywhere north of $67^{\circ}15'N$, while at the north pole it disappears for 175 days. However, twilight is present through all but a short period during mid-winter, and it is possible that the plants could utilize this very low intensity for photosynthetic purposes. If so, the period of dormancy would have been comparatively short.

All warm-temperate or sub-tropical plants now are adapted to about 12 hours of light and 12 hours of dark in any 24 hour period, and many require a growing season which extends throughout the year. Perhaps ecotypes existed that permitted growth under the humid, warm polar conditions prevailing during the Albian. Even so, the image of such a flora standing dormant through the long polar darkness, and perhaps the polar twilight, for a number of months is perplexing.

The possibility of continental drift or polar wandering must also be considered. Perhaps during the Albian, the region of the Canadian Arctic Islands (i.e. Sverdrup Basin) was at a more southerly latitude, with photoperiods similar to those of modern representatives of the plants. Most evidence suggests that a relative east-west motion of North America and Eurasia occurred during the Cretaceous and Tertiary, rather than any significant north-south motion. Therefore, it would appear that Ellef Ringnes Island was in a polar area during the late Albian-early Cenomanian.

Existing evidence on both ecotypical variation and continental drift and polar wandering is inadequate to give a reasonable answer at the present time. But warm temperate to subtropical plants occur in Cretaceous rocks in what is now a polar area; the biological and geological implications of this must be considered in more detail in future work.

PALYNOLOGY

SAMPLES AND TECHNIQUES

Field work and collection of samples for palynological study were done during a reconnaissance of Ellef and Amund Ringnes Islands during July and early August of 1971. Eight samples were collected through the Hassel Formation on southern Ellef Ringnes Island at Hoodoo Dome; another five samples were collected on the north-eastern part of the island near Cape Cairo (Fig. 2). The sections at the two localities also included the underlying Christopher Formation and the overlying Kanguk and basal Eureka Sound Formations. These latter units, although palynologically examined, are not included in this report.

As described previously, the Hassel Formation in this area is composed mainly of sandstone with thin carbonaceous shale and coal layers. Both shale and coal were collected for palynological examination. Maceration followed standard palynological techniques, including breakdown of the rocks in hydrochloric and hydrofluoric acids, followed by heavy liquid separation, oxidation and staining. The residues were mounted permanently in glycerine jelly on glass slides.

DISCUSSION OF THE PALYNO-ASSEMBLAGES

The Hassel microflora is comparatively small, consisting of only 52 species contained in 37 genera. This does not, however, include the bisaccate conifer pollen (with exception of cf. Cedrus and cf. Podocarpidites) which were not subdivided into genera. The Hassel palynomorphs are present throughout all samples, with only minor variations in proportions. Evidently, neither the climate nor the flora changed significantly during the period of Hassel deposition in this area (see previous discussion in this report).

Subsequent comments on abundance are not quantitative and result only from general impressions.

Emphasis is placed on the botanical significance of the microfossils and lesser concern is expressed for conventional taxonomic considerations. Consequently, each major taxonomic subdivision is followed by a few brief remarks relating to that subdivision, and comments regarding the climatic distribution of that taxa in the modern world flora.

In this section, as well as in the sections to follow, the climatic terms such as "tropical" or "temperate" are used in the sense of Dorf (1955), i.e. a mean annual temperature of 80° F is tropical; 70° is subtropical; 60° is warm temperate; and a 50° mean annual temperature is regarded as temperate.

The writers are well aware of the inadequacies of this system and recognize the many imperfections in using only a mean annual temperature rather than more precise, defined variables such as equability, mean annual precipitation, mean range of temperature, etc. (For a full discussion of these problems and their application to fossil floras see Axelrod and Bailey, 1969, and Wolfe, 1971). However, in rocks of this age, a more precise analysis of climate, such as is increasingly feasible with Tertiary floras, is not warranted.

Division EUMYCOTA

Class Fungi Imperfecti

Form genus Pleuricellaesporites van der Hammen ex Clarke

Pleuricellaesporites sp.

Plate I, figure 1

Abundance. Rare

Division BRYOPHYTA

Family Sphagnaceae

Genus Sphagnum Erhart

Sphagnum antiquasporites Wilson and Webster

Plate I, figure 2

Sphagnum cf. S. australe (Cookson) Drozh.

Plate I, figure 3

Sphagnum cf. S. regium Drozh.

Plate I, figure 4

Sphagnum cf. S. australe parvum (Cookson) Elsik

Plate I, figure 5

Abundance. All four of these species are very abundant, especially S. antiquasporites. However, it should be mentioned that a great variation exists in the spore morphology of these species and many appear to be intergradational. They all appear to be members of the Sphagnaceae.

Remarks on Sphagnaceae. At the present time, this family is world-wide in distribution but forms extensive bogs only in the northern hemisphere. It is represented by only one genus (Sphagnum) and some 100 species. The family shows an almost unbroken record from the Carboniferous to the present, and appears to have been essentially modernized by the late Mesozoic. At present, Sphagnum is restricted to moist areas, especially in bogs and ponds, where it thrives on low pH conditions, and grows within an excellent environment for the preservation of fossil material (Gray and Groot, 1966; Scagel et al., 1965).

Division LYCOPODOPHYTA

Family Selaginellaceae

Form Genus Cingulatisporites Thomson, in Thomson and Pflug

Cingulatisporites cf. C. radiatus Stanley

Plate I, figure 6

Abundance. Rare.

Cingulatisporites sp.

Plate I, figure 7

Abundance. Rare.

Form Genus Apiculatisporis Potonié and Kremp

Apiculatisporis sp.

Plate I, figure 8

Abundance. Rare.

Comments. This type has been found in spores of the modern Selaginella subabor-
escens group (Brenner, 1967).

Remarks on Selaginellaceae. As with the Sphagnaceae, there appears to have been little evolutionary change in spores of the Selaginellaceae since the Carboniferous. Most species are characteristic of the wet tropics but a few occur in temperate regions and a very few can exist in the desert or subarctic. Generally they prefer damp and shaded sites, but a few grow well in xeric areas (Scagel et al., 1965; Willis, 1966).

Family Lycopodiaceae

Form Genus Lycopodiumsporites Thiergart ex Del. and Sprum.

Lycopodiumsporites austroclavatidites (Cookson) Potonié

Plate I, figure 9

Abundance. Rare.

Lycopodiumsporites sp.

Plate I, figure 10

Abundance. Rare.

Form Genus Camaronzonosporites (Pant ex Potonié) Klaus

Camaronzonosporites insignis Norris

Plate I, figure 11

Abundance. Locally fairly common.

Form Genus Lycopodiacidites (Couper) Potonié

Lycopodiacidites cf. L. caperatus Singh

Plate I, figure 12

Abundance. Locally fairly common.

Comments. There is some doubt whether these last two species can be consistently separated as there is considerable variation in size, as well as in the width, length, pattern of the verrucae, and presence or development of interradial crassitudes. However, obviously both are closely related. L. caperatus is virtually identical to the modern spore of Lycopodium alopecuroides.

Lycopodiacidites sp.

Plate I, figure 13

Abundance. Rare.

Form Genus Sestrosporites Dettmann

Sestrosporites pseudoalveolatus (Couper) Dettmann

Plate I, figure 14

Abundance. Very rare.

Comments. This form genus is comparable to spores of the modern species Lycopodium manii and L. laterale (Dettmann, 1963, p. 66).

Remarks on Lycopodiaceae. Modern lycopods are small herbaceous plants which have shown little change since the Carboniferous. This family is now composed of two genera, one of which, Lycopodium, occurs over most of the modern earth. Lycopods are tropical to Arctic in their occurrence, with most tropical forms being epiphytic (Andrews, 1961; Lawrence, 1951).

Division PTEROPHYTA

Family Osmundaceae

Form Genus Osmundacidites Couper

Osmundacidites wellmanii Couper

Plate I, figures 15, 16

Abundance. Occurs in small numbers in all samples.

Form Genus Baculatisporites Thomson and Pflug

Baculatisporites comaumensis (Cookson) Potonié

Plate I, figure 17

Abundance. Comparatively common.

Remarks on Osmundaceae. This family has a long history, dating back to the Permian. It had world-wide distribution throughout the Mesozoic, but gradually became restricted during the Tertiary. Osmunda is represented in the Cretaceous by extensive vegetative remains which indicate that the genus was essentially modernized by that time. The three genera comprising the Osmundaceae are restricted now to temperate to tropical swampy regions (Lawrence, 1951; Miller, 1971; Scágel et al., 1965).

Family Schizaeaceae

Form Genus Cicatricosisporites Potonié and Gelletich

Cicatricosisporites cf. C. hallei Del. and Sprum.

Plate I, figure 18

Abundance. Rare.

Cicatricosisporites cf. C. australiensis (Cookson) Potonié

Plate I, figure 19

Abundance. Rare.

Cicatricosisporites sp.

Plate I, figure 20

Abundance. Rare.

Form Genus Appendicisporites Weyland and Krieger

Appendicisporites sp.

Plate I, figure 21

Abundance. Very rare.

Comments. The form genera Cicatricosisporites and Appendicisporites both have their counterparts in spores from the modern schizaeaceous genera Mohria and Anemia.

Form Genus Trilobosporites Pant ex Potonié

Trilobosporites apiverrucatus Couper

Plate I, figure 22

Abundance. One specimen only; probably reworked.

Comments. In the Russian literature, this form is known as Lygodium mirabilis and has its counterpart in spores of the modern genus Lygodium (Bolkhovitina, 1959).

Remarks on family Schizaeaceae. The Schizaeaceous ferns have a fossil record that extends back to the Carboniferous. That the family was widespread during the Mesozoic is indicated by abundant fronds, sporangia and dispersed spores. From the Cretaceous to the present, fossils assignable to the four modern genera are abundant, but from the middle Cretaceous to the present they have shown an increasingly restricted distribution.

Today the family is represented by four genera and about 160 species of terrestrial ferns. They are mostly tropical and subtropical with a few representatives from warm temperate regions (Bolkhovitina, 1959; Lawrence, 1951; Scagel et al., 1965).

Family Gleicheniaceae

Form Genus Gleicheniidites Ross

Gleicheniidites senonicus Ross

Plate I, figure 23

Abundance. Abundant in all samples.

Comments. We have included a rather wide variety of morphological variation in this species, and although they may or may not be all included in the same natural species, there is no doubt they all belong to the same genus.

Remarks on Gleicheniaceae. Plants of this family have been found in rocks ranging in age from the Carboniferous to the present. They were widespread throughout the Mesozoic, reaching a maximum distribution during Cretaceous time. At the time of their maximum extension they extended as far north as Spitzbergen and Greenland, and as far south as Patagonia. Apparently, Tertiary climatic cooling caused the extinction of this family in what is now the temperate northern hemisphere.

The family now consists of one genus, Gleichenia, a terrestrial fern with four subgenera. Although a few temperate species occur in southern Europe and the southern United States, they are in the main a tropical fern, often of the drier habitats (Andrews, 1961; Boulter, 1971; Gray and Groot, 1966; Lawrence, 1951; Scagel et al., 1965).

Family Cheiroleuriaceae

Form genus Dictyophyllidites (Couper) Dettmann

Dictyophyllidites sp.

Plate I, figure 24

Abundance. Moderately common.

Family cf. Polypodiaceae

Form Genus Laevigatosporites (Ibrahim) Schopf, Wilson & Bentall

Laevigatosporites ovatus Wilson and Webster

Plate I, figure 25

Abundance. Rare.

Comments. Although psilate monolete spores are most characteristic in the Polypodiaceae, they do occur in virtually all the fern families, including the Gleicheniaceae.

Remarks on Polypodiaceae. The earliest representatives of this family are found in the Triassic. In the northern hemisphere, the family rapidly declined in significance from the Cretaceous through the Tertiary. Approximately 20 extant genera are distributed through the tropics and subtropics (Scagel et al., 1965).

Family Cyatheaceae and/or Dicksoniaceae

Form Genus Cyathidites Couper

Cyathidites australis Couper

Plate II, figure 26

Abundance. Rare.

Cyathidites minor Couper

Plate II, figure 27

Abundance. Rare.

Remarks on Cyatheaceae and Dicksoniaceae. It is frequently difficult, or impossible, to separate these two families on the basis of spore morphology alone. Both of these families have been traced back to the Jurassic and appear to have been moderately abundant during the later Mesozoic. At the present time, both families are subtropical to tropical, though some species extend into the warm temperate regions (Hedlund, 1966; Scagel et al., 1965).

Spores - Incertae Sedis

Form Genus Deltoidospora (Miner) Potonié

Deltoidospora juncta (Kara-Murza) Singh

Plate II, figure 28

Abundance. Rare.

Comments. Gleicheniaceae ?

Deltoidospora sp.

Plate II, figure 29

Abundance. Rare.

Comments. Gleicheniaceae?

Form Genus Reticulatisporites (Ibrahim) Potonié and Kremp

Reticulatisporites sp.

Plate II, figure 30

Abundance. Rare.

Comments. Lycopodiaceae?

Form Genus Undulatisporites Pflug in Thomson and Pflug

Undulatisporites sp.

Plate II, figure 31

Abundance. Rare.

Form Genus Verrucosisporites (Ibrahim) Potonié and Kremp

Verrucosisporites sp.

Plate II, figure 32

Abundance. Rare.

Form Genus Trilites Cookson ex Couper

Trilites sp.

Plate II, figure 33

Abundance. One specimen only observed.

Comments. Lycopodiaceae?

Division PTERIDOSPERMOPHYTA

Family Caytoniaceae

Form Genus Vitreisporites (Leschik) Jansonius

Vitreisporites pallidus (Reissinger) Nilsson

Plate II, figure 34

Abundance. Fairly common in all samples.

Remarks on Division Pteridospermophyta. The pteridosperms, now extinct, have a fossil record ranging from the Lower Carboniferous to the Cretaceous. The family Caytoniaceae is represented by abundant vegetative remains in rocks ranging in age from Triassic to Early Cretaceous, with pollen extending at least through the Cenomanian (Couper, 1958; Scagel et al., 1965). Because there are no modern "seed ferns", little can be said about their ecological requirements.

Division CYCADOPHYTA

Order Bennettitales

Form Genus Cycadopites Wodehouse ex Wilson and Webster

Cycadopites cf. C. scabratus Stanley

Plate II, figure 35

Abundance. Rare.

Cycadopites sp.

Plate II, figure 36

Abundance. Rare.

Comments. Monocolpate pollen grains are widespread in Mesozoic rocks throughout the world. The ginkgophytes, the cycadophytes, and many of the Mesozoic pteridosperms have monocolpate pollen of the same general morphology, with overlapping size ranges and blending morphological characteristics. Generally it seems possible to separate ginkgophyte from cycadophyte pollen on the basis of a width-length ratio. Furthermore, monocolpate pollen grains greater than 50μ in length are known only from the Bennettitales (see below for exception); consequently, we feel the most likely assignment for these grains lies in this order (Couper, 1958; Wodehouse, 1935).

It should be pointed out that the Magnoliaceae, among perhaps the earliest of angiosperms, has pollen virtually indistinguishable from that of the Bennettitales. Indeed, it has been pointed out (Wieland, 1929) that the two groups may have had the same genetic origin. Consequently, a remote possibility exists that we have here the pollen of very early representative of the Magnoliaceae; unfortunately, this can not be demonstrated without fructifications and vegetative remains.

Remarks on Division Cycadophyta. The extant order, Cycadales, was widespread throughout the Mesozoic, but has steadily declined from the Jurassic through to the present. The nine existing genera are found in limited parts of the tropics and subtropics.

The Bennettitales evolved in the Carboniferous or Permian, reaching a maximum extent during the Jurassic, then declining to extinction in the Late Cretaceous. Presumably they existed in an environment similar to that of the Cycadales.

The Magnoliaceae, considered the earliest and most primitive of angiosperm families, are largely north-temperate to tropical in environment (Scagel et al., 1965; Willis, 1966).

Division GNETOPHYTA

Family Ephedraceae

Genus Ephedra L.

Ephedra sp.

Plate II, figure 37

Abundance. Rare.

Remarks on Ephedraceae. The history of this family is obscure, but fossil pollen grains of Ephedra-type morphology are found back to the Permian. The Ephedraceae, now represented by the one genus, Ephedra, and 40 species, is distributed in warm temperate latitudes. Ephedra is xerophytic and grows best on sandy or rocky sites (Scagel et al., 1965; Willis, 1966).

Division CONIFEROPHYTA

Order Coniferales

Family Pineaceae

Form Genus Tsugaepollenites (Potonié and Venitz) Potonié

?Tsugaepollenites sp.

Plate II, figure 38

Abundance. Several specimens found.

Comments. The writers feel considerable doubt about this identification. It is possible they are aberrant pollen grains of Sciadopitys.

Genus Cedrus Link

cf. Cedrus sp.

Plate II, figure 39

Abundance. Rare.

Miscellaneous bisaccate conifer pollen

Not Illustrated

Abundance. Always present, but never abundant.

Comments. A number of nondescript bisaccate conifer pollen was encountered, showing varying size and morphology. All are assigned to the Pineaceae and most are probably assignable to, or closely related to, the modern genus Pinus.

Remarks on Pineaceae. This family has a fossil record extending back to the Jurassic; Pinus has been recovered from Lower Cretaceous rocks, but other genera are not recognized in rocks older than Upper Cretaceous or Tertiary. The family is almost exclusively distributed in temperate areas of the northern hemisphere (Scagel et al., 1965).

Family Taxodiaceae

Genus Taxodium Richard

Taxodium cf. T. hiatipites Wodehouse

Plate II, figure 40

Abundance. Moderately common.

Genus Glyptostrobus Endlicher

Glyptostrobus cf. G. vacuipites Wodehouse

Plate II, figure 41

Abundance. Occasional.

Genus Metasequoia Miki ex Ilu and Cheng

cf. Metasequoia sp.

Plate II, figure 42

Abundance. Occasional.

Comments. A questionable identification is given here because of the frequent difficulty of separating pollen of the genera Metasequoia, Sequoia, and Cryptomeria. Obviously, morphologic separation of Cretaceous specimens is even more difficult. The papillae on the specimens encountered here tend to be larger than those encountered in any of the modern genera.

Genus Sciadopitys Siebold and Zuccarini

Sciadopitys sp.

Plate II, figure 43

Abundance. Rare.

Comments. Many will take exception to the application of modern generic names in this family. However, this was done partly because all these grains (with the exception of cf. Metasequoia) appear identical to modern forms. It is known that the fossil record of the Taxodiaceae goes well back into the Mesozoic with most of the extant genera becoming distinct in the Cretaceous or early Tertiary. Fossil evidence indicates that Sequoia, Metasequoia, Taxodium and Glyptostrobus were widespread tree elements in the early Tertiary (Scagel et al., 1965) hence they probably had a significant pre-Tertiary history. We feel it probable that the Hassel taxodiaceous genera were sufficiently close to the modern forms to justify the use of a modern generic name.

Remarks on Taxodiaceae. A family of ten genera now restricted to Tasmania, eastern Asia and North America, living mainly in temperate to warm temperate climates (Lawrence, 1951; Willis, 1966). According to Piel (1971, p. 1893), distribution of the modern Taxodium distichum "corresponds very closely to the summer-wet, winter-dry areas of 35-50 in. annual rainfall. The maximum development of the species is in the area where the summer and winter temperatures are over 80° F and 48-64° respectively."

Family Podocarpaceae

Genus Podocarpidites Cookson ex Couper

cf. Podocarpidites sp.

Plate II, figure 44

Abundance. Rare.

Remarks on Podocarpaceae. Pollen attributable to this family has been reported in low amounts from most Cretaceous rocks of the Northern Hemisphere. Oddly enough, unquestioned megafossils of this family are rare in the Northern Hemisphere Cretaceous although, recently, Ramanujam (1972) identified fossil wood as Podocarpaceae from the Campanian of Alberta. Leaves found in other areas in rocks of various ages occasionally bear a resemblance to Podocarpaceae (see MacGinitie, 1953) but these leaves also bear resemblance to those of the Taxaceae, such as Torreya or Cephalotaxus. Because of the rarity of undoubted Cretaceous megafossils of the Podocarpaceae, the possibility remains that Podocarpus was very rare in North America, and that the pollen grains described from this family may in fact be abortive or freak bisaccate grains of other conifer genera. Hence the generic identification here is questioned pending further study.

If members of the Podocarpaceae did exist in North America during the Cretaceous, the family must have retreated southward during the Tertiary, because their northern limit is now Mexico in the Americas, and China-Japan in Asia (Boulter, 1971; Gray and Groot, 1966; Hopkins, 1971a; Scagel et al., 1965).

Families Cupressaceae or Taxaceae

Form Genus Inaperturopollenites Thomson and Pflug

Inaperturopollenites sp.

Plate II, figure 45

Abundance. Abundant.

Comments. Pollen of the Cupressaceae and Taxaceae generally are not diagnostic and it is virtually impossible to separate them. Morphologically most of the grains encountered are identical to pollen from modern Juniperus.

Remarks on Cupressaceae and Taxaceae. The Taxaceae has a fossil record extending back to the Carboniferous, and has been distinct from other conifer families since that time, including the Cupressaceae which has a fossil record back to the early Mesozoic. Although there is no known relationship, pollen of the two families are very similar, and are usually difficult to distinguish. The Cupressaceae is a large family of 16 genera, which are mainly temperate conifers, and most abundant in the northern hemisphere. The Taxaceae is a smaller family of 3 genera, mostly restricted to temperate parts of the northern hemisphere (Lawrence, 1951; Scagel et al., 1965; Willis, 1966).

Family Cheirolepidaceae

Form Genus Classopollis (Pflug) Pocock and Jansonius

Classopollis classoides (Pflug) Pocock and Jansonius

Plate II, figure 46

Abundance. Rare.

Remarks on Cheirolepidaceae. This is an extinct family with several megafossil conifer genera, all of which have pollen of the Classopollis-type (Barnard, 1968).

Incertae Sedis

Form Genus Eucommiidites (Erdtman) Couper

Eucommiidites troedssonii Erdtman

Plate II, figure 47

Abundance. Very rare.

Comments. Eucommiidites is thought to be related to the Ginkgoales, Cycadales or Pteridosperms, or even possibly to some totally unknown plant (Reymanowna, 1968).

Division ANTHOPHYTA

Class Dicotyledonae

Form Genus Tricolpopollenites Pflug in Thomson and Pflug

Tricolpopollenites cf. T. crassimurus Groot and Penny

Plate II, figure 48

Abundance. Rare.

Tricolpopollenites cf. T. elongatus Groot and Groot

Plate II, figure 49

Abundance. Rare.

Tricolpopollenites cf. T. parvulus Groot and Penny

Plate II, figure 50

Abundance. Rare.

Form Genus Retitricolpites van der Hammen ex Pierce

Retitricolpites sp.

Plate II, figures 51, 52

Abundance. Occasional.

Form Genus Tricolpites Cookson ex Couper

Tricolpites sp.

Plate II, figure 53

Abundance. Rare.

Comments. Species differentiation of these small and comparatively simple tricolpate grains is a dubious exercise at best. The significant fact is the appearance of tricolpate pollen grains and their definite diversification into various morphological types.

Smiley (1966) remarked that the oldest angiosperm leaves found in northern Alaska were in the late Albian Kungok flora, and these appear to be some sort of water lily. Later, Smiley (1967) added that only very few angiosperm leaves were found in the Albian and they appear to be referable to the families Lauraceae and Sterculiaceae. Interestingly enough, several genera of the Sterculiaceae have small, reticulate tricolpate pollen similar to some of those encountered in this study.

Remarks on Anthophyta. The plant associations of these tricolpate pollen grains are not known. However, both the Sterculiaceae and Lauraceae are tropical to subtropical with a few representatives extending into the warm temperate (Smiley, 1967; Willis, 1966).

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- Figure 25. Laevigatosporites ovatus Wilson and Webster (x1000)
(GSC loc. C-11065) (31763)

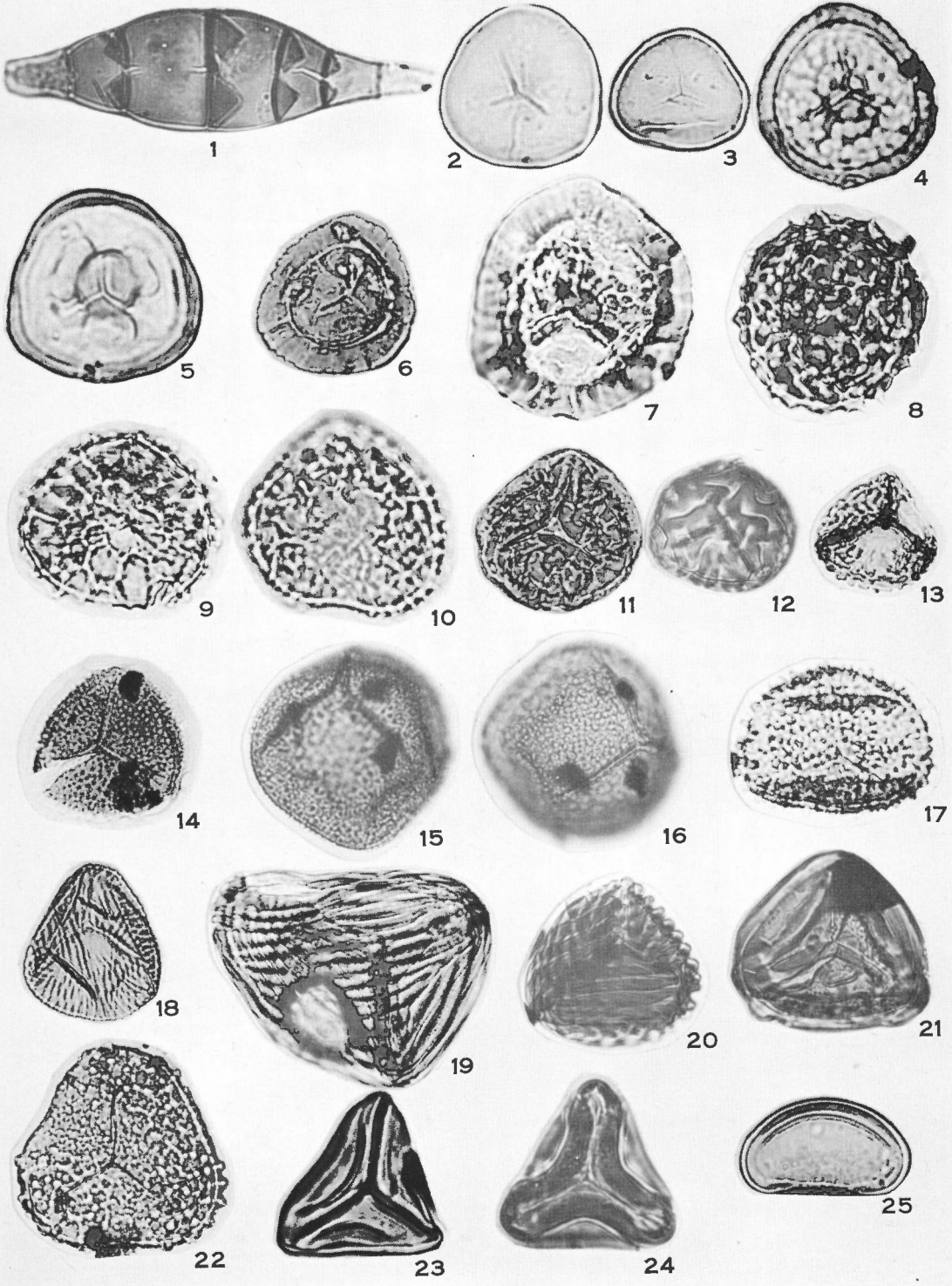


Plate II

- Figure 26. Cyathidites australis Couper (x500)
(GSC loc. C-11055) (31764)
- Figure 27. Cyathidites minor Couper (x500)
(GSC loc. C-11068) (31765)
- Figure 28. Deltoidospora junctum (Kara-Murza) Singh (x1000)
(GSC loc. C-11068) (31766)
- Figure 29. Deltoidospora sp. (x500)
(GSC loc. C-11056) (31767)
- Figure 30. Reticulatisporites sp. (x500)
(GSC loc. C-11055) (31768)
- Figure 31. Undulatisporites sp. (x1000)
(GSC loc. C-11064) (31769)
- Figure 32. Verrucosiporites sp. (x1000)
(GSC loc. C-11078) (31770)
- Figure 33. Trilites sp. (x1000)
(GSC loc. C-11065) (31771)
- Figure 34. Vitreisporites pallidus (Reissinger) Nilsson (x500)
(GSC loc. C-11055) (31772)
- Figure 35. Cycadopites cf. C. scabratus Stanley (x500)
(GSC loc. C-11055) (31773)
- Figure 36. Cycadopites sp. (x500)
(GSC loc. C-11066) (31774)
- Figure 37. Ephedra sp. (x1000)
(GSC loc. C-11068) (31775)
- Figure 38. ?Tsugaepollenites sp. (x500)
(GSC loc. C-11055) (31776)
- Figure 39. cf. Cedrus sp. (x500)
(GSC loc. C-11065) (31777)
- Figure 40. Taxodium cf. T. hiaticipes Wodehouse (x500)
(GSC loc. C-11065) (31778)
- Figure 41. Glyptostrobus cf. G. vacuipites Wodehouse (x750)
(GSC loc. C-11068) (31779)
- Figure 42. cf. Metasequoia sp. (x1000)
(GSC loc. C-11066) (31780)
- Figure 43. Sciadopitys sp. (x500)
(GSC loc. C-11066) (31781)
- Figure 44. cf. Podocarpidites sp. (x500)
(GSC loc. C-11063) (31782)
- Figure 45. Inaperturopollenites sp. (x1000)
(GSC loc. C-11065) (31783)
- Figure 46. Classopollis classoides (Pflug) Pockock and Jansonius (x500)
(GSC loc. C-11060) (31784)
- Figure 47. Eucommiidites troedssomi Erdtman (x1000)
(GSC loc. C-11066) (31785)
- Figure 48. Tricolpopollenites cf. T. crassinurus Groot and Penny (x1000)
(GSC loc. C-11065) (31786)
- Figure 49. Tricolpopollenites cf. T. elongatus Groot and Groot (x1000)
(GSC loc. C-11068) (31787)
- Figure 50. Tricolpopollenites cf. T. parvulus Groot and Penny (x1000)
(GSC loc. C-11064) (31788)
- Figures 51, 52. Retitricolpites sp. (x1000)
(GSC loc. C-11065, C-11064) (31789, 31790)
- Figure 53. Tricolpites sp. (x1000)
(GSC loc. C-11078) (31791)

