

PALYNOLOGICAL STUDY OF THE CONTINENTAL SHELF
SEDIMENTS OF THE LABRADOR SEA

by

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ABSTRACT

A detailed palynological examination was made of Tertiary pollen and spore assemblages from six exploratory wells located along the continental margins of the Labrador Sea. From north to south, the study wells are Kangamiut 1, Hekja O-71, Karlsefni A-13, Herjolf M-92, Roberval K-92 and Cartier D-70. Using local extinction events of zonally diagnostic species to define the tops of intervals, eight provisional pollen and spore zones were established. The zones and their relative ages are as follows: *Tsuga igniculus* (middle to late Miocene); *Fagus granulata* (early to middle Miocene); *Parviprojectus* sp. A (early Oligocene); *Araliaceopollenites megaporifer* (latest Eocene/earliest Oligocene); *Rhoipites latus* (middle to late Eocene); *Pistillipollenites mcgregorii* (early to middle Eocene); *Tricolpites* sp. A (middle to late Paleocene); and *Paraalnipollenites alterniporus* (early to middle Paleocene). The middle and upper Oligocene is apparently absent in the study wells.

When used in conjunction with dinoflagellate assemblages, the zonation provides the potential for additional biostratigraphic resolution in the Tertiary marine sediments of the Labrador Sea. It is especially useful in upper Eocene and stratigraphically higher sections in which pollen and spores are the dominant component of the palynoflora. In addition, the basic similarity of pollen and spore assemblages across much of

northern and western Canada suggests the zonation may also be successfully applied in those regions.

The relative abundance and distribution of four major populations (i.e., Paleozoic, Upper Jurassic/Lower Cretaceous, Upper Cretaceous and Paleogene) of redeposited palynomorphs were determined. The species composition of recycled and in-situ Paleogene palynomorphs supports independent clay mineralogical data that much of the sediment (including a high percentage of the palynomorphs) was delivered to offshore Labrador Sea basins via a "super" river system that drained a large portion of the western interior and Arctic regions of Canada during the Tertiary.

The taxonomic composition of the indigenous Paleogene pollen and spore flora supports both paleontological and isotope data that relatively high paleotemperatures prevailed at high northern latitudes during the Paleogene. The climatic optimum in the Labrador Sea region was reached in the early to early-middle Eocene.

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CHAPTER 1. GENERAL INTRODUCTION TO PALYNOLOGICAL STUDY OF THE CONTINENTAL SHELF SEDIMENTS OF THE LABRADOR SEA

The continental margins of the Labrador Sea and their structural configuration provide a favorable setting for petroleum exploration. The Labrador Sea is situated between Labrador and western Greenland approximately between the latitudes of 53° and 66°N (see Figure 1 for a map of the region). Southern Baffin Island and Davis Strait mark the northern boundary of the basin and, to the south, it is bounded by the Cartwright Arch and the Farewell Fracture Zone. The continental shelves extend offshore for tens of kilometers and, beyond an inner belt of Precambrian rocks, are characterized by thick sequences of predominantly Cretaceous and Tertiary sediments with isolated outliers of Paleozoic strata. During the past couple of decades, numerous magnetic and seismic geophysical surveys have been taken across the various basins and in 1971 the first exploratory well was drilled off southern Labrador. Since then, over 25 wells have been drilled on the continental shelves of Labrador, southern Baffin Island and western Greenland. Significant hydrocarbon discoveries have been found in several wells off Labrador and southern Baffin Island and the discovery of additional oil and gas reserves are anticipated (McMillan, 1980).

This intensive drilling activity has provided numerous cuttings and sidewall core samples for paleontological, geochemical and sedimentological analyses, which have resulted in the generation of a

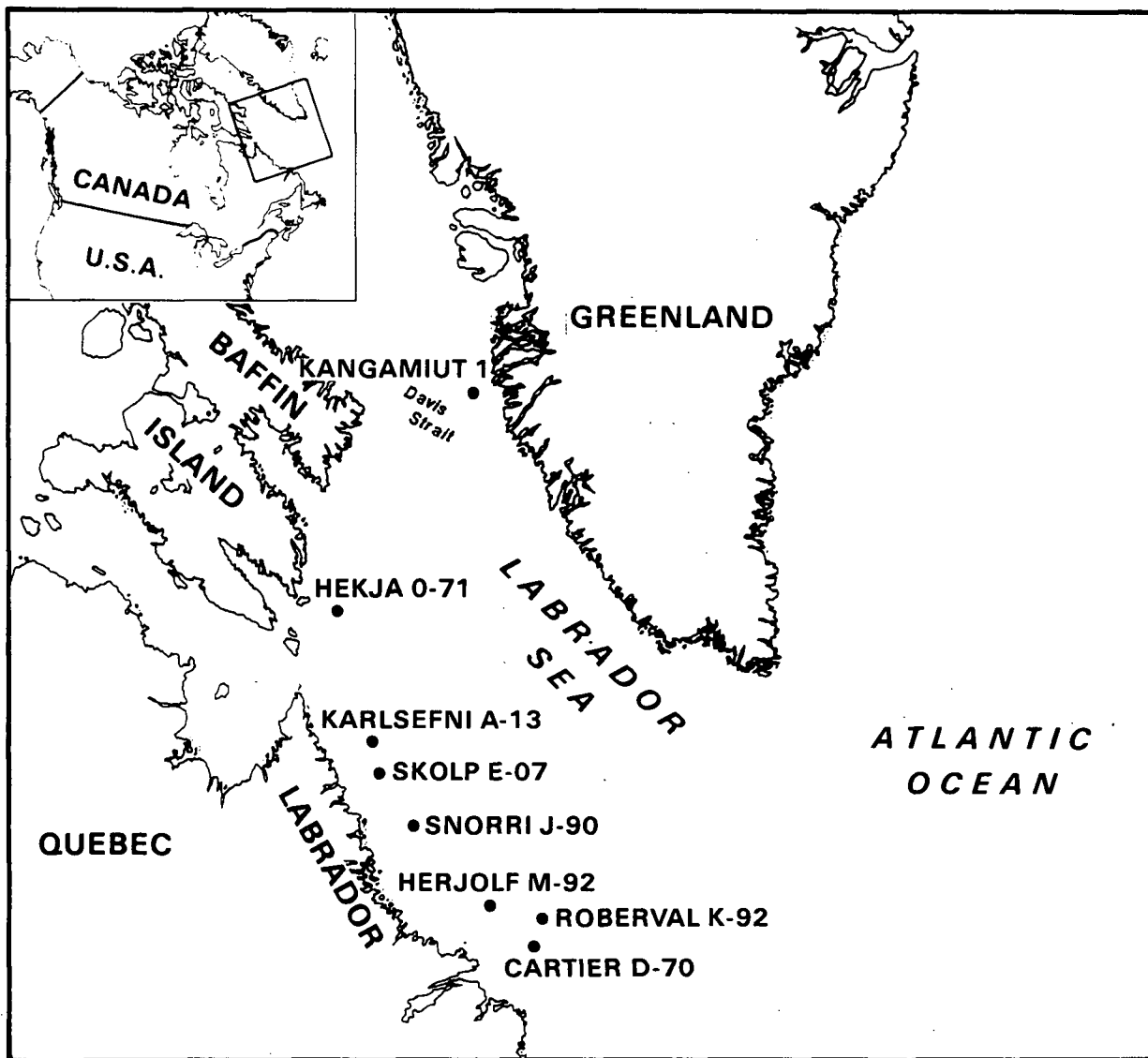


Figure 1. Location map of the Labrador Sea and the eight offshore wells used in this study.

large volume of data regarding the shelf sediments and geological history of the Labrador Sea. To help aid the understanding of the stratigraphy and paleoecology of the region, the palynology of selected Cretaceous and Tertiary intervals of seven Labrador Sea wells were examined in detail. The objectives of this research were to:

- (1) establish a provisional palynological zonation of the Tertiary marine sediments of the Labrador Sea based on pollen and spores, to be used as a framework for more detailed biostratigraphic studies;
- (2) identify various different age-categories of recycled palynomorphs and determine their relative distribution through time along the Labrador shelf;
- (3) interpret the likely provenance of the Paleogene sediments of the Labrador Sea based upon the palynofloral composition of contemporaneous and recycled palynomorph assemblages; and
- (4) interpret the general paleoclimatic trends that persisted in the general Labrador Sea region during the Paleogene.

Seven Labrador Sea wells were examined in detail. From north to south they are Kangamiut 1, Hekja O-71, Karlsefni A-13, Skolp E-07, Herjolf M-92, Roberval K-92 and Cartier D-70. An eighth well, Snorri J-90,

was examined for recycled palynomorphs. The location of each of the study wells is shown in Figure 1. Prepared palynological slides of selected sections from Kangamiut 1, Karlsefni A-13, Skolp E-07, Herjolf M-92 and Cartier D-70 were provided on loan from Total-Eastcan. The sampling interval for most of these samples was broadly spaced (approximately 100 meters); and cuttings were the most predominant type of sample used. Washed cuttings from Roberval K-92 and unwashed cuttings from Hekja O-71 were provided by Aquitaine of Canada Ltd. (now Canterra) and processed in the palynological laboratory at the University of British Columbia. The Snorri J-90 samples were studied at the Atlantic Geoscience Center in Dartmouth, Nova Scotia, where they are on file.

The most northerly of the wells examined was Kangamiut 1, which lies approximately 120 kilometers offshore West Greenland at latitude 66°N. Drilled on a structural high, Kangamiut 1 penetrated Precambrian gneiss at a depth of 3874 meters (Henderson et al., 1980). Hekja O-71 was drilled offshore southern Baffin Island to a depth of 4566 meters. The basal 1000 meters of Hekja O-71 is comprised of alkalic volcanics interbedded with chalky clays (Klose et al., 1982). At a depth of 3212 meters a gas/condensate zone in a Paleocene sand was discovered (McMillan, 1982).

Of the five wells from offshore Labrador that were studied in detail, fairly complete sections of Tertiary sediments were penetrated in

Karlsefni A-13, Herjolf M-92, Cartier D-70 and Roberval K-92. Upper Cretaceous marine and Lower Cretaceous fluvial sands of the Bjarni Formation were encountered in Skolp E-07, Herjolf M-92 and Roberval K-92. In Roberval K-92, a thin Paleozoic carbonate was found beneath Lower Cretaceous volcanics of the Alexis Formation.

The wells were drilled on elevated blocks associated with a northwest-southeast trending structural basin, the Eric Graben, which lies roughly parallel to the east coast of Labrador. The graben is infilled with a thick sequence of Lower Cretaceous, non-marine fluvial sediments of the Bjarni Formation. The first indication of oil on the Labrador Shelf came from a core of the Bjarni sand in Roberval K-92 (McMillan, 1982). Although no significant hydrocarbon discoveries were made in any of the study wells, five large gas/condensate and one oil show were reported from six other Labrador Sea wells.

GEOLOGICAL HISTORY OF THE LABRADOR SEA

Magnetic and seismic geophysical surveys of the Labrador Sea indicate a sea-floor spreading model for the origin of the Labrador Sea. The north-south trending mid-Labrador oceanic ridge is positioned approximately midway between Labrador and West Greenland and represents the western arm of a triple junction with the mid-Atlantic ridge. There is a gravity low in the middle of the basin which is associated with

the median valley of the Labrador Sea ridge. Also, on the Labrador side of the ridge axis the structure is progressively more disturbed from south to north (Hinz et al., 1979; and Srivastava et al., 1980).

Van der Linden (1975), Srivastava (1978), Hinz et al. (1979), Umpleby (1979), Gradstein and Srivastava (1980), Grant (1980), McWhae (1981) and Srivastava et al. (1980) discuss in detail the history of the Labrador Sea. The initial stage of the break-up between Greenland and Labrador was characterized by an updoming of the continental crust followed by rifting. During uplift, normal faulting perpendicular to the present Labrador coastline formed horst and graben structures. Thick sequences of non-marine fluvial sediments were shed into the newly formed structural basins. Lamprophyre dikes on southern Labrador and western Greenland and basalt flows on the Labrador and, possibly, the southern Baffin Island shelves indicate an Early Cretaceous age for the rifting. Eventually, oceanic material was created and actual sea-floor spreading commenced during Anomaly 32 time (Gradstein and Srivastava, 1980). The actual location of the continental-oceanic crust boundary in the Labrador Sea is uncertain however. The earliest marine sediments identified palynologically (Barss et al., 1979; this study) on the Labrador shelf indicate that the incursion of marine waters into the newly formed basin did not occur until the early Late Cretaceous (Cenomanian to Coniacian). The opening phase of the Labrador Sea coincided with a widespread marine transgression that persisted into the Eocene (Gradstein and Berggren,

1981). By the late Eocene, just prior to Anomaly 13, spreading activity in the Labrador-Baffin Bay region ceased and deeper water conditions were generally replaced by shallow marine facies (Gradstein and Srivastava, 1980).

LITHOSTRATIGRAPHY

PRECAMBRIAN

The structurally complex Precambrian geology and orogenic history of the Labrador, southern Baffin Island and West Greenland region are discussed by Higgs (1977), Umpleby (1979) and Srivastava et al. (1980). Precambrian Shield rocks outcrop extensively on landmasses surrounding the Labrador Sea. In eastern Labrador three Precambrian structural provinces are present. Granitic and granodioritic gneisses of the Nain Province lie along Labrador's east coast. West of the Nain Province, the northern coast of Labrador and Baffin Island lie within the Churchill Province which is characterized by high-grade metamorphics (e.g., migmatites, granulites and granulitic gneisses) and anorthosite plutonics. The southern coast of Labrador is included in the Grenville Province. Though small outcrops of metasediments are present, it is mainly characterized by amphibolite-granulite facies metamorphics cut by igneous intrusives. The Precambrian of western Greenland is characterized by acidic plutonics and supracrustal

metasediments and metavolcanics. Seismic reflectors and well data show that Precambrian shield rocks extend seaward and underlie thick wedges of Cretaceous and Tertiary sediments of the Labrador and West Greenland continental margins. These basement rocks were penetrated in Kangamiut 1, Karlsefni A-13, Herjolf M-92, Cartier D-70 and Roberval K-92 which were drilled on structural highs.

PALEOZOIC

Paleozoic rocks are poorly represented in Labrador Sea sediments and on adjacent landmasses. They represent isolated remnants of a sedimentary cover that was laid down in a Lower Paleozoic epeiric sea. Epeirogenic uplift associated with the Taconic and Acadian Orogenies of the Appalachian System to the south helped cause the retreat of the sea from the Labrador-West Greenland region (McWhae, 1981). Outliers of Ordovician and Carboniferous carbonates preserved in the Eric Graben have been penetrated in several wells drilled on the Labrador Shelf. The locations of these outliers are important because of their gas reservoir potential. Other occurrences of Paleozoic rocks in the area include some Lower Paleozoic erratics and some outliers of Cambrian rocks along Labrador's southern coast. In West Greenland there is an outcrop of breccia which contains some Lower Paleozoic marine rocks, and off southern Baffin Island, Ordovician and possibly

Silurian carbonates were dredged and drilled by the Atlantic Geoscience Center (McMillan, 1980).

MESOZOIC AND CENOZOIC

The Mesozoic and Cenozoic rocks of the continental shelves of the Labrador Sea are primarily comprised of thick sequences of Cretaceous and Tertiary shales, mudstones and sandstones. Volcanics associated with episodes of tectonism are also found. Schematic lithostratigraphic columns of offshore Labrador and West Greenland are illustrated in Figure 2.

The oldest Mesozoic rocks found to date on the continental shelves of the Labrador Sea are volcanics. On the Labrador shelf they form the Alexis Formation which is characterized by repeated sequences of weathered and hydrothermally altered, grey to purplish to green-grey volcanics. The type section of the Alexis Formation was designated by Umpleby (1979) in the Bjarni H-81 well off southern Labrador. It was also penetrated in Leif M-48, Indian Harbour M-52, Roberval K-92 and Herjolf M-92. The Alexis Formation rests unconformably on much older Paleozoic and/or Precambrian basement rocks. The hiatus is regionally widespread and represents the Labrador Unconformity (McWhae, 1981). The top of the section varies depending upon location. Absolute K-Ar isotope dates on the volcanics range from approximately 104 to 139 Ma (McWhae and Michel, 1975). Assuming the latter age date is correct,

on the Harland et al (1982) geologic time scale the Alexis Formation was formed during the Early Cretaceous between latest Berriasian and late Barremian times. King and McMillan (1975) report sedimentary breccias cut by lamprophyre dikes on the east shore of Ford's Bight in southern Labrador. The dikes have been dated Early Cretaceous and are probably coeval with the Alexis Formation. Early Cretaceous volcanics may also be present on the southern Baffin Island shelf. The volcanism of the Alexis Formation marks the commencement of rifting in the Labrador Sea region prior to sea-floor spreading.

The good stratigraphic control established in the petroleum exploratory wells drilled along the continental margin of Labrador provides more information about the Mesozoic and Cenozoic rock sequence of the Labrador shelf than in the rest of the area. Based upon the work of Umpleby (1979), McWhae et al. (1980) and McMillan (1982), the Labrador shelf sedimentary units are briefly described in the next few pages.

Bjarni Formation.

The type section of the Bjarni Formation is located in Herjolf M-92 (Umpleby, 1979). It is characterized by non-marine, deltaic sediments consisting of mainly light brown to dark gray, coarse-grained arkosic sandstones. Silty shale and thin coal layers are found interbedded sporadically throughout the sands. Shales within the formation have been dated palynologically by Williams (Barss et al., 1979) who assigned an age ranging from Barremian to Albian. The top of the Bjarni

Formation is marked by the Avalon Unconformity (McWhae, 1981) which separates Bjarni continental molasse deposits from the overlying Markland Formation. The Labrador Unconformity separates the Bjarni Formation from Precambrian and Paleozoic basement rocks and, locally, it rests disconformably on the Alexis Formation. It is possible that sedimentation of the basal Bjarni Formation sands was contemporaneous with the youngest basalts of the Alexis Formation.

Markland Formation.

The Markland Formation consists mainly of fine- to very fine-bedded, green to dark grey shale and silty shale with rare interbeds of siltstone and sandstone. Thin dolomitic limestone beds are also locally present. The lithology is indicative of a marine neritic to upper bathyal depositional environment. In several wells, notably Freydis B-87 and Skolp E-07, drilled along the Labrador shelf, a shallow marine to paralic arenaceous facies is present, forming the Freydis Member of the Markland Formation. It consists of light grey fine- to coarse-grained quartzose sandstone and poorly sorted arkosic sandstone. The type section of the Markland Formation is in the Bjarni H-81 well (McWhae et al., 1980). It is also found in Gudrid H-55, Herjolf M-92, Freydis B-87 and Skolp E-07. Based upon foraminifera (Gradstein and Srivastava, 1980) and dinoflagellate (Barss et al., 1979) studies, the Markland Formation ranges in age from Cenomanian to early Paleocene. The Avalon Unconformity (McWhae, 1981) separates the base of the marine Markland Formation from the

underlying continental deposits of the Bjarni Formation or, in some wells, from older basement rocks. Deposition of the Markland Formation records the incursion of marine waters into the Labrador Sea basin upon sea-floor spreading.

Cartwright Formation.

The Cartwright Formation was redefined by McWhae et al. (1980) to include only the Tertiary section of the Cartwright Formation as defined by Umpleby (1979). It is characterized by a variety of lithologies including brown-grey claystone, siltstone and thin, fine-grained sandstone turbidite partings. Depending upon location, the Cartwright Formation rests conformably or disconformably on the more compact, uniform shales of the Markland Formation. This contact is easily distinguishable on seismic logs and represents McWhae's Bylot Unconformity. The type section is located in Bjarni H-81 and it is represented in most of the wells. Thickness of the Cartwright Formation varies from between 114 to 250 meters. Palynological and micropaleontological studies generally agree that the age of the Cartwright Formation ranges from middle Paleocene to early Eocene. Gradstein and Srivastava (1980) consider paleodepths as upper bathyal based upon benthic foraminiferal studies.

Gudrid Formation.

The Gudrid Formation is a quartzose and arkosic sandstone unit that is laterally equivalent to and interdigitated with the Cartwright Forma-

tion. It is also middle Paleocene to early Eocene in age. The type section is in the Gudrid H-55 well where it forms an almost 200 meter thick continuous sandstone unit. In Cartier D-70 it is divided into upper and lower tongues. The base of the formation rests on the Markland Formation at the Bylot Unconformity. The Gudrid Formation represents a turbiditic, deep-sea fan deposit. Foraminifera data (Gradstein and Srivastava, 1980) indicate these sands are deep neritic.

Mudstones (Kenamu Formation of McWhae et al., 1980).

Sediments overlying the Cartwright Formation are characterized by brown-grey marine shales, siltstones and fine-grained sandstone. The lower part is marked by a slightly calcareous and silty brown mudstone. Thin dolomitic limestone beds are found throughout the unit. Near the top of the section is an approximately 200 meter thick fine-grained, quartzose sandstone unit referred to as the Leif Sand. This unnamed Mudstone unit (Kenamu Formation) is well-represented in most of the wells. Foraminiferal studies (Gradstein and Srivastava, 1980) place the age of the sediments between early and late Eocene. Palynological studies (Barss et al., 1979; this study), on the other hand, indicate an early Eocene to earliest Oligocene age. Marine shelf and bathyal conditions prevailed during deposition of most of the mudstone; however, the light colored, clean Leif member sandstone is probably neritic or tidal in origin (Gradstein and Srivastava, 1980).

Mokami Formation.

An approximately 700 meter-thick brownish claystone and shale with thin beds of siltstone, sandstone, calcareous sandstone and limestone overlie, possibly unconformably, the mudstone (Kenamu Formation). The unit was named the Mokami Formation by McWhae et al. (1980) and represents part of Umpleby's (1979) Saglek Formation and the lower Saglek Mudstone of McMillan (1982). The age of the Mokami is not well established. However, foraminiferal studies (Gradstein and Berggren, 1981) indicate that it may range in age from early Oligocene to middle Miocene.

Saglek Formation

The Saglek Formation as defined by McWhae et al. (1980) is the uppermost pre-Quaternary unit on the Labrador shelf. It is comprised of unconsolidated, white or brown to grey feldspathic and cherty sands with silt and clay interbeds. The sediment is poorly sorted and contains abundant pelycepod fragments and some lignite. The unit is widespread on the Labrador shelf and reaches thicknesses of over 1000 meters in the northern part of the shelf. The top is bounded by poorly sorted, unconsolidated Quaternary glacial deposits at an erosional unconformity. It was laid down in a marginal to nearshore marine depositional environment. Although an age is difficult to assign to the Saglek because of the paucity of indigenous palynomorphs and an abundance of recycled forms in the sediments, it is probably late Miocene to Pliocene.

The general stratigraphy and structure of the southern Baffin Island continental shelf is briefly described by McMillan (1982) and Klose et al. (1982). Fairly thick sequences of Cretaceous and Tertiary clastic and volcanic rocks rest unconformably on either local outliers of Ordovician carbonates or Precambrian crystalline basement rocks. Much of our knowledge of the lithology comes from results of the two exploratory wells, Hekja O-71 and Gjoa G-37. Alkalic volcanics with interbedded shales and clays are found in the lower section of each well. The age of the volcanics is questionable. Potassium-argon dates on the lower basalts in Hekja O-71 vary from 105 to 119 Ma whereas paleontological data indicates an early Paleocene age. In Gjoa G-37 the K-Ar age of the uppermost basalt is approximately 56 Ma. The lavas were probably extruded along transform faults identified by geophysical surveys of the area. In Hekja O-71, the basalts are overlain by interbedded light colored sandstones (Hekja sand) and dark gray shales of Paleocene age. In Gjoa G-37 the sands are absent. Eocene and younger sediments generally consist of shallow neritic to neritic gray and brown interbedded shales, mudstones and siltstones. Some coal may be locally present.

Henderson et al. (1980), Manderscheid (1980) and Rolle (1985) discuss in detail the geology of the Cretaceous-Tertiary sedimentary basin offshore West Greenland. Near the Nussauq Embayment and Disko Island,

outcrops of Early Cretaceous upper delta-plain fluvial sediments are overlain by Upper Cretaceous and Paleocene marine mudstones and local interbeds of shale and sand. A thick sequence of Tertiary basalts cap the sediments. Offshore western Greenland, five dry exploratory wells between latitudes $64^{\circ}20'$ and 70°N were drilled. Unlike the Labrador shelf, the sedimentary cover of the continental margin off southwestern Greenland is fairly thin. Further north in the vicinity of Baffin Bay, the shelf widens and the sediments are considerably thicker.

Rolle (1985) of the Geological Survey of Greenland has divided the Upper Cretaceous and Tertiary sedimentary sequence into seven new formations (see Figure 2). The coarse-grained predominantly arkosic Narssarmitut Formation is discontinuous and generally equivalent to the Freydis Member of the Markland Formation along the Labrador shelf. The Ikermiut Formation is characterized mainly by a fairly low-energy shelf to deep marine transgressive sequence of dark gray carbonaceous shaley mudstones. It is fairly widespread and generally corresponds to the Late Cretaceous to Early Tertiary Markland and Cartwright Formations from offshore Labrador. The Hellefisk Formation is comprised generally of a gray to dark gray silty mudstone with poorly sorted calcareous sandstone interbeds. It was found in only one of the wells and probably interfingers laterally with the Ikermiut Formation. The Eocene Nukik Formation, which has no direct equivalent along the Labrador shelf, is characterized by interbedded, fairly thin turbiditic layers of unconsolidated sand and mud, arranged more or

less into a coarsening upwards sequence. Conformably overlying the Nukik is the late Eocene-Oligocene Kangamiut Formation. It consists of a fairly thick, predominantly unconsolidated sandstone with some interbeds of siltstone and mud. There are apparently no lithological units equivalent to the Kangamiut on the western side of the Labrador basin. The Manitsoq Formation (Oligocene? to Miocene) is characterized by an upward-coarsening argillaceous arkose with interbeds of light gray silty and sandy mudstone. It is widespread along the West Greenland shelf and is stratigraphically equivalent to the Saglek Formation from offshore Labrador. The Manitsoq is overlain by Miocene to Pleistocene unconsolidated argillaceous fine sands and muds. Rolle (1985) calls this upper unit the Ataneq Formation, however, its overall distribution is unknown as it was found in only one of the wells.

THESIS FORMAT

The main text of the thesis has been divided into four major chapters, which are to be submitted separately for eventual publication. Though interrelated, each of these sections deals with a specific problem regarding the palynology of the continental shelf sediments of the Labrador Sea. Preceding the main text is an introductory chapter (CHAPTER 1) in which the purpose of the thesis is stated and the general geology of the Labrador Sea is described. The final chapter (CHAPTER 6) summarizes the main points discussed in the thesis and

enumerates the major conclusions which resulted from the study. A brief description of the main body of the thesis follows.

The first major subject (CHAPTER 2) is stratigraphic rather than taxonomic and concerns the palynozonation of Tertiary sediments from the Labrador Sea. In this chapter, the results of my provisional pollen and spore zonation from six Labrador Sea wells are presented and compared with regional palynozones that were established by other workers who based their zones essentially upon the stratigraphic occurrences of dinoflagellates. What is being tested is whether or not the pollen and spores recovered from the predominantly marine Tertiary sediments can be used in conjunction with dinoflagellates and other marine algae to increase our biostratigraphic resolution along the continental shelves of the Labrador Sea. Charts showing the stratigraphic ranges of pollen and spore taxa found in the six wells used in this part of the study are located in the APPENDIX at the end of the thesis.

The second and third parts of the main text (CHAPTERS 3 and 4) address the problem of redeposited palynomorphs. The former discusses the relative merits of the different parameters used to recognize recyclants. In addition, the distribution and relative abundances of different age-categories of recycled palynomorphs in the Cretaceous and Tertiary sections of seven of the study wells are discussed. The latter chapter, on the other hand, focuses on the provenance of the

abundant recycled and contemporaneous Paleogene palynomorphs from the Labrador Sea.

The third major section (CHAPTER 5) of the thesis is interpretive and is based in part upon the results of the previous three chapters. Using published literature that relates fossil palynofloral assemblages with modern floral affinities of known climatic tolerance, the contemporaneous Lower Tertiary pollen and spore assemblages from the Labrador Sea are used to help describe the major climatic trends of the region during the Paleogene. These trends are compared with Tertiary climatic patterns of the Canadian Arctic, Alaska and British Columbia.

Because each of these sections has been written as a separate paper, there is some repetition at the beginning of each chapter with regards to the study wells and the general geology. Also, at the end of each section is a list of references cited in that particular chapter. A compilation of all of the references is located in the BIBLIOGRAPHY at the end of CHAPTER 6.

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CHAPTER 2. PROVISIONAL TERTIARY POLLEN AND SPORE ZONATION OF THE CONTINENTAL SHELF SEDIMENTS OF THE LABRADOR SEA

INTRODUCTION

Pollen and spores are commonly found in association with dinoflagellates in marine sediments. Their dispersal in the marine realm is influenced in large part by both the distance and mechanism of transport as well as by the hydrodynamic properties of the grains themselves. Significant concentrations exhibiting the greatest amount of diversity are most commonly associated with nearshore marine, delta lobe and turbidite sedimentary environments. Nevertheless, the stratigraphic utility of pollen and spores in marine sediments is often overlooked in lieu of dinoflagellate assemblages which are particularly suitable for defining zones. In intervals where the concentration of dinoflagellates in comparison to pollen and spores is low, or where only long-ranging dinoflagellate species persist, however, pollen and spore assemblages can be very useful for establishing biostratigraphic control.

Although the Cenozoic continental shelf sediments of the Labrador Sea have yielded a fairly diverse and abundant terrestrial microflora, pollen and spores have not been used up to this time to establish a biostratigraphic zonation for the Tertiary sediments of the Labrador

Sea. Previously established palynological zonations by Williams (*in* Gradstein and Williams, 1976; Williams and Bujak, 1977; Barss et al., 1979) and Ioakim (1979) are based almost exclusively upon dinoflagellate assemblages. Therefore, the Tertiary pollen and spore assemblages from six Labrador Sea wells (Figure 1) were examined in detail for the purpose of determining their biostratigraphic potential in the Labrador Sea region. Four of the wells, Karlsefni A-13, Herjolf M-92, Roberval K-92 and Cartier D-70 (from north to south), are located along the Labrador continental shelf. Hekja O-71 lies off the southern tip of Baffin Island and Kangamiut 1 is situated off the west coast of Greenland.

The generalized lithology and stratigraphic distribution of the Tertiary sections studied in each of the wells are illustrated in Figure 2. The dominant lithologies represented in the wells consist of shales, mudstones, siltstones and sandstones (Umpleby, 1979; McWhae et al., 1980; McWhae, 1981; McMillan, 1980, 1982). Foraminiferal data (Gradstein and Williams, 1981), from six offshore Labrador wells (including Karlsefni A-13, Herjolf M-92 and Cartier D-70) suggests bathyal (slope) to deep neritic deposition in the Paleocene and Eocene and a shift towards shallow neritic to marginal marine in the upper Oligocene, Miocene and Pliocene. Information from Karlsefni A-13 also suggests that non-marine deposition prevailed along the northern part of the shelf during much of the Miocene.

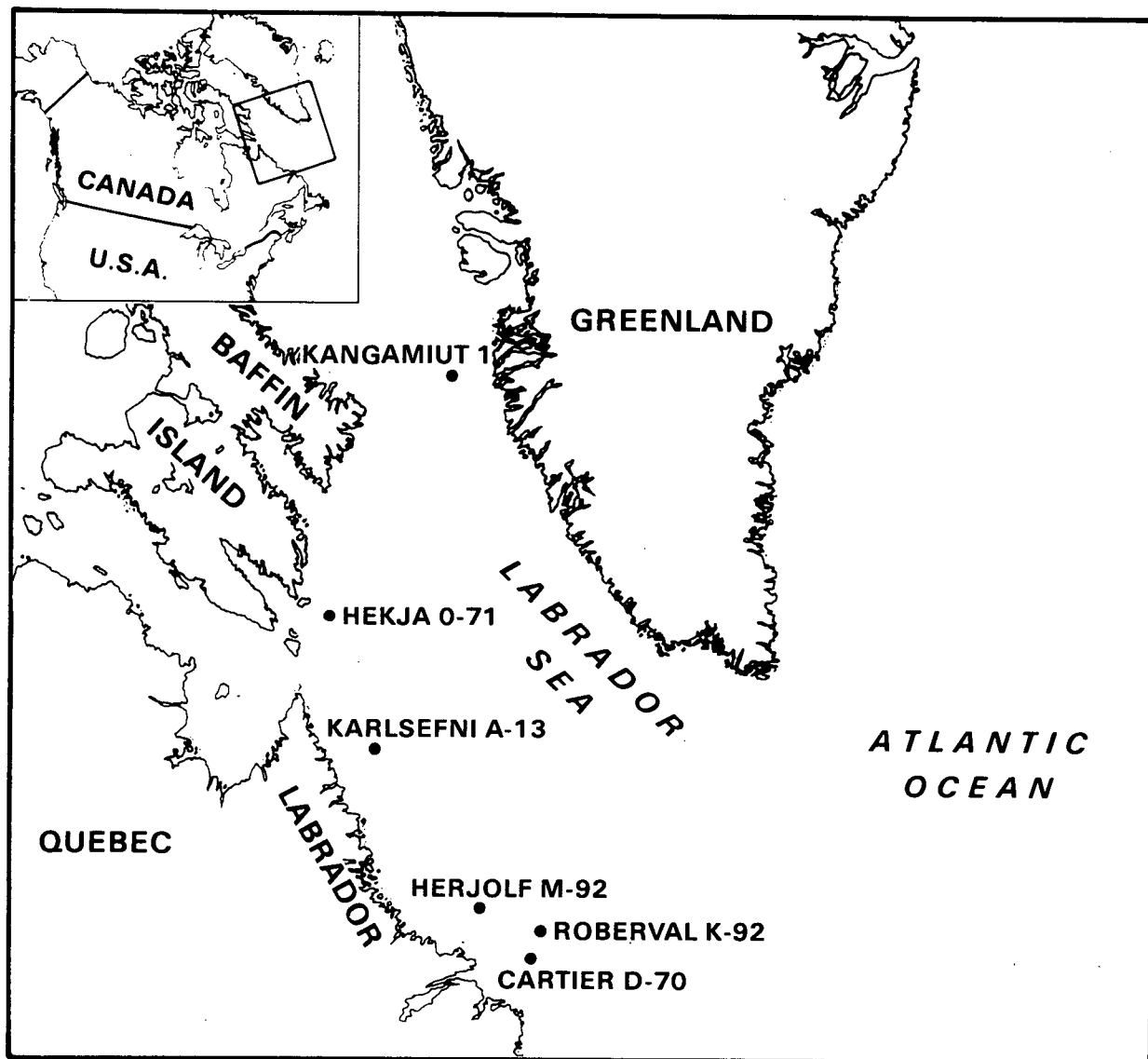


Figure 1. Location map of the Labrador Sea and the six offshore wells used in this study.

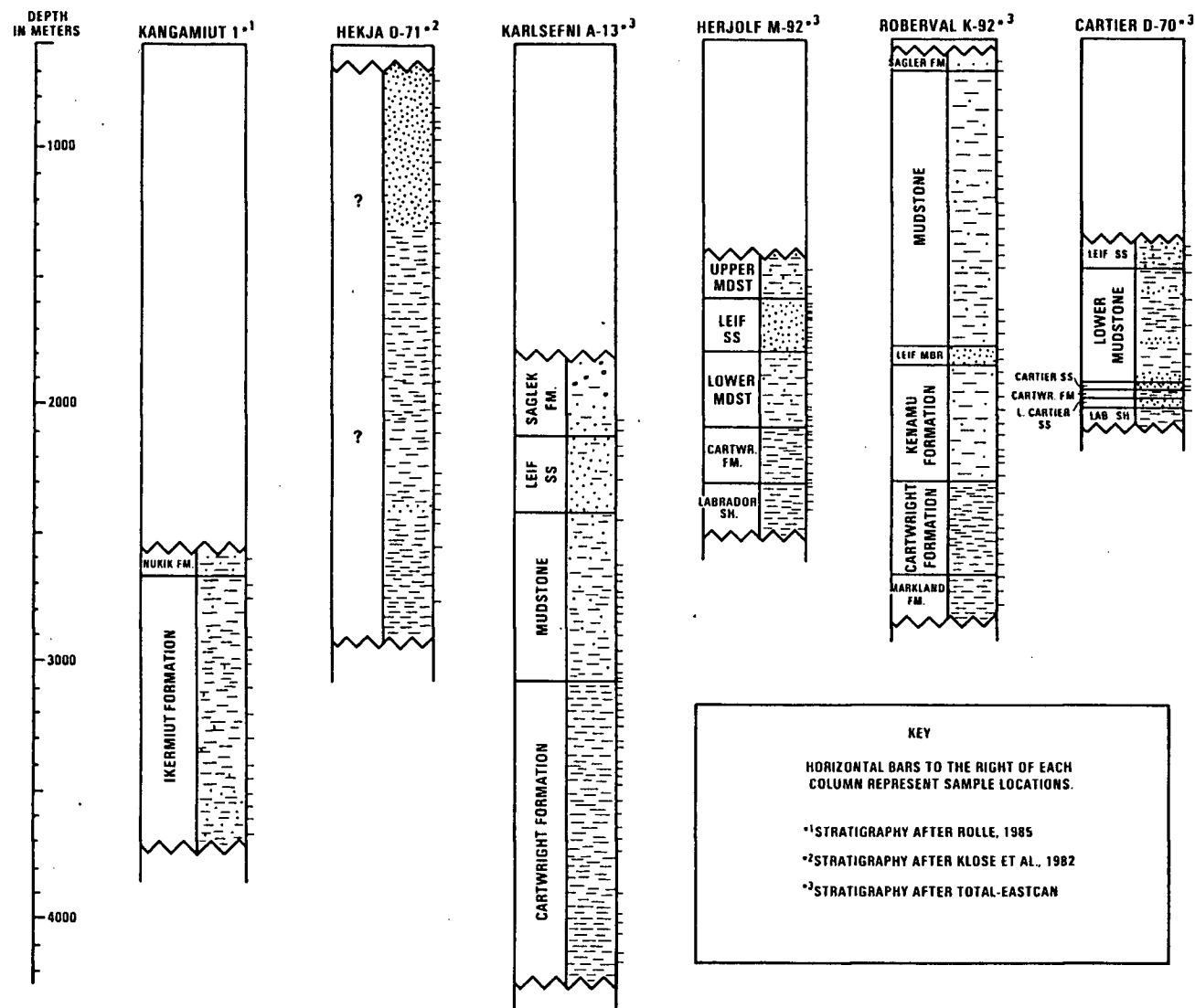


Figure 2. Generalized lithostratigraphic columns of the Tertiary sections of the six study wells.

The stratigraphic ranges of over 130 pollen and spore as well as 100 dinoflagellate species were recorded from 171 samples. Prepared palynological slides of selected Tertiary sections from Kangamiut 1, Karlsefni A-13, Herjolf M-92 and Cartier D-70 were provided on loan from Total-Eastcan courtesy of Dr. N. J. McMillan, then of Aquitaine. Most of these samples consisted of cuttings, although a few sidewall core samples were also made available. In addition, raw cuttings samples from Hekja O-71 and washed cuttings from Roberval K-92 were provided by Aquitaine (now Canterra) and processed at the University of British Columbia.

PREVIOUS WORK

Since the commencement of drilling in the circum-Labrador Sea region in 1971, two palynological zonations of Tertiary Labrador shelf sediments have been published. Both zonations are based primarily on local extinction events of zonally diagnostic dinoflagellate species.

A preliminary palynological examination of Cenozoic Labrador Shelf sediments was made and reported by Williams and Bujak (1977). Subsequent to this initial informal palynozonation, Williams (Barss et al., 1979) expanded the data base to encompass eleven wells including Karlsefni A-13, Herjolf M-92 and Cartier D-70. A total of ten

Cenozoic assemblage zones were identified. With the exception of the Pliocene-Pleistocene which was defined by the presence and abundance of the conifer pollen *Tsuga igniculus*, range tops of dinoflagellates were used to characterize the remaining zones. The distribution of zones as well as a list of selected palynomorphs found associated within individual zones are described for each well in Barss et al., 1979. The middle to late Miocene *Operculodinium centrocarpum* assemblage and early Miocene *Paralecaniella indentata* assemblage are present in the majority of wells as are the middle to late Eocene *Wetzeliella lunaris* and early Eocene *Areoligera senonensis* assemblages. Generally, the Paleocene is divided into two zones, the early Paleocene *Palaeoperidinium pyrophorum* and the late Paleocene *Deflandrea speciosa* assemblages. However, a middle Paleocene *Alisocysta circumtabulata* assemblage is recognizable in four of the wells. The middle to late Oligocene is absent or poorly defined throughout most of the wells.

The informal biostratigraphic zones established by Williams have provided a useful biostratigraphic framework for more detailed palynological studies of Labrador Sea sediments. Ioakim (1979), as part of her doctoral dissertation, palynologically examined the Eocene and Paleocene sections of two southern Labrador shelf wells (Bjarni H-81 and Freydis B-87). Over 120 species of dinoflagellates were recorded. The highest stratigraphic occurrences of selected species were used to define ten Eocene (six within the lower Eocene) and two

Paleocene zones. Most of the Eocene zones were based upon locally restricted ranges of species Ioakim identified within the *Wetzeliella-Apectodinium* complex (i.e., *Wetzeliella*, *Rhombodinium*, *Kisselovia*, *Dracodinium* and *Apectodinium*) of dinoflagellates. The range top of *Palaeoperidinium pyrophorum* divides the early from the late Paleocene, the upper limit of which is defined by the last stratigraphic appearance of *Deflandrea speciosa*.

A preliminary palynostratigraphic study of the Kangamiut 1 well was made by Croxton (1978). Although palynomorph recovery from the upper 2600 meters of the well was generally poor due to coarse-grained sandy lithologies, she was able to zone the remainder of the well. Using Williams' informal dinoflagellate zonation scheme, Croxton recognized a middle to late Eocene *Wetzeliella lunaris* assemblage; early Eocene *Areoligera senonensis* assemblage; late Paleocene *Deflandrea speciosa* assemblage; and early Paleocene *Palaeoperidinium pyrophorum* assemblage. Her results suggest that dinoflagellate palynoassemblages from offshore southwestern Greenland and the Labrador shelf are correlative for at least the lower Tertiary.

Foraminiferal faunas in Paleocene through Eocene Labrador Sea sediments are characterized by a predominance of benthic flysch-type agglutinated foraminifera. At the Eocene/Oligocene boundary, the agglutinated forms essentially disappear and are replaced by calcareous benthic forms (Gradstein and Williams, 1976; Gradstein and

Srivastava, 1980). Planktic foraminifera have only an intermittent history on the Cenozoic Labrador shelf and, with the exception of certain warm water, low latitude taxa in the early and middle Eocene, are characterized by middle to high latitude types comprising relatively long-ranging forms with low species diversity.

Gradstein and Williams (1976) reported eight benthic foraminiferal zones of Cenozoic age from four Labrador Sea and northern Grand Banks wells. With an expanded data base which included Karlsefni A-13, Herjolf M-92 and Cartier D-79, Gradstein and Agterberg (1981) used a probabilistic, quantitative approach to zoning both benthic and planktic foraminiferal assemblages. With their method, they were able to erect a well-delineated, nine-fold stratigraphic subdivision of the Tertiary.

Gradstein and Srivastava (1980) discussed the regional stratigraphy and distribution of planktic as well as benthic foraminifera in the Labrador Sea and Baffin Bay area, whereas Gradstein and Berggren (1981) compared the flysch-type agglutinated fauna of the Labrador Sea with those of the North Sea. Miller et al. (1982) examined Late Cretaceous and Early Tertiary deep sea sediment cores from DSDP Site 112 located in the southern Labrador Sea. They reported diverse agglutinated foraminiferal assemblages similar to those found on the Labrador shelf.

Detailed stratigraphic charts of the Labrador and Newfoundland shelves comparing planktic and benthic foraminiferal zones with palynological zones were published in Gradstein and Williams (1981). The foraminiferal zones are helpful in providing some chronostratigraphic control for assigning ages to palynozones.

Thomas and Gradstein (1981) examined the stratigraphic distribution of diatoms in Tertiary sediments from offshore Eastern Canada. Three wells, including Karlsefni A-13, from the Labrador shelf were part of the study. Diatoms have a very low diversity and are comprised of essentially four pyritized, discoid species. The authors found a broad correlation between Gradstein and Agterberg's (1981) foraminiferal zonation and diatom numerical peaks. In general, however, with the exception of an abundance peak of diatoms at the Paleocene/Eocene boundary, diatoms appear to have little biostratigraphic value in the Labrador sea region.

PALYNOLOGICAL ZONATION

Eight provisional palynological interval zones based upon pollen and spores are proposed herein. According to the North American Commission of Stratigraphic Nomenclature (1983), an interval zone is defined as the interval which lies between successive biostratigraphic events. Because cuttings samples were mainly used in this study, local ex-

inction events (range tops) are used to define the zones. The intervals are named after the species whose highest stratigraphic occurrence is used to define the upper limit of a zone. The zone extends stratigraphically downward to but not including the range top of the species defining the top of the immediately underlying zone. Because of widely spaced sample intervals as well as the rarity of some of the zonally nominate species, the zones are considered informal.

The zones are briefly discussed in the following pages in descending stratigraphic order. Included in their descriptions are the diagnostic pollen and spores which best characterize each zonal assemblage. Although not always mentioned in the zone descriptions, gymnosperm pollen and monolete and trilete fern spores were ubiquitous throughout the wells and, in some horizons, the dominant elements within an assemblage.

Some of the dinoflagellates associated with the pollen and spore zones are also included. Because most of the dinoflagellate species identified in the study wells were also reported by Williams (Williams and Bujak, 1977; Barss et al, 1979) and Ioakim (1979) from the Labrador shelf, the reader is referred to those publications for more detailed species lists.

The ranges of some of the more zonally diagnostic species of pollen and spores used to characterize the proposed zones are illustrated in

Figure 3 (see APPENDIX for more detailed range charts of pollen and spore occurrences recorded from each of the study wells). The range bases shown on the chart are not precisely defined because of the almost exclusive use of cuttings samples. Where botanical affinities with modern genera have been established (Frederiksen, 1969, 1980, 1985; Rouse, 1977), modern extant rather than fossil form genus names are used. With regards to dating samples, relative ages have been provisionally assigned to the zones based mainly upon the well-documented stratigraphic ranges of age-diagnostic dinoflagellates from Canada, the Atlantic coastal plain of North America, North Atlantic and northwestern Europe.

1. *Tsuga igniculus* Interval Zone

The top of the zone is defined by the range top of *Tsuga igniculus* (Pl. 1, Fig. 1) and the base by the range top of *Fagus granulata*. Because the zone represents the uppermost interval in the wells studied, the range top of its nominate species must be considered artificial. For this reason, ranges of taxa that have their last stratigraphic appearance at the top of the *Tsuga igniculus* zone may extend upwards into the overlying sediments.

The *T. igniculus* zone is found in only two of the wells, Hekja 0-71 and Roberval K-92. It is characterized by a low diversity and rela-

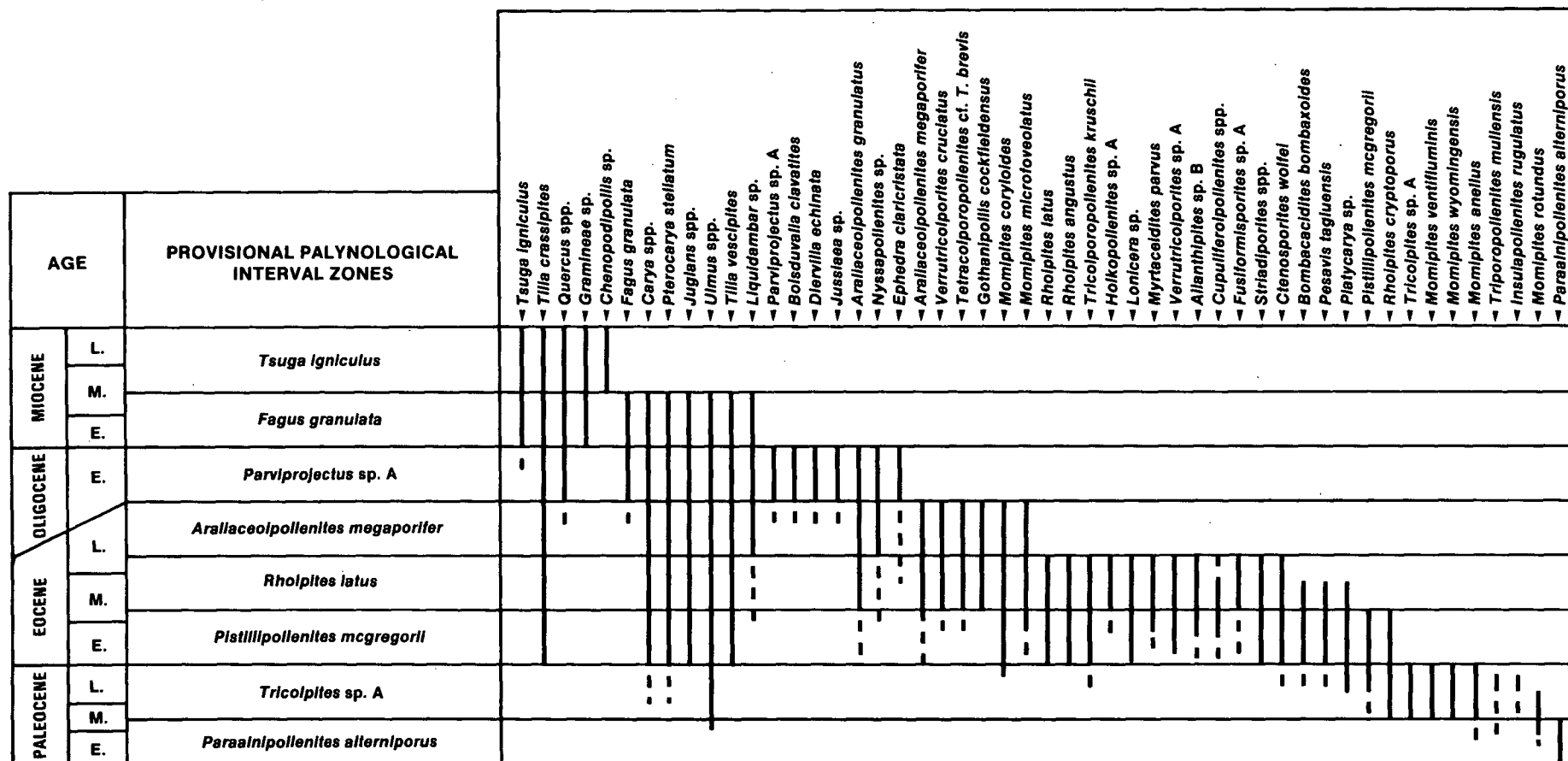


Figure 3. Ranges of selected pollen and spores used to establish provisional zones.

tively sparse floral assemblage which is dominated by an abundance of *Picea* spp., *Pinus* spp. and *Tsuga igniculus*. Common to the assemblage are *Osmunda* (Pl. 1, Fig. 2) and *Laevigatosporites*. Small numbers of the deciduous broadleaf tree pollen *Alnus*, *Betula* (Plate 1, Fig. 3), *Quercus* form B (Pl. 1, Fig. 5) and *Tilia* are also present. Rare occurrences of *Chenopodipollis* sp. (Pl. 1, Fig. 4) and Gramineae (Pl. 1, Fig. 5) spp. were also recorded.

Although dinoflagellates within the zone are extremely rare, several were noted. These include a few specimens of *Paralecaniella indentata*, *Operculodinium* cf. *O. centrocarpum* and an undescribed dinoflagellate cyst characterized by a smooth, medium sized, rounded to oval cavate form, in which the paratabulation is not indicated and the archeopyle type is uncertain. This species is informally referred to as Form sp. A herein.

The age of the assemblage is difficult to determine. Whereas Norris (1986) and Bujak (personal communication) report a late Miocene range top of *Tsuga igniculus* for the Canadian Arctic, a Pleistocene range top for *T. igniculus* is reported from the Grand Banks and Scotian Shelf (Williams and Brideaux, 1975; Barss et al., 1979), as well as from the Pliocene/Pleistocene of the Labrador Sea (Barss et al., 1979; Mudie, personal communication). In light of the modern climatic tolerance and range of *Tsuga* in offshore eastern Canada (Mudie, 1982), it is likely that during the Pleistocene temperatures in the Labrador Sea

region would have been too cold to support its growth. The younger occurrences of *T. igniculus* may, therefore, represent recycled grains.

Although a younger age can not be discounted, the *T. igniculus* assemblage in the study wells is interpreted as probable late middle to late Miocene. The floral elements, though less diverse, are similar to those reported by Martin and Rouse (1966) from the Upper Skonun Formation on the Queen Charlotte Islands. Champigny et al. (1981) correlated molluscan faunas within the Upper Skonun with the Wishkakan stage of coastal Washington State and the latest or post-Seldovian stage in Alaska which, according to Berggren and van Couvering's 1974 time scale, is 11-13 Ma. Also, Norris (1986) records the range top of *T. igniculus* from the southern Beaufort Sea to lie within the Mackenzie Bay Formation, which he interprets as probable Miocene.

2. *Fagus granulata* Interval Zone

The top of the zone is defined by the range top of *F. granulata* (Pl. 1, Figs. 6-7) and the base by the range top of *Parviprojectus* sp. A. The *Fagus granulata* zone is well-defined by its constituent pollen and spore assemblage. It is characterized by a greater diversity of deciduous, broadleaved tree pollen than in the overlying *Tsuga igniculus* zone. Some of the pollen include: *Liquidambar* forms A and B (Pl. 1, Figs. 10-11), *Quercus* form A (Pl. 1, Fig. 8), *Juglans*,

Ulmus, *Carya*, *Pterocarya* and *Tilia vesicipes*. Most of these taxa make their last stratigraphic appearance within the zone. *Picea-Pinus*, *Taxodium*, *Sequoia* (Pl. 1, Fig. 12), *Metasequoia*, *Tsuga igniculus*, *T. viridifluminipites* (Pl. 1, Fig. 13), ericaceous tetrads, *Sphagnum* and *Laevigatosporites* are common constituents of this palynomorph assemblage.

Several dinoflagellate species were noted. Those making their last stratigraphic appearance in the zone are *Cordosphaeridium cantharellum*, *Systematophora ancyrea*, *Paleocystodinium golzowense*, *Paralecaniella indentata*, and *Svalbardella* sp. A. Even though the samples in this interval are marine, they are dominated by an abundance of terrestrially derived organic matter, which can make finding dinoflagellates on a sample slide difficult. Fluorescence microscopy can be a useful tool for helping to locate dinoflagellates in such intervals, especially if the sample is unstained and the material on the slide is too densely distributed.

An early Miocene age is assigned to this interval based mainly upon the range top of *Cordosphaeridium cantharellum*. The extinction of *C. cantharellum* in the early Miocene is recorded from the Grand Banks on the Atlantic continental margin of Eastern Canada (Williams and Brideaux, 1975; Williams and Bujak, 1977), the Atlantic coastal plain region of the southeastern United States (Stover, 1977) and the Norwegian-Greenland Sea (Manum, 1976). Although all of the aforemen-

tioned terrestrial flora and dinoflagellate cysts associated within this zone have known ranges that extend down into the Oligocene, support for an early Miocene age is furthered by the presence of Gramineae spp. at the base of the zone in a sidewall core sample from Karlsefni A-13. The first stratigraphic occurrence of Gramineae at high northern latitudes is in the early Miocene (Rouse, personal communication).

Mudie (1985) has reported the presence of some of the species (e.g., *Liquidambar* and *Juglans*) that have their range tops within this zone in younger strata from the Arctic and Labrador Sea. Because these species were not found in the overlying *T. igniculus* zone, plus the fact that *Cordosphaeridium cantharellum* and *Systematophora ancyrea* are present, indicates that the younger recorded occurrences by Mudie may represent redeposited grains. In order to better resolve and better document the range tops of some of these taxa, better sample control and additional sections need to be studied.

3. *Parviprojectus* sp. A Interval Zone

The range top of *Parviprojectus* sp. A (Pl. 1, Fig. 14) marks the top of the interval and the range top of *Araliaceoipollenites megaporifer* the base. The zone is generally characterized by the common occurrence of triporate pollen including *Corylus/Carpinus* (Pl. 1, Figs.

15-16) and *Myrica* (Pl. 1, Fig. 17). Also characteristic of the assemblage though not restricted to it are *Ilex* spp. (Pl. 1, Figs. 18-21), *Fagus*, *Quercus*, *Liquidambar*, *Tilia* (Pl. 2, Fig. 1), *Alnus* (Pl. 2, Fig. 3), *Ulmus* (Pl. 2, Figs. 2 and 6), *Juglans*, (Pl. 2, Fig. 7, *Carya* (Pl. 2, Figs. 4-5) and *Pterocarya*. Although infrequent to rare, several zonally diagnostic species make their last stratigraphic appearance in this interval. They are *Parviprojectus* sp. A, *Diervilla echinata*, *Jussiaea* sp. (Pl. 2, Fig. 8) *Boisduvalia clavatites* (Pl. 2, Fig. 9) and *Acanthaceae* sp. (Pl. 2, Fig. 13). Other range tops recorded within the zone are *Nyssapollenites* (Pl. 2, Fig. 15), *Araliaceoipollenites granulatus* (Pl. 2, Figs. 11-12), *A. profundus* (Pl. 2, Fig. 17), *Rousea araneosa* (Pl. 2, Fig. 10), *R. monilifera* (Pl. 2, Fig. 14), and *Ephedra claricristata* (Pl. 2, Fig. 16). Rounding out the terrestrial floral assemblage are common occurrences of ericaceous tetrads, *Picea-Pinus*, *Taxodium*, *Metasequoia*, *Laevigatosporites* and *Osmunda*.

Parviprojectus resembles *Aquilapollenites* in that they are both characterized by three equatorial projections and pronounced polar areas. Some workers consider *Parviprojectus* a reworked species of *Aquilapollenites* (Srivastava, personal communication). However, with the exception of a couple of species that range up into the early to middle Paleocene of the western interior of the United States and Canada (Leffingwell, 1971; Sweet, 1978; this author, unpublished technical report), most *Aquilapollenites* species became extinct at the

Cretaceous/Tertiary boundary. The Oligocene species of *Parviprojectus*, however, has not been described from either Senonian or Paleocene assemblages. Because of its distinct morphology, it is considered herein as part of the indigenous flora.

Dinoflagellates are very rare in the samples examined from this interval. Only several occurrences of the long-ranging species *Paralecaniella indentata* were noted.

An early Oligocene age is assigned to the *Parviprojectus* sp A. zone based upon the restricted range top of *Parviprojectus* within the early Oligocene of the Canadian Arctic (Staplin, 1976; Rouse, 1977; Norris, 1986) and British Columbia (Rouse, 1977; Rouse and Mathews, 1979). Wiggins (personal communication) has also found similar pollen types from the Oligocene of Alaska. In addition, the range top of *Boisduvalia clavatites* has been recorded from the early Oligocene of interior British Columbia (Piel, 1971; Hopkins et al, 1972; Rouse, 1977; Rouse and Mathews, 1979) and the Canadian Arctic (Rouse, 1977; Ioannides and McIntyre, 1980). *Jussiaea* has also been recorded from the early Oligocene in central British Columbia (Rouse, 1977). Piel (1977) shows the range of *Jussiaea* extending up into the early Miocene, however, that one occurrence is now considered to have been reworked (Piel, personal communication).

The assignment of an early Oligocene age to this zone reveals an apparent hiatus in the stratigraphic record that spans much of the Oligocene. A possible explanation for the presumed gap in the record is suggested by Gradstein and Srivastava (1980) who used micropaleontological data to identify a broad shelf regression during this time period.

4. *Araliaceoipollenites megaporifer* Interval Zone

The range top of *Araliaceoipollenites megaporifer* (Pl. 3, Figs. 1-2) defines the top of the zone and the range top of *Rhoipites latus* the base. The floral assemblage associated with the zone is dominated by pollen and spores and is characterized, in part, by the fairly common occurrence of many of the same taxa (e.g., *Juglans*, *Tilia*, *Carya*, *Pterocarya*, *Ulmus* and *Liquidambar*) found in the overlying *Parviprojectus* sp. A zone. *Fagus*, *Quercus* and onagraceous pollen, however, are rare and, with the exception of one specimen, *Parviprojectus* sp. A is absent. *Araliaceoipollenites megaporifer*, most species of *Verrutricolporites* spp., *Tetracolporites* cf. *T. brevis* (Pl. 3, (Fig. 3), *Momipites coryloides* and *M. microfoveolatus* (Pl. 3, Figs. 7-8) make their last stratigraphic appearance within the zone. With the exception of one occurrence in Herjolf M-92 (sample 4500 ft.), the range top of *Gothanipollis cockfieldensis* (Pl. 3, Fig. 4) is also associated within this zone. In general, there is a drop

in the number of triporates from the previous zone and a gradual increase in tricolporates. Also, ericaceous tetrads (Pl. 3, Fig. 9-10) which are found throughout the Tertiary of the Labrador Sea reach their peak abundance in this zone. Gymnosperm pollen and fern spores are also ubiquitous.

Dinoflagellates are uncommon and are comprised mainly of *Paralecaniella indentata* and Form sp. A with rare occurrences of *Chiropteridium* cf. *C. aspinatum*, *Deflandrea* sp. A and *Phthanoperidinium* sp. A. In Herjolf M-92, the acritarch genus, *Michrystidium*, is abundant.

The age of the zone is uncertain and is considered here as transitional across the Eocene/Oligocene boundary. The ranges of dinoflagellates associated with this zone are not age-diagnostic. Regarding the pollen and spores, Frederiksen (1969, 1980) reports the ranges of *Araliaceipollenites megaporifer*, *Verrutricolporites cruciatus* (Pl. 3, Figs. 5-6), *Momipites coryloides* and *M. microfoveolatus* extending up into the lower part of the Vicksburg Group (lower Oligocene) and *Gothanipollis cockfieldensis* only up into the Yazoo Clay (upper Eocene). On the Grand Banks, Williams and Brideaux (1975) show the range of *Verrutricolporites* spp. extending up into the lowermost Oligocene. In south central British Columbia, the range top of *Gothanipollis cockfieldensis* was extended from the Eocene (Rouse, 1977) to the early Oligocene (Rouse and Mathews, 1979). Until

a more detailed study can be made that would utilize shorter sampling intervals and sidewall core material, the age-range of the zone can not be precisely determined at this time.

5. *Rhoipites latus* Interval Zone

The top of the zone is defined by the range top of *Rhoipites latus* (Pl. 3, Fig. 11). and the base by the range top of *Pistillipollenites mcgregorii*. This zone is well-defined in each of the study wells and is characterized by an abundance and diversity of tricolporate pollen mainly belonging to the genera *Araliaceopollenites*, *Verrutricolporites* (Pl. 3, Figs. 5-6 and 19-22). and *Cupuliferoipollenites*. *Tilia* becomes more common and *Fagus*, *Quercus* and *Corylus/Carpinus* are absent to rare, suggesting that their range bases lie within this zone. Fungal spores are a relatively common component of the flora with *Punctodiporites* sp. (Pl. 3, Fig. 25), *Striadiporites* spp. (Pl. 3, Figs. 28-29), *Fusiformisporites* sp. A (Pl. 3, Figs. 26-27) and *Ctenosporites* making their last stratigraphic appearance. Aside from *Rhoipites latus*, the following species have their range tops within this interval: *Caprifoliipites* sp. A (Pl. 3, Fig. 12), *Tricolporopollenites kruschii* (Pl. 3, Fig. 18), *Symplocoipollenites* spp. (Pl. 3, Figs. 16-17), *Holkopollenites* sp. A, *Lonicera* sp. A, *Myrtaceidites parvus*, *Verrutricolporites* sp. A (Pl. 3, Fig. 19) and *Ailanthipites* sp. B (Pl. 3, Fig. 23). Near the base of

the zone, *Bombacacidites bombaxoides* (Pl. 3, Fig. 24) makes its last stratigraphic appearance.

The lower half of the *Rhoipites latus* zone is characterized by an abundance of small, 12-17 μ m pollen belonging to the genera, *Cupuliferoipollenites* (Plate 3, Figs. 13-15). Because this peak occurrence is consistent and easily recognizable, it should be considered a subzone of the *Rhoipites latus* interval.

Dinoflagellates make up a significant proportion of the total palynomorph assemblage in Kangamiut 1, Karlsefni A-13, Herjolf M-92 and Cartier D-70, especially near the base of the zone. Among the species present are *Achilliodinium biformoides*, *Araneosphaera araneosa*, *Diphyes colligerum* and *Wetzeliella lunaris*, all of which have their range tops in this interval.

A late-middle to late Eocene age is assigned to the *Rhoipites latus* zone based mainly upon the well-defined range top of *Diphyes colligerum* from the late Eocene of England (Eaton, 1976), the North Sea (Ioakim, 1979), the Norwegian-Greenland Sea (Manum, 1976), the Grand Banks and Scotian Shelf (Williams and Brideaux, 1975; Williams and Bujak, 1977) and the Canadian Arctic (Ioannides and McIntyre, 1980). Eaton (1976) also reports the range tops of *Araneosphaera araneosa* and *Achilleodinium biformoides* in the late Eocene of England. *Achilleodinium biformoides* is also reported from the late Eocene of

the Grand Banks and Scotian Shelf (Williams and Bujak, 1977; Barss et al., 1979).

6. *Pistillipollenites mcgregorii* Interval Zone

The top of the zone is defined by the range top of *Pistillipollenites mcgregorii* (Pl. 4, Figs. 1, 6, 11-12). and the base, tentatively, by the range top of *Tricolpites* sp. A. It is a well-defined zone that is found in all six of the study wells. The zone is characterized by an abundance of tricolporate pollen (e.g., *Rhoipites*, *Araliaceoipollenites*, *Verrutricolporites*, *Caprifoliipites* and *Tricolporopollenites*). The number of *Cupuliferoipollenites* drops off rather sharply from the immediately overlying zone. *Tilia*, *Carya*, *Juglans*, *Rhoipites latus*, and *R. angustus* (Pl. 4, Fig. 2) are fairly common. Fungal spores, e.g., *Dicellaesporites*, *Multicellaesporites* and *Pesavis tagluensis* (Pl. 4, Fig. 4), have their greatest abundance in this interval. Towards the base of the zone, the number of *Verrutricolporites* drops off and the frequency of tricolpate pollen increases. Juglandaceous pollen of the *Momipites* complex (e.g., *M. coryloides*) are more frequent than in the previously described zones. The range top of *Platycarya* (Pl. 4, Figs. 3 and 7) coincides with the range top of *Pistillipollenites mcgregorii* in Hekja 0-71, Karlsefni A-13 and Herjolf M-92 and in the remaining wells its range top extends into the base of the overlying *Rhoipites latus* zone. *Azolla* glochidia

(Pl. 4, Fig. 5), which are usually associated with the Maastrichtian and lower Paleocene (Leffingwell, personal communication; Sweet, personal communication), are found in the *Pistillipollenites mcgregorii* interval. The specimens are fairly common and well-preserved and are considered at present to be in place. Norris (1986) also reports middle Eocene occurrences of *Azolla* from the southern Beaufort Sea.

The dinoflagellate assemblage associated with this zone is generally the most diverse and abundant of those found in the Tertiary interval from the Labrador Sea. It is distinguished by an abundance of *Areoligera senonensis*, *Adnatosphaeridium* spp. and *Glyphyrocysta* sp. Also relatively common to the zone are *Wetzeliella* spp., *Deflandrea phosphoritica*, *Cordosphaeridium* sp., *Apectodinium homomorphum*, *Paleotetradinium exilimurum*, *Spiniferites* spp. and *Thalassiphora pelagica*. Among the dinoflagellates making their last stratigraphic appearance are *Eatonicysta ursalae*, *Homotryblum tenuispinosum*, and *Rhombodinium condylos*. The range tops of *Apectodinium quinquelatum*, *A.* cf. *A. hyperacanthum* and *A. parvum* were recorded near the base of the zone.

The age of the *Pistillipollenites mcgregorii* zone is interpreted as early Eocene to early middle Eocene. The range top of *Eatonicysta ursalae* is reported from the early middle Eocene of the North Sea (Ioakim, 1979; Heritier, et al., 1979) and England (Eaton, 1976) and *Rhombodinium condylos* makes its last stratigraphic appearance in the

early Eocene of England (Downie, Hussain and Williams, 1971; Eaton, 1976), the North Sea (Ioakim, 1979) and the middle to early Eocene of the Grand Banks and Scotian Shelf (Williams and Brideaux, 1975; Williams and Bujak, 1977; Barss et al., 1979).

The range top of *Pistillipollenites mcgregorii* is well-defined in the early middle Eocene of the Canadian Arctic (Staplin, 1976; Rouse, 1977; Norris, 1986), British Columbia (Rouse et al., 1971, Rouse, 1977) and the western United States (Newman, 1981, 1983; Cushman, 1983; Reiswig, 1983; Wingate, 1983). Leopold and McGinitie (1972), Newman (1980, 1981, 1983), Cushman (1983) and Wingate (1983) report the range top of *Platycarya* from the western United States as early to middle Eocene and Frederiksen and Cristopher (1978) and Frederiksen (1980) report a middle Eocene range top from the southeastern United States.

7. *Tricolpites* sp. A Interval Zone

The top of this zone is tentatively defined by the range top of *Tricolpites* sp. A (sensu Rouse 1977) and the base by the range top of *Paraalnipollenites alterniporus*. However, because of the rare and sporadic occurrence of *Tricolpites* sp. A, this zone would be more appropriately considered an assemblage zone characterized by the concurrent association of *Pistillipollenites mcgregorii*, *Tricolpites* spp.

(including *T. cf. T. hians*, *T. densus* and *T. reticulatus*), *Rhoipites cryptoporus*, *Intratropipollenites* sp. A. and *Carya* spp., which includes a pre-*Carya* form (Pl. 4, Fig. 13) that has at least one of its three pores located on the equator. Bladder conifer and taxodiaceous pollen and pteridophyte fern spores are generally the main terrestrially derived component of the palynoflora.

Tropipollenites mullensis and *Momipites rotundus* have their range tops within the zone and several occurrences of *Insulapollenites rugulatus* (Pl. 4, Fig. 12) were also noted. In a sidewall core sample from Herjolf M-92 and cuttings samples from Karlsefni A-13, several Paleocene *Momipites* spp., e.g., *M. ventifluminis* (Pl. 4, Fig. 10), *M. wyomingensis* (Pl. 4, Figs. 8-9), *M. amplus* (Pl. 4, Fig. 15) and *M. anellus* (Pl. 4, Fig. 14), were recorded.

The assemblage of pollen and spores in this zone differs from the overlying *Pistillipollenites mcgregorii* zone in that there is a significant increase in the number of tricolpate pollen. Also, tricolporate species tend to have generally smaller and less well-defined pores. *Araliaceoipollenites* and *Verrutricolporites* are absent from the assemblage. Another observed trend is the tendency for a reduction in the number of gemmae on the Paleocene forms of *P. mcgregorii*.

Dinoflagellates are abundant but less diverse than in the previous zone. The most diagnostic feature of the dinoflagellate assemblage is a peak abundance of *Apectodinium* spp. at the top of the zone. Other abundant forms are *Areoligera* spp. and *Adnatosphaeridium* spp. Among the dinoflagellates that have their range tops within the zone are *Deflandrea speciosa* and *D. cf. D. dartmooria*.

The age of this zone is being interpreted as late Paleocene (possibly even latest Paleocene to earliest Eocene). The last stratigraphic appearance of *Deflandrea speciosa* is reported from the late Paleocene of the North Sea (Ioakim, 1979), Heritier et al., 1979) and the Grand Banks and Scotian Shelf (Williams and Bujak, 1977; Barss et al., 1979). Peak abundances of *Apectodinium* spp. are recorded from the latest Paleocene and/or earliest Eocene of the North Sea (Knox et al., 1981), England (Downie et al., 1971; Costa and Downie, 1976) and Denmark (Heilman-Clausen, 1985).

A late Paleocene range top is reported for *Tricolpites* sp. A from the Canadian Arctic (Rouse, 1977). *Momipites ventifluminis*, *M. wyomingensis*, *M. anellus* and *M. amplus* also have their range tops in the late Paleocene of the Wind River Basin (Nichols and Ott, 1978) and *M. strictus* becomes extinct in the latest Paleocene of South Carolina (Frederiksen and Christopher, 1978). The range top of *M. rotundus* and *M. coryloides* is in the late middle Paleocene of the Canadian Arctic (Rouse, 1977) and Alberta (this author, unpublished technical report),

and late Paleocene of the Powder River Basin (Leffingwell, 1971). The range base of *Tilia* in the Canadian Arctic and British Columbia is placed at the base of the Eocene. In sidewall core samples from Herjolf M-92, Kangamiut 1 and Karlsefni A-13 from both above and below the interpreted Paleocene/Eocene boundary, *Tilia* is found only above the boundary.

8. *Paraalnipollenites alterniporus* Interval Zone

The top of the zone is defined by the range top of *Paraalnipollenites alterniporus* (Pl. 4, Figs. 16-17). The base of the zone is artificially defined by the first appearance downhole of Cretaceous dinoflagellates (e.g., *Phelodinium* sp., *Isabelidinium* sp. and *Amphidiadema nucula*). The *Paraalnipollenites alterniporus* interval is comprised of a low diversity pollen and spore assemblage characterized by abundant bladdered conifer (predominantly *Picea* (Pl. 4, Fig. 26) and *Pinus*) and taxodiaceous pollen (Pl. 4, Fig. 20) as well as monolete (Pl. 4, Fig. 25) and trilete fern spores. *Paraalnipollenites alterniporus*, the Betulaceae-Myricaceae pollen complex (Pl. 4, Figs. 21-22), *Casuarinidites* spp. (Pl. 4, Fig. 24) and reticulate (Pl. 4, Figs. 19-23), scabrate and psilate tricolpate grains are present but never abundant. With the exception of several rare occurrences of *Momipites* (e.g., *Momipites actinus*, Pl. 4, Fig. 18), this zone is essentially devoid of juglandaceous pollen.

Dinoflagellates are a common constituent of the palynomorph assemblage. Just above the top of the zone, there is a well-defined dinoflagellate interval marked by the last stratigraphic appearance of *Alisocysta margarita*, and the range top of *Palaeoperidinium pyrophorum* is usually found near the middle of the zone. Dinoflagellates having their range tops within the zone are *Alisocysta circumtabulata*, *Deflandrea diebeli* and *D. striata*.

An early to middle Paleocene age is assigned to this zone based upon the range top of *Alisocysta circumtabulata* in the middle Paleocene (lower Thanetian) of the North Sea (Heritier et al., 1979; Knox et al., 1981) the Grand Banks and Scotian Shelf (Williams and Bujak, 1977) and the Atlantic coastal plain sediments of Virginia (Witmer, personal communication). In addition, *Palaeoperidinium pyrophorum* makes its last stratigraphic appearance at the top of the Danian in the North Sea (Heritier et al., 1979; Ioakim, 1979; Knox et al., 1981), the Grand Banks and Scotian shelf (Williams and Bujak, 1977; Barss et al., 1979) and the Atlantic coastal plain (Witmer, personal communication) and near the middle Selandian in Denmark (Heilman-Clausen, 1985).

The range top of *Paaralnipollenites alterniporus* is reported from the middle Paleocene of the Canadian Arctic (Rouse, 1977) and Alberta

(this author, unpublished technical report; Sweet, personal communication). Also, the low diversity pollen and spore assemblage of the *P. alterniporus* interval is very typical of early to middle Paleocene floras reported from the Canadian Arctic (Rouse, 1977), the western interior of the United States and Canada (Leffingwell, 1971; Sweet, 1978; Hotton, 1983) and Alabama (Srivastava, 1972).

DISTRIBUTION OF PROVISIONAL ZONES IN STUDY WELLS

The distribution of the eight preliminary pollen and spore zones among the six study wells is shown in Figure 4. As previously mentioned, the ages assigned to the various zones are only relative and are based for the most part on the well documented range tops of certain dinoflagellate species. Range charts of pollen and spores with species arranged in descending order by last stratigraphic occurrence for each well can be found in the APPENDIX. The depths between which zonal boundaries are drawn are also indicated. The charts for Kangamiut 1, Karlsefni A-13, Herjolf M-92 and Cartier D-70 plot only the ranges of the most common and/or zonally diagnostic species; whereas, the range charts for Hekja O-71 and Roberval K-92 show a more detailed representation of the Tertiary suite of pollen and spores recovered from the continental shelf sediments of the Labrador Sea. The *Tsuga igniculus* and *Fagus granulata* zones are fairly well-documented

		AGE	PALYNOZONE	KANGAMIUT 1	HEKJA 0-71	KARLSEFNI A-13	HERJOLF M-92	ROBERVAL K-92	CARTIER D-70
T E R T I A R Y	NEOGENE	MIDDLE TO LATE MIOCENE	<i>Tsuga igniculus</i>		X			X	
		EARLY MIOCENE	<i>Fagus granulata</i>		X	X		X	
	PALEOGENE	EARLY OLIGOCENE	<i>Parviprojectus</i> sp. A	X	X		X	X	
		EARLY OLIGOCENE TO LATE EOCENE	<i>Araliaceopollenites megaporifer</i>		X	X	X	X	
		LATE EOCENE	<i>Rhoipites latus</i>	X	X	X	X	X	X
		MIDDLE TO EARLY EOCENE	<i>Pistillipollenites mcgregorii</i>	X	X	X	X	X	X
		LATE PALEOCENE	<i>Tricolpites</i> sp. A	X		X	X	X	X
		MIDDLE TO EARLY PALEOCENE	<i>Paraalnipollenites alterniporus</i>	X		X	X	X	X

Figure 4. Distribution of provisional pollen and spore interval zones in the six study wells.

in Hekja 0-71 and Roberval K-92. Their apparent absence from the other wells is interpreted as an artifact of not having representative samples from these intervals available for study. Although a set of samples between 950 and 2500 m. from Kangamiut 1 were provided, they were overmacerated and contained a considerable amount of mineral matter and, therefore, were not studied in detail. Nevertheless, some in-situ pollen, primarily *Picea* and *Pinus* with minor occurrences of *Tsuga igniculus*, *Ilex*, *Alnus*, *Osmunda*, *Laevigatosporites* and ericaceous tetrads, were noted. Because these grains are long-ranging, it is difficult to assign them to any one zone. However, the general lack of diversity and the predominance of conifers (including *Tsuga igniculus*) suggests that at least part of this interval belongs to the *T. igniculus* zone.

One sidewall core sample (6374 ft.) from Karlsefni A-13 has been tentatively assigned to the *Fagus granulata* zone. Present in the assemblage are not only *Picea*, *Tsuga igniculus* and Gramineae pollen, but also pollen belonging to the juglandaceous group (e.g., *Juglans*, *Carya* and *Pterocarya*) as well as *Ulmus* and *Corylus/Carpinus*. Although only one questionable occurrence of *Fagus granulata* was recorded, the presence of Gramineae pollen and the diversity of the assemblage indicates the sample should be assigned to the *F. granulata* zone.

The *F. granulata* zone is interpreted as probable early Miocene, however, it should be noted that the majority of pollen (e.g.,

Corylus/Carpinus, *Fagus*, *Quercus* and *Betula*) recorded from the interval range down section into the Oligocene and, in some cases, even lower. In Roberval K-92 between 790 and 1400 m., the recovery of in-situ palynomorphs is relatively poor. Because of the absence of Gramineae pollen in these samples, it is possible that they represent, at least in part, the middle to late Oligocene. Unfortunately, with the exception of a couple of recorded occurrences of *Paralecaniella* and Form sp. A, the samples in question are essentially barren of dinoflagellates. Dinoflagellates can often be helpful in distinguishing Miocene and Oligocene palynofloral assemblages from one another (Helby et. al., 1984). Because pre-Eocene samples from nearby Cartier D-70 were not available for study, it can not be determined if a similar undiagnostic zone is present in that well. Whether or not there is a middle to late Oligocene hiatus in the continental shelf sediments of the Labrador Sea remains to be seen. Hopefully, the recent ODP, Leg 105 cruise to the Labrador Sea and Baffin Bay will shed some light on this problem (Gradstein, personal communication).

The *Parviprojectus* sp. A zone is found in Kangamiut 1, Hekja O-71, Herjolf M-92 and Roberval K-92. Many of the pollen (e.g., *Boisduvalia*, *Jussiaea*, *Araliaceoipollenites granulatus* and *Rousea* spp.) found associated with *Parviprojectus* in this zone are not found in Kangamiut 1. However, because only one rather silty sample (2600 m.) was examined, the absence of the missing forms may be due to both the poor sample control and the lithology. In Roberval K-92, the top

of the zone has been drawn just above 1420 m., based upon the range tops of *Boisduvalia* and *Jussiaea*. The last stratigraphic occurrence of *Parviprojectus* is found 50 meters below that sample at 1470 m. The top of the interval is difficult to define because of the abundance of recycled Carboniferous spores which overwhelmingly dilute the in-situ taxa in this zone, as well as in the underlying *Araliaceoipollenites megaporifer* zone. The absence of the *Parviprojectus* sp. A zone in Karlsefni A-13 is very likely due to the approximate 400 ft. gap between samples.

The *Araliaceoipollenites megaporifer* zone can be recognized in Hekja O-71, Karlsefni A-13, Herjolf M-92 and Roberval K-92. Because the zone can be quite narrow, its apparent absence in Kangamiut 1 may be due to the 100 meter spacing between samples 2600 and 2700 m.

Whether or not the zone is present in Cartier D-70 is questionable and is, therefore, not shown in Figure 4. The pollen and spore flora from two sidewall core samples (4240 and 4270 feet) is not very diagnostic and is characterized by an abundance of bladdered conifers. The presence of several species of *Araliaceoipollenites* and a single specimen of *Jussiaea* suggests the samples may belong to either the *Parviprojectus* sp. A or *Araliaceoipollenites megaporifer* zones. However, the presence of *Araneosphaera araneosa* (range top in the late Eocene) in sample 4270 feet suggests instead that the interval belongs to the *Rhoipites latus* zone.

Samples collected from silty to shaly intervals within and in close proximity to sand bodies are often characterized by a depauperate in-situ palynomorph assemblage consisting mainly of poorly preserved and oxidized bladdered conifers, spores and dinoflagellates. In these intervals recycled palynomorphs, in addition to degraded and non-degraded vitrinite are commonly a major component of the overall assemblage of organic matter.

Another factor affecting the concentration of pollen and spores, especially in Eocene and older Tertiary and Late Cretaceous shales and mudstones, is an increase in the abundance of marine derived dinoflagellates and other marine algae, as well as fluffy appearing amorphinite. In some samples within these intervals, the dominant pollen and spore type consists of bisaccate pollen. This situation corresponds with the observation by Mudie (1982) that in the recent offshore sediments of eastern Canada, bladdered conifer pollen is generally transported further offshore than other pollen types via wind and/or water transport.

The *Rhoipites latus* and *Pistillipollenites mcgregorii* zones are found in all six study wells. Both zones are fairly easy to recognize in spite of a problem with uneven recovery of pollen and spores in samples within these intervals. In some of these samples the number and

diversity of the terrestrially derived palynomorphs in very low, especially in Karlsefni A-13. This problem with spotty recovery of pollen and spores continues down section into the *Tricolpites* sp. A and *Paraalnipollenites alterniporus* zones.

The *Tricolpites* sp A zone was identified in Karlsefni A-13, Herjolf M-92 and Roberval K-92 and, tentatively, in Kangamiut 1 and Cartier D-70. Because of the rarity of the zonally nominate species, the top of the *Tricolpites* sp. A zone can be difficult to identify. In Kangamiut 1 the top of the zone is tentatively placed between samples 3099 and 3201 meters. The positioning of the boundary in this well is based in part upon the recorded range tops of *Momipites rotundus* and *Triporopollenites mullensis*, as well as the relative abundance of tricolpate pollen in relation to tricolporates and the absence of *Tilia*, *Araliaceoipollenites* and *Verrutricolporites* from sample 3201 meters. Using absence data is questionable though when working with cuttings samples. The pollen and spore data is supported, however, by associated dinoflagellate assemblages which are very useful for helping to interpret the upper limits of the zone. The range tops of *Deflandrea speciosa* and *Apectodinium hypercanthum* coincide with or very closely approximate the boundary between the *Pistillipollenites mcgregorii* and the *Tricolpites* sp. A zones.

In Cartier D-70 the top of the *Tricolpites* sp. A zone lies within a broad interval between 5500 and 5810 feet. It is very difficult to

determine its position more precisely because the samples examined from this interval (5600 and 5720 feet) are from sandy units within or near the Upper Cartier Sandstone. The recovery of palynomorphs is fairly poor and there is some contamination by cavings. Sample 5810 feet is interpreted to lie within the *Tricolpites* sp. A zone based on the combined occurrence of *Momipites rotundus*, *Triporopollenites mullensis* and *Insulapollenites rugulatus*. The range tops of these species lie within the zone. *Deflandrea speciosa* and *Apectodinium hypercanthum* are also associated with the assemblage.

The *Paraalnipollenites alterniporus* zone is found in the same wells as is the *Tricolpites* sp. A zone. The zone is fairly easy to identify, but its stratigraphic relationship to the range tops of *Alisocysta margarita* and *Palaeoperidinium pyrophorum* can vary. Although the relative positioning of the range tops of *Paraalnipollenites alterniporus* and these two dinoflagellates appears to be mainly dependent upon the sampling interval, the last consistent stratigraphic occurrence of *Alisocysta margarita* tends to lie just above the range top of *Paraalnipollenites alterniporus*

In Hekja 0-71 the *Tricolpites* sp. A and *Paraalnipollenites alterniporus* zones were not identified. Samples below 2600 meters were not examined because of the difficulty in picking reliable range tops. The problem was due to the ubiquitous presence of Paleocene pollen and spores throughout the well.

The boundaries between provisional zones in Hekja 0-71 are fairly narrow and occur anomalously high in the section. For example, the boundary between the *Fagus granulata* and *Parviprojectus* sp. A zones lies between 935 and 970 meters; and the transitional Eocene/Oligocene *Araliaceoipollenites megaporifer* zone lies between 1400 and 1605 meters. These data are contradictory to the relative ages reported by Klose et al. (1982) in their description of the general lithology of the well. Based on foraminifera fauna, they place the Oligocene-Miocene boundary at approximately 1830 meters and the Eocene-Oligocene boundary at 2600 meters. In addition, they describe the lithology of the sediments as predominantly sandy down to a depth of approximately 1300 meters. However, most of the raw samples received from Aquitaine for study did not appear sandy or silty.

The rather gross discrepancies between the relative ages of boundaries presented herein and the data from Klose et al. (1982) could possibly be due to several different factors, namely, sample contamination via drilling additives or cavings and/or redeposition of palynomorphs. Mud additives the same age as rock units being drilled can greatly bias palynological studies. One very common additive is lignite from the Paleocene Ft. Union Formation from North Dakota. Many of the Paleocene species of pollen and spores found in Hekja 0-71 are similar in composition to palynological assemblages from the Ft. Union. How-

ever, according to McMillan (personal communication), Tertiary drilling muds and/or lignite additives were not used in drilling Hekja 0-71.

In Hekja 0-71, Paleocene pollen and spores (e.g., *Momipites* spp. and *Insulapollenites rugulatus*) are fairly common constituents throughout the well. If mud contamination can be ruled out, the Paleocene palynomorphs must be considered redeposited. The problem is to determine if they are in place or if they have caved down section from younger sediments along with other pollen and spores that were interpreted as in-situ. During the Pliocene-Pleistocene in the Labrador Sea region, there was considerable erosion of land surfaces, resulting in the offshore deposition of abundant recycled material of different ages. Because cuttings samples were used in studying Hekja 0-71, the pollen and spore assemblages examined from the well could represent cavings of recycled palynomorphs that dominate Pliocene-Pleistocene assemblages.

If the palynomorphs were derived from recycling, an unroofing effect would be expected, whereby the age of the sequence while working stratigraphically down section would be inverted from oldest to youngest. This is not the case, however. Although there are abundant Paleocene pollen and spores found throughout the well, the range tops of species considered in-situ progress successively from youngest to oldest. Furthermore, this pattern would not be expected if the

palynomorphs just represented cavings. Even though contamination by cavings can not be ruled out, the apparent youngest to oldest stratigraphic succession of range tops of pollen and spores downhole can not be dismissed. For this reason, therefore, zonal boundaries are presented as discussed, until such time that new data and/or better sample control is provided. A detailed study of the assemblages in fluorescent light might help to resolve the problem of identifying in situ palynomorphs from caved and redeposited grains (Bujak, personal communication). As an aside, it should be noted that other palynological workers, e.g., McIntyre (personal communication) and Rouse (personal communication) have also found Hekja 0-71 a biostratigraphically confusing well to work.

COMPARISON OF LABRADOR SEA PALYNOLOGICAL ZONATIONS

Two palynological zonations of the Tertiary sediments of the Labrador Sea were previously established by G. L. Williams (Williams and Bujak, 1977; Barss et al., 1979) and Ioakim (1979). Both zonations are based essentially on just dinoflagellate assemblages. How these zonal schemes correlate with the pollen and spore zonation proposed herein is illustrated in Figure 5. The G. L. Williams zonation covers the complete Tertiary section, whereas the Ioakim scheme involves just the Paleocene and Eocene. The relative ages shown in Figure 5 are only approximations.

A single zone, *Tsuga igniculus* was established by G. L. Williams for the Pliocene. No correlative pollen and spore zone could be established because material of known Pliocene age was not examined in any of the six study wells. The Miocene section, on the other hand, shows two zones for each zonal scheme. The *T. igniculus* and *Fagus granulata* zones correspond to the *Operculodinium centrocarpum* and *Paralecaniella indentata* zones, respectively. Because the range top of *T. igniculus* is artificially defined in this study due to the lack of stratigraphically higher samples, it is possible that the upper limits of this zone may extend into the *T. igniculus* zone of G. L. Williams.

		MA* AGE	BARSS, BUJAK AND WILLIAMS, 1979	IOAKIM, 1979	WILLIAMS (HEREIN)
TERTIARY	NEOGENE	LATE PLIOCENE	<i>Tsugaepollenites igniculus</i> Assemblage		
		EARLY PLIOCENE			
		LATE MIOCENE	<i>Operculodinium centrocarpum</i> Assemblage		<i>Tsuga igniculus</i> Zone
		MIDDLE MIOCENE			
		EARLY MIOCENE	<i>Paralecaniella indentata</i> Assemblage		<i>Fagus granulata</i> Zone
	PALEOGENE	24.6	<i>Cordosphaeridium fibrospinosum</i> - <i>Deflandrea</i> sp. C Assemblage		?
		32.8			(no data)
		38.0	<i>Wetzeliiella ovalis</i> Assemblage		?
		LATE EOCENE	<i>Wetzeliiella lunaris</i> Assemblage	<i>Rhombodinium intermedium</i> Zone	<i>Parviprojectus</i> sp. A Zone
		42.0		<i>Wetzeliiella articulata</i> Zone	<i>Araliaceipollenites megaporifer</i> Zone
		MIDDLE EOCENE		<i>Kisselovia edwardsii</i> Zone	<i>Rhoipites latus</i> Zone
		50.5	<i>Areoligera senonensis</i> Assemblage	<i>Rhombodinium condylos</i> Zone	<i>Pistillipollenites mcgregorii</i> Zone
		EARLY EOCENE		<i>Wetzeliiella verielongitudina</i> Zone	
		54.9		<i>Wetzeliiella similis</i> Zone	
		LATE PALEOCENE	<i>Ceratiopsis speciosa</i> Assemblage	<i>Wetzeliiella mecklefeldensis</i> Zone	<i>Tricolpites</i> sp. A Zone
		60.2	<i>Alisocysta circumtabulata</i> Assemblage	<i>Apectodinium hyperacanthum</i> Zone	<i>Paraalnipollenites alterniporus</i> Zone
		EARLY PALEOCENE	<i>Palaeoperidinium pyrophorum</i> Assemblage	<i>Deflandrea speciosa</i> Zone	
		65.0		<i>Palaeoperidinium pryrophorum</i> — <i>Deflandrea striata</i> Zone	

*Harland et al., 1982

Figure 5. Comparison of previously established Tertiary palynological zonations of the Labrador Sea and the provisional pollen and spore zones.

A late Oligocene *Cordosphaeridium fibrospinosum* - *Deflandrea* sp. C zonal assemblage is reported by G. L. Williams. No corresponding pollen and spore zone was found in the study wells. The pollen and spores indicate a hiatus in the depositional record during this interval. The uppermost early Oligocene dinoflagellate *Wetzeliella ovalis* zone tends to correspond with the *Parviprojectus* sp. A zone. Whereas pollen and spores indicate a transition zone (*Araliaceoipollenites megaporifer*) across the Eocene/Oligocene boundary, the boundary is marked by the tops of the *Wetzeliella lunaris* and *Rhombodinium intermedium* zones.

The top of the *Pistillipollenites mcgregorii* zone appears to be a good zonal marker for the upper middle Eocene for which there are no zonally diagnostic dinoflagellate range tops or assemblages indicated. *P. mcgregorii* was found in all of the study wells and, though not common, its occurrence is consistent and it is associated with a characteristic assemblage.

Ioakim's zonal resolution for the Eocene of the Labrador Sea sediments is the most detailed of the three zonations. This is particularly true of the early Eocene, which she has divided into five zones. The early Eocene of the Labrador Sea region was a time during which the diversity and relative abundance of dinoflagellates were highest. Unfortunately, her zonation was somewhat difficult to apply because not all of the zonally nominate species were present in the wells investi-

gated and, in some instances, their stratigraphic occurrences not always consistent. This problem may possibly be due in part, however, to the wide intervals between samples, palynomorph preservation and contamination by cavings and/or redeposition.

Dinoflagellates are more useful for establishing zonal boundaries in the Paleocene than are the pollen and spores. Three zones were recognized by both Ioakim and G. L. Williams whereas only two have been identified using pollen and spores. The characteristically low diversity and reduced numbers of pollen and spores in this part of the section are a major difficulty with regards to further refining the zonal resolution of the *Tricolpites* sp. A and *Paraalnipollenites alterniporus* zones.

The zone comparisons illustrated in Figure 5 demonstrate that pollen and spores can be useful in the Tertiary marine sections of the Labrador Sea for helping to establish biostratigraphic control, particularly when used in conjunction with dinoflagellate assemblages. The provisional zonation proposed herein is especially important in sections where terrestrial palynomorphs predominate, e.g., Eocene through Miocene of Hekja 0-71 and upper Eocene and younger sections of the remaining study wells. There is an excellent potential for increasing the biostratigraphic zonal resolution in these intervals by taking a combined detailed taxonomic and statistical approach to the study of the pollen and spore assemblages. The maintenance of careful

control over sample spacing and quality would be essential, however, for such analyses.

DISCUSSION

The proposed provisional pollen and spore zonation may be applicable to other northern latitude regions. Many of the zonally diagnostic floral elements found in the Tertiary sediments of the Labrador Sea are also known to extend across the Canadian Arctic and into north-western North America.

Pollen and spore assemblages of Paleocene age have been described from the Canadian Arctic (Rouse and Srivastava, 1972; Doerenkamp et al., 1976; Rouse, 1977; Ioannides and McIntyre, 1980). Although many of the same species are common to the two areas, on the Labrador Shelf there is a fairly strong marine influence and the pollen and spores do not show as great a diversity as in the largely terrestrial assemblages from the Arctic. Rouse was able to divide the early and middle Paleocene into three zones (P-1 to P-3) which correspond to the single *Paraalnipollenites alterniporus* zone from the Labrador Sea. Almost all of the pollen and spores (including the zonally nominate species, *Tricolpites* sp. A) from the late Paleocene of the Labrador Sea is also present in Rouse's late Paleocene P-4 assemblage. Many of

the same elements are also reported by Ioannides and McIntyre (1980) from the Caribou Hills section of the Mackenzie delta.

The Eocene pollen and spore assemblages of the Labrador Sea, Canadian Arctic, British Columbia and northwestern Washington State are remarkably similar. Over this extensive area, the Eocene assemblages are very diverse, with a large number of species making their first stratigraphic appearance during this time interval. Pollen and spore assemblages comparable to the *Pistillipollenites mcgregorii* zone (this paper) are reported from the early to middle Eocene of the Caribou Hills section in the Mackenzie delta (Ioannides and McIntyre, 1980), the southern Beaufort Sea (Norris, 1986), the Eureka Sound Formation and equivalent beds in the Canadian Arctic and south central British Columbia (Rouse, 1977), the Burrard Formation in coastal British Columbia (Rouse et al., 1971) and the Chuckanut Formation just south of the Canadian-United States border in northwestern Washington State (Reiswig, 1983).

The flora represented by the late-middle to late Eocene *Rhoipites latus* zone is equivalent to the E-2 assemblage described by Rouse (1977) from the Canadian Arctic and south central British Columbia. Similar assemblages have also been described from the Kitsilano Formation in coastal British Columbia (Hopkins, 1969; Rouse et al., 1971) and the Chuckanut Formation in northwestern Washington (Reiswig, 1983). Rouse (personal communication) has also noted

Araliaceopollenites megaporifer, *Verrutricolporites* and other pollen associated with the *Araliaceopollenites megaporifer* zone from the Beaufort Sea.

The early Oligocene *Parviprojectus* sp. A zonal assemblage from the Labrador Sea is similar to that described from the Caribou Hills section of the Mackenzie delta (Interval D of Ioannides and McIntyre, 1980), from central British Columbia (Piel, 1971 and 1977) and from the Northern Rocky Mountain Trench in British Columbia (Hopkins et al., 1972).

An early to middle Miocene pollen and spore assemblage similar to that used to characterize the Labrador Sea *Fagus granulata* zone is reported from the Whatcom Basin of southwestern British Columbia and northwestern Washington (Hopkins, 1968), south central British Columbia (Piel, 1977) and Alaska (Wolfe and Leopold, 1967). The lower Miocene pollen and spore flora reported by Norris (1986) for the southern Beaufort Sea is less diverse than the *F. granulata* zonal assemblage from the Labrador Sea. The *Tsuga igniculus* zone in the Labrador Sea is very similar to the late middle-upper Miocene assemblages of the Canadian Arctic (Rouse, personal communication) and, though less diverse, to the Upper Skonun Formation of the Queen Charlotte Islands (Martin and Rouse, 1966), estimated between 11-13 Ma (Champigny et al., 1981).

The general similarity of pollen and spore assemblages across northern and western Canada raises some interesting speculation with regards to the provenance of the grains. Because Tertiary outcrops in the circum-Labrador Sea area are almost non-existent, it is not possible to determine if in-situ terrestrial palynomorphs represent the "local" flora of the area or if they were transported for long distances via a combination of wind and running water. Although some of the palynofloral elements were undoubtedly indigenous to the surrounding area, the species composition of redeposited Paleogene palynomorphs along with clay mineralogy data (Hiscott, 1984) indicate that at least some portion of the palynoflora was derived from the western interior and Arctic regions of Canada (see CHAPTER 4 for detail).

Pollen and spore assemblages from the offshore areas of Newfoundland, Nova Scotia and the northeastern United States seem to share fewer floral components with the Labrador Sea region than do northern and western Canada. A number of the zonally diagnostic pollen and spores used to characterize the eight provisional zones proposed for the continental shelf sediments of the Labrador Sea are not reported by Williams and Brideaux (1975) from the Grand Banks or by Bebout (1980) from the Baltimore Canyon COST No. B-2 well. Some form of provincialism between the Labrador Sea and the Grand Banks/Scotian Shelf areas is also suggested by dinoflagellate assemblages (Bujak, personal communication). There are apparently some differences in dinoflagellate species composition between the two geographical re-

gions (Williams and Brideaux, 1975; Williams and Bujak, 1977; and Barss et al., 1970).

With the exception of a greater abundance and diversity of extratriporate pollen, the Paleocene pollen and spore assemblage from the Grand Banks is quite similar to that from the Labrador Sea region. It is generally characterized by long-ranging species of low diversity and abundance. In the Baltimore Canyon well the Paleocene is absent.

The Eocene and early Oligocene pollen and spore assemblages from the Grand Banks and Baltimore Canyon are very similar to one another and share many of the same elements found in the more northerly assemblages. However, some of the important zonally diagnostic pollen (e.g., onagraceous pollen, *Parviprojectus*, *Pistillipollenites mcgregorii*, and *Rhoipites latus*) and fungal spores (e.g., *Striadiporites*, *Fusiformisporites* and *Pesavis*) common to the Labrador Sea, Canadian Arctic and British Columbia were not reported by Williams and Brideaux or Bebout.

The Miocene of the Labrador Sea, Grand Banks and Baltimore Canyon is generally characterized by an abundance of conifer pollen (e.g., *Picea*, *Pinus* and *Tsuga*) and the last consistent stratigraphic appearance of a number of arboreal pollen species (e.g., *Fagus*, *Tilia*, *Juglans* and *Liquidambar*). The ranges of several of these taxa extend stratigraphically higher in the Grand Banks and Baltimore Canyon than

they appear to farther north in the Labrador Sea and Canadian Arctic, where climatic cooling associated with the onset of glaciation was more pronounced.

Based upon the recorded distribution of Tertiary pollen and spore assemblages from northern North America, the provisional zonation proposed herein may successfully be applied across a broad regional zone that extends westward and northward from the Labrador Sea to include at least portions of the Canadian Arctic and British Columbia. The application of the zonation to the south into the Grand Banks, Scotian Shelf and Atlantic coastal plain areas of the northeastern United States is questionable, however, because of the apparent absence and/or differences in the stratigraphic ranges of many of the zonally diagnostic species used to characterize the zones.

CONCLUSIONS

1. The diversity and abundance of pollen and spores in the Tertiary marine sediments of the Labrador Sea, provide sufficient material to use as a basis for establishing biostratigraphic control in the region. Using range tops, eight preliminary pollen and spore interval zones are proposed.

2. A comparison between the Tertiary pollen and spore zonation proposed herein with previously published dinoflagellate zonations from the Labrador Sea demonstrates the utility of pollen and spores for helping to establish stratigraphic control in marine sediments. Although dinoflagellates lend themselves particularly well to high-resolution biostratigraphy (as evidenced by Ioakim's rigorous zonation of the Eocene), the stratigraphic ranges of pollen and spores when integrated with those of dinoflagellates, maximizes the total amount of information that can be derived from a palynological study of marine sediments. This is especially true in intervals where there is a strong terrestrial influence (e.g., Eocene through Miocene sections in Hekja O-71 and Roberval K-92). The use of both pollen/spores and dinoflagellates not only helps to refine the zonation of the stratigraphic sections in these two wells, but also helps to distinguish and correlate facies.

3. The proposed pollen and spore zonation for the Tertiary of the Labrador Sea can be extended regionally across the Canadian Arctic and interior British Columbia. Although some ranges may shift slightly due to local climatic or physiographic factors, the general succession and content of the terrestrial palynoflora appears to be continuous across northern Canada. South of the Labrador Sea in the Grand Banks and Scotian Shelf area, however, most of the zonally nominate species have not been recorded. This apparent provinciality between the two areas may also be observed in the dinocyst palynoassemblages.

4. The proposed provisional pollen and spore zonation represents a good palynostratigraphic framework for future studies. There is a strong potential for refinement of this zonation especially for the Eocene and younger sediments. Before this can be done, however, it will be necessary to establish better sidewall core control and to tighten the intervals between samples.

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EXPLANATION OF PLATES

All specimens were recovered from offshore Tertiary sediments from the Labrador Sea. The taxa illustrated are generally arranged according to the sequence in which they are discussed in the text. All photomicrographs were photographed in transmitted light under Nomarski differential interference contrast. Figure captions contain information on the well, sample depth and type of sample (i.e., cuttings or sidewall core) from which specimens came. The orientation and focus level of specimens, magnification and photo numbers (i.e., negative number, year and frame number) of the photomicrographs are also included.

PLATE 1

FIGURE 1: *Tsuga igniculus* (Potonie) Potonie and Venitz 1934. Monosaccate pollen with loosely convoluted velum surrounding saucer-shaped body. Zonally nominate species. Range top = *T. igniculus* Zone. Roberval K-92; 710 m. (cuttings); mid-focus; 800x; ROB B:81:7.

FIGURE 2: *Osmunda* sp. Trilete spore exhibiting irregular rugulo-baculate ornamentation. Genus long-ranging with greatest abundance in Miocene. Range top = *T. igniculus* Zone. Hekja 0-71; 935-965 m. (cuttings); polar view, mid-focus; 1000x; TH 1:84:9.

FIGURE 3: *Betula claripites* Wodehouse 1933. Triporate pollen with protruding aspidate pores. Range top = *T. igniculus* Zone. Hekja 0-71; 740-830 m. (cuttings); polar view, mid-focus; 800x; TH 1:84:1.

FIGURE 4: *Chenopodipollis* sp. Multiporate pollen. Range top = *T. igniculus* Zone. Hekja 0-71; 740-830 m. (cuttings); mid-focus; 800x; TH 1:84:2.

FIGURE 5: Gramineae sp. Monoporate pollen with pore surrounded by annulus. Range top = *T. igniculus* Zone. Hekja 0-71; 740-830 m. (cuttings); high-focus; 800x; TH 2:84:20.

FIGURES 6 and 7: *Fagus granulata* Martin and Rouse 1966. Broadly elliptical tricolporate pollen with narrow colpi and large elliptical pores. Fine (Fig. 7) to coarsely (Fig. 6) granulate ornamentation. Zonally nominate species. Range top = *F. granulata* Zone. Fig. 6: Hekja 0-71; 935-965 m. (cuttings); equatorial view, mid-focus; 1000x; TH 1:84:7. Fig. 7: Hekja 0-71; 935-965 m. (cuttings); equatorial view, mid-focus; 1000x; TH 1:84:13.

FIGURE 8: *Quercus* form A. Tricolpate, fine to moderately granulate form. Range top = *F. granulata* Zone. Hekja 0-71; 935-965 m. (cuttings); equatorial view, mid-focus; 900x; TH 1/2:84:7.

FIGURE 9: *Quercus* form B. Tricolpate, coarsely granulate form. Range top = *T. igniculus* Zone. Hekja 0-71; 935-965 m. (cuttings); equatorial view, mid-focus; 900x; TH 1:84:4.

FIGURE 10: *Liquidambar* form A. Polyporate pollen with large rounded elliptical pores. Differs from form B by larger size (29 μ m to 40 μ m) and fewer but larger pores. Range top = *F. granulata* Zone. Hekja 0-71; 1205-1250 m. (cuttings); mid-focus; 1000x; TH 2:84:4.

FIGURE 11: *Liquidambar* form B. Polyporate pollen with numerous, small rounded pores. Differs from form A by size (22 μ m to 27 μ m) as well as number and shape of pores. Hekja O-71; 935-965 m. (cuttings); mid-focus; 1000x; TH 1:84:5.

FIGURE 12: *Sequoia* sp. Pollen grain with coarsely scabrate ornamentation and pronounced papilla. Range top = *F. granulata* Zone. Hekja O-71; 910-930 m. (cuttings); mid-focus; 1000x; TH 4:84:21.

FIGURE 13: *Tsuga viridifluminipites* Wodehouse 1933. Monosaccate pollen with low, tightly convoluted velum. Fine spinae attached to velum (visible along outer margin of saccus). Range top = *F. granulata* Zone. Hekja O-71; 935-965 m. (cuttings); mid-focus; 800x; TH 4:84:35.

FIGURE 14: *Parviprojectus* sp. A sensu Rouse 1977. Retistriate isopolar pollen with three thin equatorial projections (4 μ m to 6 μ m) that narrow to a point at their free end. Colpi narrow and extend only about one third to one half the distance to the poles (Fig. 14b). Zonally nominate species. Range top = *Parviprojectus* sp. A Zone. Hekja O-71; 970-1010 m. (cuttings); equatorial view, mid-focus; 900x (Fig. 14a) and 1500x (Fig. 14b); HEK 2:82:9.

FIGURES 15 and 16: *Corylus/Carpinus* spp. Triporate pollen. Group long-ranging but most abundant in early Oligocene sections of study wells. Range top = *T. igniculus* Zone. Hekja O-71; 1205-1250 m. (cuttings); polar view, mid-focus; 1000x; TH 4:84:5 (Fig. 15) and TH 4:84:7 (Fig. 16).

FIGURE 17: *Myrica* sp. Triporate pollen with pronounced annulus. Enlargement of pore area (Fig. 17b) shows coarse granular "teeth-like" texture on the inner wall. Range top = *T. igniculus* Zone. Hekja O-71; 970-1010 m. (cuttings); polar view, mid-focus; 900x (Fig. 17a) and 1200x (Fig. 17b); HEK 2:82:30.

FIGURES 18-21: *Ilex* spp. Elliptical to round tricolporate pollen showing wide variation in size and arrangement of clavate ornamentation. Colpi extend to poles (Fig. 20) and pores indistinct. Range top = *F. granulata* Zone. Fig. 18: Hekja O-71; 1205-1250 m. (cuttings); euqatorial view, mid-focus; 1000x; TH 1/2:84:3. Fig. 19: Kangamiut 1; 2700 m. (cuttings); equatorial view, mid-focus; 1000x; KANG G:79:27. Fig. 20: Hekja O-71; 1905-1945 m. (cuttings); polar view, mid-focus; 1000x; TH 4:84:17. Fig. 21: Hekja O-71; 2305-2330 m. (cuttings); equatorial view, mid-focus; 1000x; TH 3:84:7.

PLATE 1

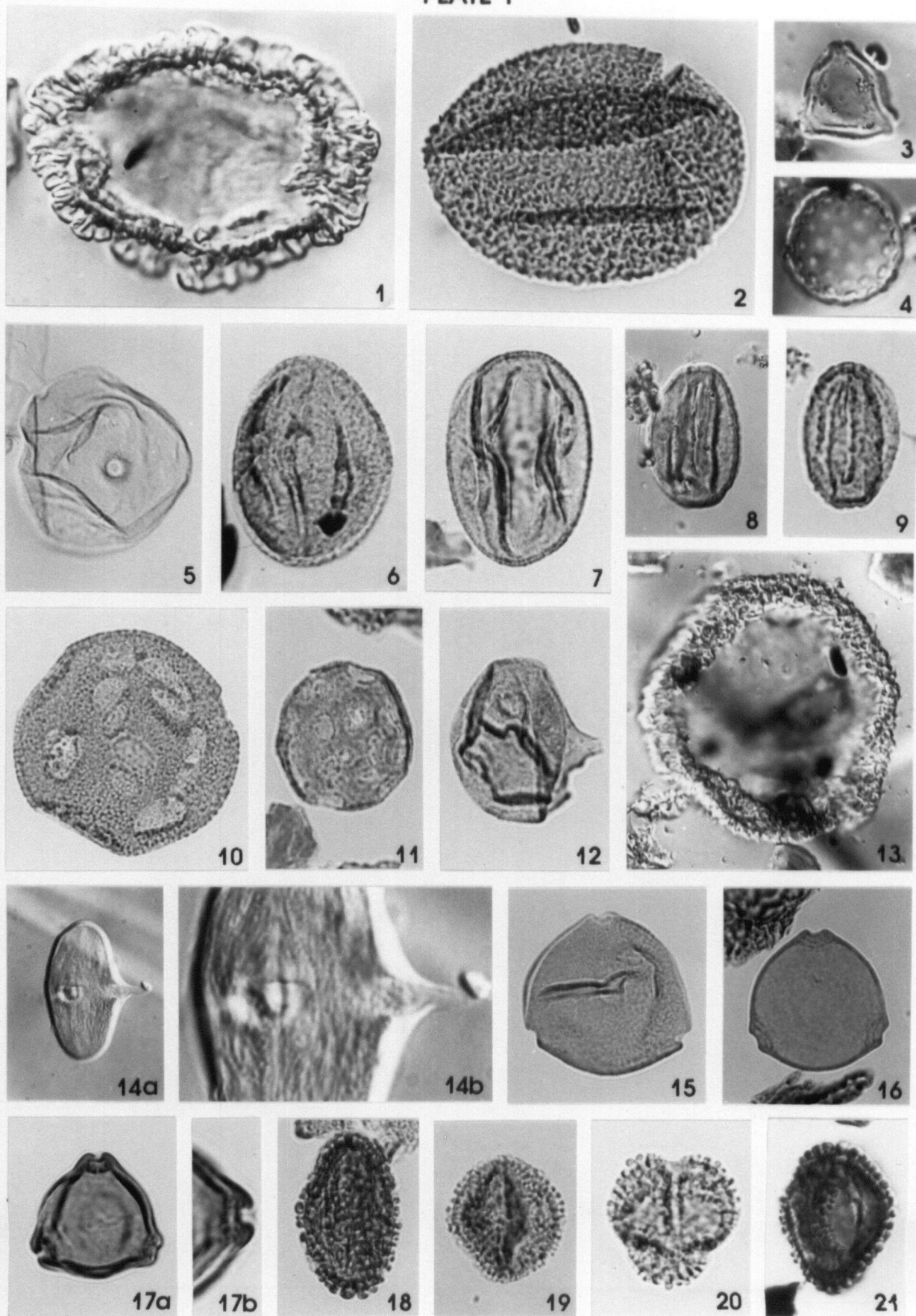


PLATE 2

FIGURE 1: *Tilia crassipites* Wodehouse 1933. Large rounded, reticulate tricolporate pollen with short colpi obscured by thick pad-like thickenings surrounding the pores. Specimen shows reticulum finer on one pole (Fig. 1b) and coarser on the other (Fig. 1a). Range top = *Fagus granulata* Zone. Hekja 0-71; 970-1010 m. (cuttings); polar view, low-focus (Fig. 1a) and high-focus (Fig. 1b); 1000x; TH 1:84:26 and 27.

FIGURES 2 and 6: *Ulmus* spp. Triporate to pentaporate pollen with characteristic but variable rugulate to rugo-verrucate sculpture. Commonly tetraporate and quadrangular (Fig. 2) to rounded (Fig. 6) in outline. Range top = *Fagus granulata* Zone. Fig. 2: Karlsefni A-13; 8600 ft. (cuttings); polar view, mid-focus; 1000x; KARL A:80:13. Fig. 6: Hekja 0-71; 970-1010 m. (cuttings); polar view, mid-focus; 1000x; TH 1:84:17.

FIGURE 3: *Alnus* sp. Porate pollen with variable number of pores (typically 5). Pores annular and connected by thickened arci. Range top = *Tsuga igniculus* Zone. Karlsefni A-13; 6720 ft. (cuttings); polar view, mid-focus; 1000x; KARL A:80:19.

FIGURES 4 and 5: *Carya* spp. Rounded to subtriangular triporate pollen. Pores located equidistantly apart on one hemisphere. Range top = *Fagus granulata* Zone. Fig. 4: Hekja 0-71; 1905-1945 m. (cuttings); polar view, mid-focus; 1000x; TH 3/4:84:30. Fig. 5: Hekja 0-71; 1205-1250 m. (cuttings); polar view, mid-focus; 1000x; TH 3/4:84:5.

FIGURE 7: *Juglans* sp. Rounded periporate pollen. Range top = *Fagus granulata* Zone. Hekja 0-71; 1405-1450 m. (cuttings); polar view, mid-focus; 1000x; TH 1:84:3.

FIGURE 8: *Jussiaea* sp. Psilate triporate pollen with thick "doughnut-like" annulus surrounding pores. Range top = *Parviprojectus* sp. A Zone. Herjolf M-92; 4500-4510 ft. (cuttings); polar view, mid-focus; 1100x; HERJ 2:81:20.

FIGURE 9: *Boisduvalia clavatites* Piel 1971. Onagraceous triporate pollen with protruding pores that have dissected ridge-like appearance. Rounded verrucae/gemmae sculptural elements sparsely arranged on outer exine surface. Range top = *Parviprojectus* sp. A Zone. Herjolf M-92; 4500-4510 ft. (cuttings); polar view, mid-focus; 1000x; HERJ 2:81:0.

FIGURE 10: *Rousea araneosa* (Frederiksen) Frederiksen 1980. Reticulate tricolpate pollen. Reticulum characterized by narrow muri and wide lumina which become smaller along the colpus. Range top = *Parviprojectus* sp. A Zone. Hekja 0-71; 1605-1645 m. (cuttings); equatorial view, mid-focus; 1000x; TH 1/2:84:14.

FIGURES 11 and 12: *Araliaceoipollenites granulatus* (Potonie) Frederiksen 1980. Granulate tricolporate pollen. Pores lalongate. Range top = *Parviprojectus* sp. A Zone. Fig. 11: Hekja 0-71; 1290-1345 m (cuttings); equatorial view, mid-focus; 1000x; HEK 3:83:7. Fig. 12: Herjolf M-92; 5600 ft. (cuttings); equatorial view, mid-focus; 1000x; HERJ 2:81:35.

FIGURE 13: *Acanthaceae* sp. Psilate tricolporate pollen with large granules located in the region of the colpus. Range top = *Parviprojectus* sp. A Zone. Hekja 0-71; 1205-1250 m. (cuttings); equatorial view, mid-focus; 1000x; TH 1:84:25.

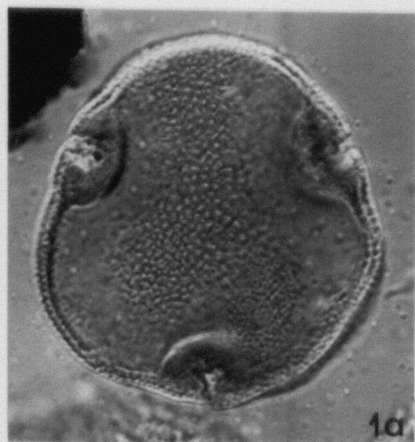
FIGURE 14: *Rousea monilifera* Frederiksen 1980. Coarsely reticulate tricolpate pollen with coarsely beaded muri. Range top = *Parviprojectus* sp. A Zone. Hekja 0-71; 1205-1250 m. (cuttings); equatorial view, mid-focus; 1000x; TH 2:84:35.

FIGURE 15: *Nyssapollenites* sp. Finely reticulate tricolporate pollen with exinal thickenings around pores. Outline subtriangular and sides straight to slightly convex. Range top = *Parviprojectus* sp. A Zone. Hekja 0-71; 2305-2330 m. (cuttings); polar view, mid-focus; 1000x; TH 2:84:21.

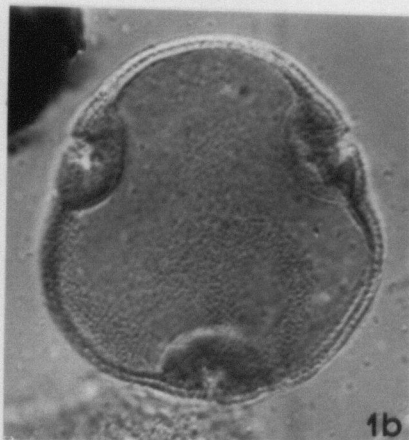
FIGURE 16: *Ephedra claricristata* Shakhmundes 1965. Range top = *Parviprojectus* sp. A Zone. Herjolf M-92; 4610-4620 ft. (cuttings); equatorial view, mid-focus; 700x; HERJ 3:81:13.

FIGURE 17: *Araliaceoipollenites profundus* Frederiksen 1980. Large granulate tricolporate pollen with deeply invaginated colpi extending length of grain. Range top = *Parviprojectus* sp. A Zone. Hekja 0-71; 1205-1250 m. (cuttings); equatorial view, mid-focus; 1200x; TH 1/2:84:9.

PLATE 2



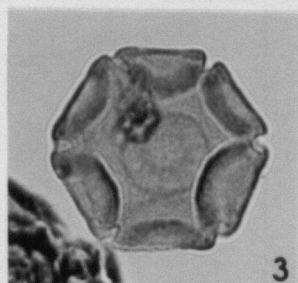
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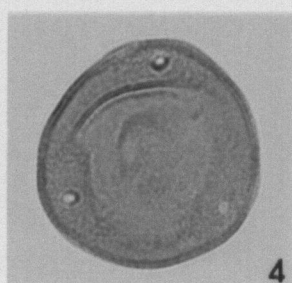
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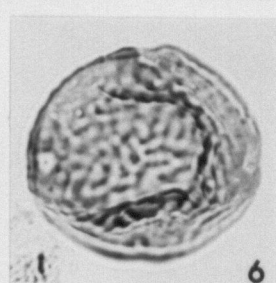
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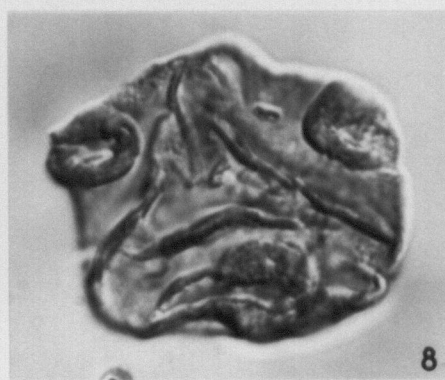
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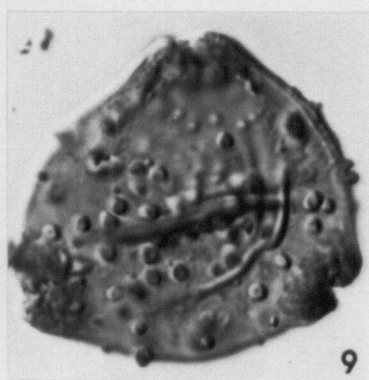
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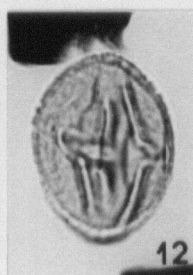
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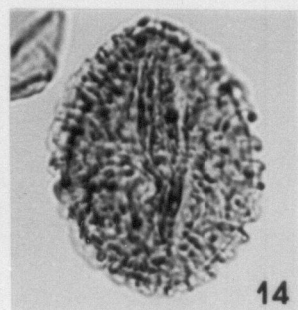
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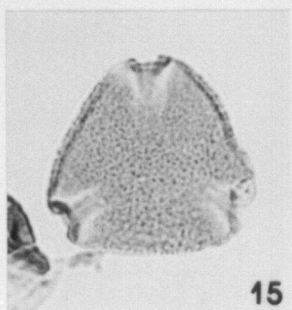
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PLATE 3

FIGURES 1 and 2: *Araliaceoipollenites megaporifer* Frederiksen 1980. Granulate tricolporate pollen. Oval with rounded ends. Pores large and rounded. Colpi narrow and extending almost the full length of grain. Zonally nominate species. Range top = *A. megaporifer* Zone. Fig. 1: Hekja O-71; 1605-1650 m. (cuttings); equatorial view, mid-focus; 1000x; TH 1/2:84:13. Fig. 2: Herjolf M-92; 5200 ft. (cuttings); equatorial view, mid-focus; 1000x; HERJ 2:84:19.

FIGURE 3: *Tetracolporites* cf. *T. brevis*. Tetracolporate pollen. Psilate to faintly punctate ornamentation and lalongate pores. Colpi extend nearly to poles. Range top = *Araliaceoipollenites megaporifer* Zone. Hekja O-71; 1405-1450 m. (cuttings); equatorial view, mid-focus; 1000x; TH 4:84:32.

FIGURE 4: *Gothanipollis cockfieldensis* Engelhardt 1964. Syncolporate pollen. In equatorial view has triangular shape with narrowly rounded, somewhat flared appearance at apertures. Range top = *Araliaceoipollenites megaporifer* Zone. Herjolf M-92; 4610 ft. (cuttings); polar view, mid-focus; 1200x; HERJ 3:81:28A.

FIGURES 5 and 6: *Verrutricolporites cruciatus* Frederiksen 1980. Verrucate tricolporate pollen. Pores lalongate. Colpi show little thickening and extend approx. 4/5 the length of grain. Range top *Araliaceoipollenites megaporifer* Zone. Fig. 5: Hekja O-71; 1405-1450 m. (cuttings); equatorial view, mid-focus; 1000x; TH 1/2:84:22. Fig. 6: Hekja O-71; 1605-1650 m. (cuttings); equatorial view, mid-focus; 1000x; TH 4:84:25.

FIGURES 7 and 8: *Momipites microfoveolatus* (Stanley) Nichols 1973. Triporate pollen. Small (12 μ m to 20 μ m) with slightly convex (Fig. 7) to concave (Fig. 8) sides. Range top = *Araliaceoipollenites megaporifer* Zone. Fig. 7: Hekja O-71; 1905-1945 m. (cuttings); polar view, mid-focus; 1000x; TH 4:84:34. Fig. 8: Kangamiut 1; 2750 m. (cuttings); polar view, mid-focus; 1000x; KANG E:79:37.

FIGURES 9 and 10: Ericaceae tetrads. Tetrads of tricolpate pollen. Shape of outline varies from triangular (Fig. 9) to rounded (Fig. 10). Rounded forms generally larger than triangular ones. Range top = *Fagus granulata* Zone. Fig. 9: Hekja O-71; 1205-1250 m. (cuttings); mid-focus; 1000x; TH 1:84:16. Fig. 10: Hekja O-71; 2305-2330 m. (cuttings); mid-focus; 800x; TH 3:84:19.

FIGURE 11: *Rhoipites latus* Frederiksen 1980. Tricolporate pollen with rounded to slightly lalongate pores. Ornamentation reticulate with lumina polygonal to longitudinally elongate. Zonally nominate species. Range top = *R. latus* Zone. Herjolf M-92; 5400 ft. (cuttings); equatorial view, mid-focus; 900x HERJ 3:81:17.

FIGURE 12: *Caprifoliipites* sp. A sensu Rouse 1977. Reticulate tricolporate pollen. Reticulum even and width of muri nearly equal to width of lumina. Pores lalongate. Range top = *Rhoipites latus* Zone. Herjolf M-92; 5400 ft. (cuttings); equatorial view, mid-focus; 800x; HERJ 2:81:29.

FIGURE 13-15: *Cupuliferoipollenites* spp. Psilate tricolporate pollen. Pores lalongate. Colpi extend 2/3 to nearly full length of grain. Range top = *Parviprojectus* sp. A Zone. Fig. 13: Hekja 0-71; 2305-2330 m. (cuttings); equatorial view, mid-focus; 1000x; TH 3/4:84:15. Fig. 14: Hekja 0-71; 1805-1850 m. (cuttings); equatorial view, mid-focus; 1000x; HEK 3:83:33. Fig. 15: Kangamiut 1; 2901 m. (cuttings); equatorial view, mid-focus; KANG I:81:16.

FIGURE 16: *Symplocoipollenites* sp. B. Tricolporate pollen. Granulate. Colpi wide, extend to pole and bordered by exinal thickenings. Pores poorly defined. Range top: *Rhoipites latus* Zone. Kangamiut 1; 2700 m. (cuttings); polar view, mid-focus; 1000x; KANG G:79:26.

FIGURE 17: *Symplocoipollenites* sp. A. Reticulate tricolporate pollen. Colpi extend approx. 1/2 to 2/3 the distance to poles and bordered only by slight thickening. Exine thickened at pores. Range top = *Rhoipites latus* Zone. Hekja 0-71; 1605-1645 m. (cuttings); polar view, mid-focus; 1000x; TH 1/2:84:23.

FIGURE 18: *Tricolporopollenites kruschii* sensu Rouse 1977. Reticulate tricolporate pollen. Reticulum finer at poles and along colpi. Colpi show slight marginal thickening and extend nearly to poles. Range top = *Rhoipites latus* Zone. Hekja 0-71; 1905-1945 m. (cuttings); polar view; mid-focus; 1000x; TH 4:84:9.

FIGURE 19: *Verrutricolporites* sp. A. Verrucate tricolporate pollen with pronounced lalongate pores and thickenings along colpi. Colpi extend approx. 4/5 the length of grain. Range top = *Rhoipites latus* Zone. Hekja 0-71; 1605-1650 m. (cuttings); equatorial view, mid-focus; 1000x; HEK 3:83:19.

FIGURE 20: *Verrutricolporites* sp. B.. Verrucate tricolporate pollen with circular to lolongate pores. Colpi extend $\frac{3}{4}$ the distance to poles. Verrucae large and irregular in design. Exine thicker at poles than at equator. Range top = *Rhoipites latus* Zone. Hekja O-71; 1905-1945 m. (cuttings); equatorial view, mid-focus; 1000x; TH 4:84:23.

FIGURE 21: *Verrutricolporites* sp. C. Verrucate tricolporate pollen with indistinct pores. Colpi without thickenings and extend nearly to poles. Range top = *Araliaceoipollenites megaporifer* Zone. Hekja O-71; 1605-1645 m. (cuttings); equatorial view, mid-focus; 1000x; TH 1/2:84:17.

FIGURE 22: *Verrutricolporites* sp. D. Rounded, verrucate tricolporate pollen with lolongate pores. Colpi with pronounced marginal thickenings extend $\frac{4}{5}$ the length of grain. Verrucae large. Range top = *Rhoipites latus* Zone. Hekja O-71; 1710-1745 m. (cuttings); equatorial view, mid-focus; 1000x; HEK 3:83:30.

FIGURE 23: *Ailanthipites* sp. B. sensu Rouse 1977. Retistriate tricolporate pollen with lolongate pores. Range top = *Rhoipites latus* Zone. Hekja O-71; 2305-2330 m. (cuttings); equatorial view, mid-focus; 1000x; TH 4:84:11.

FIGURE 24: *Bombacacidites bombaxoides* Couper 1960. Subtriangular shaped tricolporate pollen with reticulate ornamentation. Reticulum coarser at poles and finer along equator. Range top = lower *Rhoipites latus* Zone. Hekja O-71; 1905-1945 m. (cuttings); 900x; TH 4:84:3.

FIGURE 25: *Puctodiporites* sp. Diporate fungal spore with punctate ornamentation. Distinct collar surrounds pores. Range top = *Araliaceoipollenites megaporifer* Zone. Hekja O-71; 1905-1945 m. (cuttings); mid-focus; 1000x; TH 4:84:12.

FIGURES 26 and 27: *Fusiformisporites* spp. Two-celled fungal spores with longitudinal grooves. Range top = *Rhoipites latus* Zone. Fig. 26: Roberval K-92; 1900 m. (cuttings); mid-focus; 1000x; ROB B:81:11. Fig. 27: Hekja O-71; 1905-1945 m. (cuttings); mid-focus; 1000x; TH 4:84:7.

FIGURES 28 and 29: *Striadiporites* spp. Diporate fungal spore with ribbed ornamentation. Range top = *Rhoipites latus* Zone. Fig. 28: Kangamiut 1; 3090 m. (cuttings); mid-focus; 1000x; KANG I:79:0. Fig. 29: Hekja O-71; 1905-1945 m. (cuttings); mid-focus; 1000x; TH 4:84:10.

PLATE 3

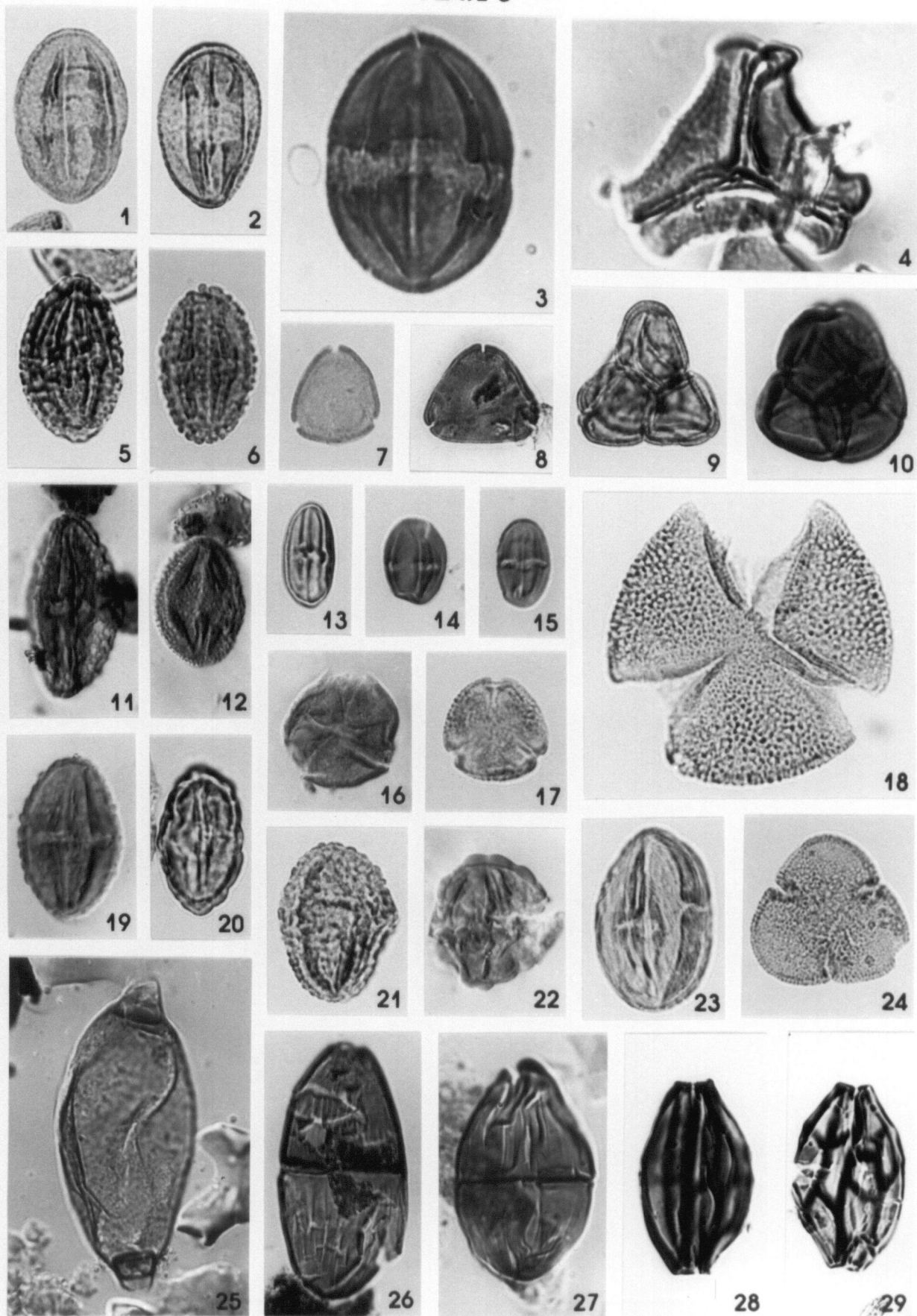


PLATE 4

FIGURES 1, 6 and 11: *Pistillipollenites mcgregorii* Rouse 1962. Triporate pollen with variable number of gemmae. Older specimens typically have fewer gemmae, usually situated near pores (Fig. 11), and younger grains tend to have numerous gemmae (Figs. 1 and 6) that may cover the entire surface of the grain. Range top = *P. mcgregorii* Zone. Fig. 1: Hekja O-71; 2020-2030 m. (cuttings); mid-focus; 1000x; TH 3:84:33. Fig. 6: Karlsefni A-13; 10,500 ft. (cuttings); mid-focus; 1000x; KARL 1:82:11. Fig. 11: Herjolf M-92; 7200 ft. (cuttings); mid-focus; 1000x; HERJ 1:81:5.

FIGURE 2: *Rhoipites angustus* Frederiksen 1980. Microreticulate tricolporate pollen with oval to diamond shaped outline. Pores rounded. Colpi appear thickened and extend nearly to poles. Range top = *Rhoipites latus* Zone. Herjolf M-92; 4610-4620 ft. (cuttings); equatorial view, mid-focus; 800x; HERJ 1:81:30.

FIGURES 3 and 4: *Platycarya* sp. Triporate pollen with 3 equatorial, atriolate pores and thin narrow troughs or pseudocolpi on each hemisphere. Range top = base *Rhoipites latus* Zone. Karlsefni A-13; 10,500 ft. (cuttings); mid-focus; 1000x; KARL 1:82:16 and 17.

FIGURE 4: *Pesavis tagluensis* Elsik and Jansonius 1974. Circular, multicellular fungal spore. Stalked central cell with two curved lateral arms and centripetal hyphae originating from each primary cell. Range top = *Rhoipites latus* Zone. Kangamiut 1; 2949 m. (cuttings); mid-focus; 1000x; KANG D:79:23.

FIGURE 5: *Azolla* glochidia. Range top = *Pistillipollenites mcgregorii* Zone. Hekja O-71; 2305-2330 m. (cuttings); mid-focus; 900x; TH 2:84:15.

FIGURES 8 and 9: *Momipites wyomingensis* Nichols and Ott 1978. Small (19 μ m to 27 μ m), straight to convex sided, triporate pollen with atriolate pores. Lacks polar island and triradiate scar. Range top = *Tricolpites* sp. A Zone. Herjolf M-92; 7200 m. (cuttings); mid-focus; 900x; HERJ 1:81:15 and 16.

FIGURE 10: *Momipites ventifluminis* Nichols and Ott 1978. Atriolate triporate pollen with convex sides. Exine thickening on one hemisphere evidenced by three thin, circular spots around pole. Range top = *Tricolpites* sp. A Zone. Herjolf M-92; 7022 m. (sidewall core); polar view, mid-focus; 900x; HERJ 4:81:15.

FIGURE 12: *Insulapollenites rugulatus* Leffingwell 1971. Parasyncolpate pollen with coarsely rugulate sculpture in interapical areas. Ornamentation becomes reticulate to finely reticulate along colpi. Range top = *Tricolpites* sp. A Zone. Herjolf M-92; 7200 ft. (cuttings); polar view, mid-focus; 800x; HERJ 1:82:14.

FIGURE 13: pre-*Carya*. *Carya*-like triporate pollen in which one or two pores have migrated from one hemisphere to the equator. Range top = *Tricolpites* sp. A Zone. Herjolf M-92; 7022 ft. (sidewall core); polar view, mid-focus; 1100x; HERJ 1:81:17.

FIGURE 14: *Momipites anellus* Nichols and Ott 1978. Convex sided triporate pollen with atriate pores. Thin exine forming a circumpolar ring surround polar area. Similar to *M. amplus* but smaller in size (18 μ m to 27 μ m). Range top = *Tricolpites* sp. A Zone. Herjolf M-92; 7300 ft. (cuttings); polar view, mid-focus; 800x; HERJ 3:81:5.

FIGURE 15: *Momipites amplus* (Leffingwell) Nichols 1973. Convex sided triporate pollen with atriate pores situated on the equator. Circumpolar ring of thin exine surrounds pole (very faint in illustrated specimen). Differs from *M. anellus* by its larger size (29 μ m to 37 μ m). Range top = *Tricolpites* sp. A Zone. Herjolf M-92; 7100 ft. (cuttings); polar view, mid-focus; 1000x; HERJ 1:81:3.

FIGURES 16 and 17: *Paraalnipollenites alterniporus* (Simpson) Srivastava 1975. Triporate pollen with pseudopores developed along ridges of exinal thickening (arci) connecting pores. Zonally nominate species. Range top = *P. alterniporus* Zone. Fig. 16: Herjolf M-92; 7600 ft. (cuttings); polar view, mid-focus; 1000x; HERJ 2:81:18. Fig. 17: Kangamiut 1; 3447 m. (cuttings); polar view, mid-focus; 1000x; KANG E:79:26.

FIGURE 18: *Momipites actinus* Nichols and Ott 1978. Straight to concave sided triporate pollen with atriate pores and triradiate thinning at one pole. Range top = *Paraalnipollenites alterniporus* Zone. Herjolf M-92; 7400 ft. (cuttings); polar view, mid-focus; 800x; HERJ 2:81:21.

FIGURE 19: *Tricolpites parvus* Stanley 1965. Reticulate tricolpate pollen. Range top = *Tricolpites* sp. A Zone. Kangamiut 1; 3600 m. (cuttings); polar view, mid-focus; 900x; KANG G:79:29.

FIGURE 20: *Taxodiaceapollenites* sp. Range top = *Tsuga igniculus* Zone. Kangamiut 1; 3600 m. (cuttings); mid-focus; 1000x; KANG G:79:32.

FIGURES 21 and 22: *Betulaceoipollenites* spp. Triporate pollen with aspidate pores. Range top = *Pistillipollenites mcgregorii* Zone. Karlsefni A-13; 13,140 ft. (cuttings); polar view, mid-focus; 1000x; KARL A:80:11 and 12.

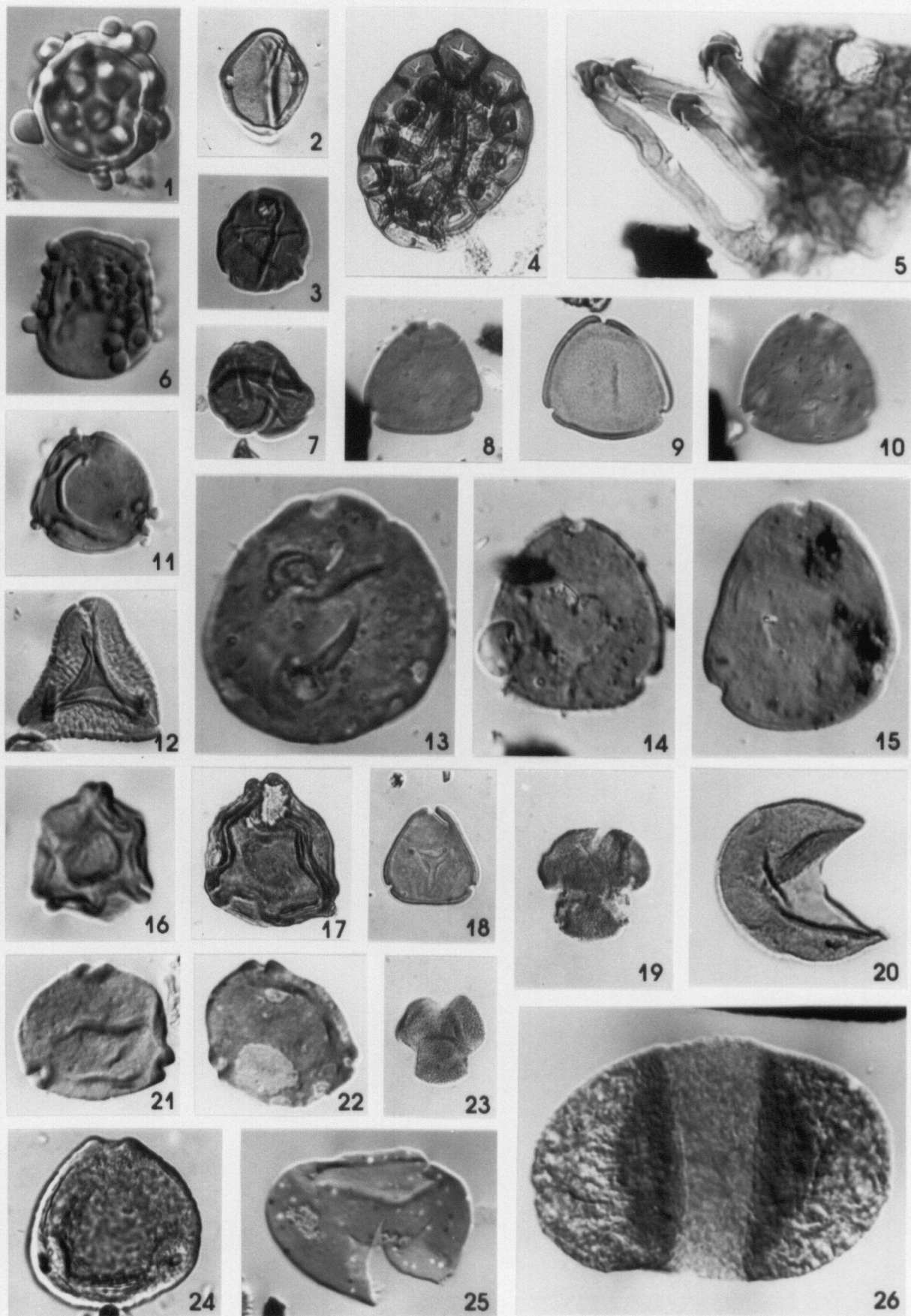
FIGURE 23: *Tricolpites* cf. *T. hians* Stanley 1965. Reticulate tricolpate pollen. Range top = *Pistillipollenites mcgregorii* Zone. Kangamiut 1; 3399 m. (cuttings); polar view, mid-focus; 900x; KANG G:79:19.

FIGURE 24: *Casuarinidites* sp. Triporate, atriate pollen. Illustrated specimen appears more coarsely granulate than others represented in this group. Range top = *Pistillipollenites mcgregorii* Zone. Herjolf M-92; 7500 ft. (cuttings); polar view, mid-focus; 900x; HERJ A:80:12.

FIGURE 25: *Laevigatosporites* sp. Psilate monolete spore. Range top = *Tsuga igniculus* Zone. Roberval K-92; 2690 m. (cuttings); mid-focus; 1000x; ROB C:80:5.

FIGURE 26: *Piceapollenites* sp. Bisaccate pollen. Range top = *Parviprojectus* sp. A Zone. Herjolf M-92; 7500 ft. (cuttings); mid-focus; 800x; HERJ A:80:5.

PLATE 4



CHAPTER 3. THE IDENTIFICATION AND DISTRIBUTION OF RECYCLED PALYNOMORPHS IN THE CONTINENTAL SHELF SEDIMENTS OF THE LABRADOR SEA

INTRODUCTION

The general distribution and relative abundances of recycled pre-Tertiary palynomorphs were determined from selected stratigraphic intervals in seven Labrador Sea wells. The purpose of the study was to find out if concentrations of certain age-groups of recyclants would reveal any information concerning sediment sources in the Labrador Sea area during a given time. The value of using redeposited palynomorphs as provenance indicators has been demonstrated by a number of workers, including Richardson and Rasul (1978), Askin and Elliott (1982), Legault and Norris (1982), Turner (1982) and Scott and Srivastava (1984). The project was funded by Aquitaine Company of Canada Ltd., (now Canterra Energy Ltd.) on behalf of the Baffin-Labrador Group, a consortium of oil companies involved in the exploration of hydrocarbons in the Labrador Sea.

From north to south, the study wells are Kangamiut 1, Karlsefni A-13, Skolp E-07, Snorri J-90, Herjolf M-92, Roberval K-92 and Cartier D-70. Their location is shown in Figure 1. Paleocene and Eocene sediments are represented in each of the wells with middle and Upper Cretaceous

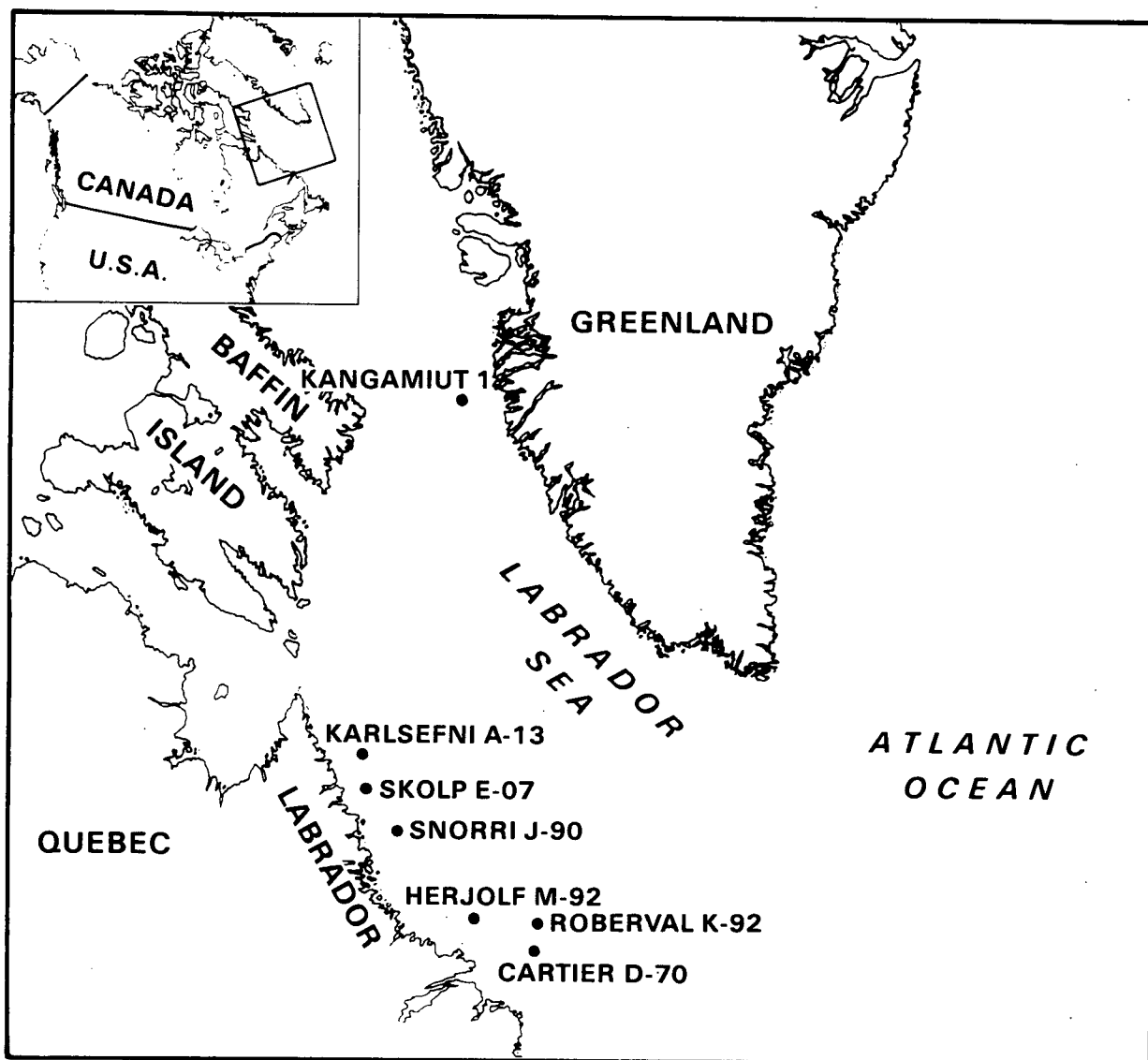


Figure 1. Location map of the Labrador Sea and the seven offshore wells used in this study.

sediments present in Skolp E-07, Herjolf M-92 and Roberval K-92. The oldest penetrated sediments represented in this study were Carboniferous, found at the base of Roberval K-92 between 3550 and 3850 meters. The ages of the sediments are based upon this author's detailed palynological study of the wells.

Prepared palynological slides of predominantly cuttings samples from Kangamiut 1, Karlsefni A-13, Skolp E-07, Herjolf M-92 and Cartier D-70 were provided on loan from Total-Eastcan, courtesy of Dr. N. J. McMillan, then of Aquitaine (Canterra Energy Ltd.) and now with the Geological Survey of Canada in Calgary, Alberta. Washed cuttings samples from Roberval K-92 were supplied by Aquitaine (now Canterra). The samples from Snorri J-90 were examined at the Atlantic Geoscience Center in Dartmouth, Nova Scotia, where the palynological slides are on file.

CRETACEOUS AND LOWER TERTIARY STRATIGRAPHY OF THE LABRADOR SEA

With the exception of small pockets of Cretaceous and Paleogene-aged sediments outcropping on West Greenland and central Baffin Island, land masses adjacent to the Labrador Sea were essentially stripped of their sediments by continental ice sheets during the Pleistocene (McMillan, 1973; Henderson et al., 1981). Our stratigraphic understanding of the Labrador Sea, therefore, is mainly dependent upon the

offshore wells drilled along the continental margins of the Labrador Sea. In places, total thickness of the Cretaceous and Tertiary sediments is greater than ten kilometers (McMillan, 1980, 1982). The general stratigraphy of the Labrador and West Greenland continental shelves is illustrated in Figure 2. Lithostratigraphic nomenclature for offshore Labrador is based on work by Umpleby (1979), McWhae et al., (1980) and McMillan (1980, 1982) and for offshore West Greenland by Rolle (1985).

The offshore Labrador wells were drilled into graben structures associated with the Saglek (Karlsefni A-13 and Skolp E-07) and Hopedale (Snorri J-90, Herjolf M-92, Roberval K-92 and Cartier D-70) basins, which are separated from one another by the Okak Arch. The Okak Arch represents a remnant structural feature related to fractures formed when Greenland and Labrador separated (McMillan, 1980; 1982). The thickness of sediments in the wells is dependent upon the control of basement highs. Cretaceous sediments are generally restricted to the central portions of the basins, whereas Tertiary sediments tend to drape over the Okak and Cartwright arches (Hiscott, 1984). Kangamiut 1 was drilled on a horst structure located offshore West Greenland (Rolle, 1985).

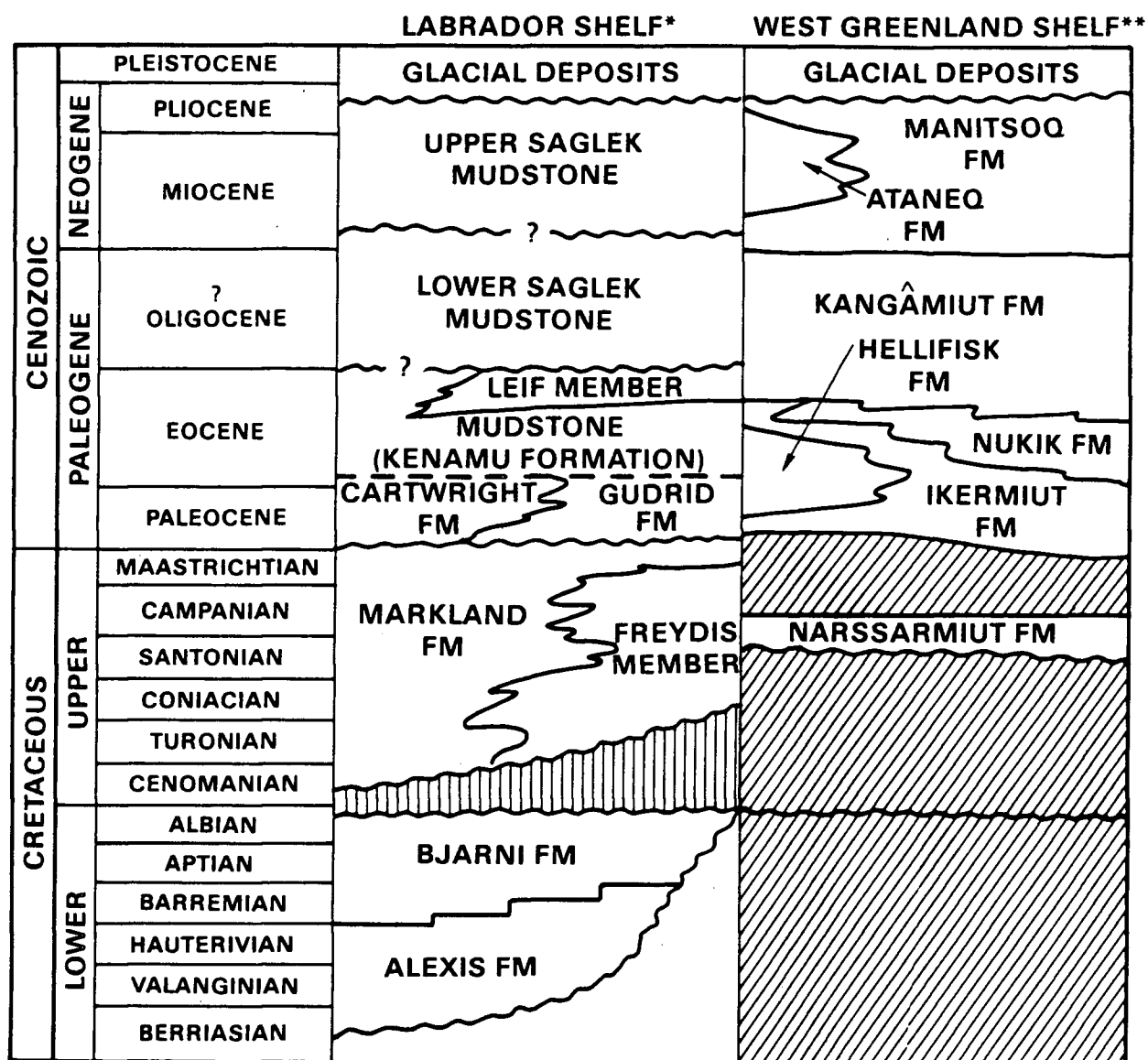


Figure 2. Generalized lithostratigraphic columns of offshore Labrador and West Greenland (not to scale). Based on Umpleby (1979)*, McWhae et al. (1980)* and Rolle (1985)**.

The Labrador Sea represents a failed rift basin that formed during the breakup of Labrador and Greenland from Early Cretaceous to latest Eocene/earliest Oligocene time (Gradstein and Srivastava, 1980). During the initial phase of crustal extension, locally derived, nonmarine fluvial sediments of Early Cretaceous age were deposited into the newly developed graben basins. On the Labrador Shelf, the Lower Cretaceous Bjarni Formation is mainly comprised of variable thicknesses of arkosic sandstones, gray silty shale and thin coal beds (Umpleby, 1979). It was penetrated in Skolp E-07, Herjolf M-92 and Roberval K-92.

Commencement of actual sea-floor spreading is marked by deposition of the dark marine, neritic to upper bathyal shales of the Markland Formation, which unconformably overlies the Bjarni Formation (Avalon Unconformity, McWhae et al., 1980). In some wells (e.g., Skolp E-07), the marine shales are intertongued with nearshore sands of the Freydis Member. Based upon the presence of marine dinoflagellates with restricted range tops in some of the Labrador Sea wells (Barss et al., 1979; this author's observation), the first incursion of marine waters into the newly developing Labrador Sea may have occurred as early as late Turonian to Coniacian time. Gradstein and Berggren (1981) report the first open-marine foraminiferal assemblages in the Labrador Sea to be Campanian to Maastrichtian in age.

Sedimentation along the continental margins of the Labrador Sea was interrupted near the Maastrichtian-Danian boundary. The unconformity (Bylot Unconformity) is not everywhere recognizable but is probably early Danian in age (McWhae et al., 1980; Rolle, 1985). This hiatus corresponds to the worldwide, first order marine regression of Vail et al. (1977).

During the Paleocene and early Eocene, large volumes of brown to gray shales and mudstones of the Cartwright Formation were being deposited into rapidly subsiding basins. McWhae et al. (1980) interprets most of these sediments to represent turbidite deposits. Coarse-grained turbiditic deep-sea fan deposits of the Gudrid Formation are found in association with the Cartwright in some of the wells, including Cartier D-70. Agglutinated "flysch-type" foraminiferal assemblages indicate increasing bathyal depths along the Labrador Shelf at this time, with maximum transgression during the early Eocene (Gradstein and Srivastava, 1980).

This was followed by a phase of marine regression characterized by a shallowing of sea level and deposition of the coarsening upward sequence of shales, siltstones and sandstones of the unnamed Mudstone unit of Umpleby (1979), i.e., Kenamu Formation of McWhae et al. (1980). It coincides with the cessation of sea-floor spreading in the Labrador Sea, just prior to Anomaly 13 (Gradstein and Srivastava, 1980). The Cartwright and Kenamu formations are roughly equivalent to

the Ikermiut and Kangamiut formations, respectively, from offshore West Greenland (Rolle, 1985). The middle and late Oligocene is poorly understood in the Labrador Sea and according to this study and the foraminiferal studies of Gradstein (Gradstein and Srivastava, 1981), may be absent along much of the Labrador Shelf. It marks a period of time characterized by erosion and/or lack of sedimentation.

IDENTIFICATION OF RECYCLED PALYNOMORPHS

The recognition of redeposited palynomorphs is important for helping to determine the sources from which sediments are derived, as well as for helping to solve stratigraphic problems. In sediments where recycled palynomorphs comprise the bulk of an assemblage, problems with dating and correlating the sediments can often result from the misinterpretation of the age of the redeposited grains. For example, in an unpublished study by this author concerning the dating and correlation of coal and shale units in south central Alberta, the age of the sediments appeared to be Maastrichtian. The palynomorph assemblage was characterized by such well preserved and abundant diagnostic pollen as *Aquilapollenites conatus*, *A. reticulatus*, *Wodehouseia spinata*, *Proteacidites thalmanii* and *Gunnera microreticulata*. An examination of interbedded exinitic-rich coal seams in the area, however, yielded good lower to middle Paleocene palynofloral assemblages characterized in part by the presence of *Wodehouseia fimbriata*,

Insulapollenites rugulatus and *Maceopolipollenites amplus*. The results demonstrated that the numerous Maastrichtian palynomorphs were recycled and that the age of the sediments was actually Paleocene.

The identification of palynomorphs as recycled is not always easy, however, and can be complicated by a combination of factors, including the age and state of preservation of the recyclants, the type of sample collected (e.g., cuttings, sidewall core or outcrop) and the thermal history of the region. Aranova (1960), Wilson (1964) and Stanley (1966) discuss different methods that can be used to identify recyclants under bright-field illumination. These criteria include taxonomic identification, differing degrees of preservation, acceptance of stain and palynomorph color. Bujak and Davies (1982, 1983), on the other hand, discuss the use of fluorescent light microscopy to distinguish reworked palynomorphs from indigenous ones, in Neogene strata from the Beaufort Sea and Upper Jurassic to Lower Tertiary sediments from offshore eastern Canada.

By far the most reliable method of determining redeposited palynomorphs is taxonomic identification of species. Unfortunately, morphological details necessary for determining species are often obscured due to oxidation, maturation and both biological and physical degradation. Also, many species have such long ranges that it is possible for them to belong to more than one group of recycled palynomorphs, e.g., similarly appearing bladdered conifer and

taxodiaceous pollen have ranges extending from the Jurassic to Recent and the monolete fern spore, *Laevigatosporites* appears to range from the Paleozoic to Recent.

Although older recycled palynomorphs often cannot be identified down to species level, it is usually possible to assign the redeposited grains to a particular genus. If the stratigraphic range of the genus is of fairly short duration, its identification can be sufficient enough to allow it to be assigned to a particular group of recyclants. However, if a palynomorph cannot be identified taxonomically or if it is long-ranging, it is necessary to use more subjective methods of identification.

The color of pollen and spores is often useful for distinguishing the relative age of a recyclant. Pollen and spores undergo a systematic change in color from light yellow-green, to yellow to yellow-orange to brown to black with increasing thermal maturation (Correia, 1967; Staplin, 1969; Raynaud and Robert, 1976). Usually, the older palynomorphs have undergone a more intensive thermal history than younger ones and are, therefore, darker. Because the samples in the study slides were subjected to oxidation (e.g., nitric acid) in the laboratory during sample preparation, the actual thermal alteration of these samples could not be determined. However, because the older pollen and spores generally retain the same relative differences in color as those in the kerogen preparation, palynomorph color can be

used with some qualification. When using color for identification, however, it is necessary to take into consideration wall thickness and ornamentation. Thick-walled and heavily ornamented specimens are invariably darker than grains of the same age and thermal history, but with thinner walls and little to no ornamentation.

Unlike pollen and spores, dinoflagellates and other marine algae do not show a systematic change in color through time and increasing thermal maturation. Although there have been some attempts made to use color changes in acritarchs to monitor thermal maturation, the results to date are too variable to use with any certainty. The unpredictable response of marine palynomorphs to changes in thermal maturation are very likely the result of differences in wall composition. For that reason, color is not a particularly useful parameter for distinguishing recycled dinoflagellates, acritarchs and other marine algae from those that are in place.

Another useful technique for identifying recyclants is the ability of the various wall layers of palynomorphs to accept organic stains such as Safranin-O. Wall composition and thickness, relative state of preservation and, especially, the degree of thermal maturation all help to determine the staining characteristics of the grains (Stanley, 1966).

In the Labrador Sea wells, staining characteristics are most useful for distinguishing recycled Tertiary pollen and spores. Contemporaneous early and middle Paleocene pollen and spores pick up only a slight, fairly even stain and late Paleocene and Eocene ones pick up an even, red stain. In contrast, Paleocene and/or early Eocene pollen and spores recycled into younger sediments characteristically have an uneven stain. Caved modern pollen and spores usually pick up a purplish red stain. Older pollen and spores (Paleozoic to Cretaceous) either do not or only partially pick up stain, which is probably due to changes in exine composition brought on by their higher degree of thermal maturation.

It is considerably more difficult to use staining characteristics to identify recycled and caved dinoflagellates and other marine algae. Some dinoflagellates, regardless of age, tend to be resistant to staining and others, of the same age, will often exhibit different intensities of color. In general, however, older, more thermally mature recycled dinoflagellates do not stain and, therefore, can be used to help spot recyclants, especially in thermally immature sediments.

In some circumstances, the state of preservation of the palynomorphs can be useful for determining redeposited grains. Older reworked palynomorphs are often less well preserved than younger recycled and/or contemporaneous grains. Depending upon the depositional history and number of orders of recycling, redeposited grains tend to

show a greater degree of chemical, biological and/or mechanical breakdown. This particular property, however, is probably the least reliable method to use for identifying recycled palynomorphs and should, therefore, be used only in conjunction with other criteria. Under certain conditions, the recyclants can actually be better preserved than in-situ grains. This is especially true in situations where the contemporaneous palynomorphs have been subjected to extensive oxidation or bacterial decay. If the recyclants have been protected from degradation, e.g., by rapid deposition and burial, they may be well-preserved.

Thermally immature to mature exinitic (hydrogen-rich) organic matter (including pollen, spores and dinoflagellates) fluoresces when excited with ultraviolet or blue light (Bostick, 1979; van Gijzel, 1979; Teichmüller and Durand, 1983). Whether biochemical, as suggested by Bujak and Davies (1982, 1983), or thermochemically induced, younger, thermally immature palynomorphs (vitrinite reflectance of approximately .2 to .3) emit blue to green wavelengths and older, more thermally mature ones emit yellow to orange to red wavelengths until, at a vitrinite reflectance of between 1.1 and 1.3, fluorescence becomes extinct (Senftle, personal communication).

The intensity and color of fluorescing palynomorphs can sometimes be very useful for identifying redeposited grains. It is a qualitative technique and, although it is best to use kerogen preparations, this

type of non-quantitative fluorescence can be measured on slides of macerated samples that have undergone chemical oxidation in the laboratory (Senftle, personal communication; Bujak, personal communication). This technique was used with limited success in the Roberval K-92 well (samples from the remaining study wells were not available for examination in fluorescent light). Unfortunately, the mounting medium used during slide preparation was too fluorescent to provide really good results. Nevertheless, two different populations of Carboniferous recyclants as well as redeposited Cretaceous grains could be distinguished. Older Tertiary palynomorphs redeposited into younger strata were more difficult to identify, however, because there was less contrast in the color and intensity of fluorescence. In spite of this, Paleocene and Eocene recyclants found in the Neogene sections of the well tended to fluoresce less intensely and appeared a deeper, more orange-red color than palynomorphs indigenous to the sediment. It should also be noted that the dinoflagellates in these samples often emitted not only a brighter fluorescence than pollen and spores of the same age, but also appeared to exhibit less variation in fluorescence intensity and color between Neogene and Paleogene forms than did the pollen and spores. The use of fluorescence to identify populations of recycled palynomorphs needs further study but it appears to be a promising technique.

In general, there are no sure methods to actually identify and accurately date every recyclant in a sample. However, by using the above

described techniques, it is possible to determine different general "age" populations of recyclants and their relative abundances through time. Usually, the older the recyclants, the easier it is to recognize them as being redeposited and, hence separate them into different groups.

CATEGORIES OF RECYCLED PALYNOMORPHS

The recycled pollen, spores and dinoflagellates found in the Cretaceous and Tertiary shelf sediments of the Labrador Sea are divisible into four major groups, categorized on the basis of relative age. Only three of these groups of recyclants (i.e., Paleozoic, Upper Jurassic/Lower Cretaceous and Upper Cretaceous) will be considered. The fourth group, which is comprised of Paleogene recyclants, is discussed in CHAPTER 4. A brief summary of the parameters used to help identify these different populations of redeposited palynomorphs is given in Figure 3.

Paleozoic Group

Recycled Paleozoic assemblages include:

Calamospora sp.
Convolutisporites sp.
Densosporites spp.

		POLLEN AND SPORES	DINOFLAGELLATES AND OTHER MARINE ALGAE
GROUPS OF RECYCLANTS	UPPER CRETACEOUS	USUALLY ASSIGNABLE TO GENUS AND SPECIES USUALLY LIGHT BROWN OR MEDIUM YELLOW-BROWN CAN PICK UP SOME STAIN USUALLY WELL-PRESERVED LOW FLUORESCENCE	USUALLY ASSIGNABLE TO GENUS AND SPECIES COLOR UNDIAGNOSTIC— USUALLY CLEAR STAIN ACCEPTANCE VARIABLE USUALLY WELL PRESERVED LOW TO MEDIUM FLUORESCENCE
	UPPER JURASSIC/ LOWER CRETACEOUS	USUALLY ASSIGNABLE TO GENERA, BUT MANY LONG-RANGING VARIOUS SHADES OF BROWN, DEPENDING UPON THICKNESS AND ORNAMENTATION DO NOT ACCEPT STAIN ORNAMENTATION SOMEWHAT REDUCED NON-FLUORESCING	USUALLY ASSIGNABLE TO GENUS COLOR UNDIAGNOSTIC DO NOT ACCEPT STAIN PRESERVATION FAIR NON-FLUORESCING?
	PALEOZOIC	USUALLY ASSIGNABLE TO GENERA WITH RESTRICTED PALEOZOIC RANGES DARK BROWN TO RED-BROWN COLOR VERY DIAGNOSTIC DO NOT ACCEPT STAIN ORNAMENTATION REDUCED OR ABSENT NON-FLUORESCING (EXCEPT SUB-GROUP OF PZ SPORES IN ROBERVAL K-92)	(NO DATA)

Figure 3. Summary of methods used to help identify different groups of redeposited palynomorphs in the Cretaceous and Tertiary shelf sediments of the Labrador Sea.

Florinites spp.
Lycospora spp.
Lycospora cf. *L. pusilla*
Knoxisporites sp.
Murospora spp.
Punctatisporites minutus Kosanke
Triquitrites spp.
T. additus Wilson & Hoffmeister
T. crassus Kosanke

The Paleozoic recyclants are comprised of non-marine monolete and trilete spores that can be divided into two general populations, based upon their physical appearance. One of these is characterized by fairly well preserved spores that are medium yellow-brown in color under bright-field illumination. They are very abundant in Roberval K-92 and consist almost exclusively of species belonging to the genera *Lycospora*, *Triquitrites* and *Punctatisporites*. The other group of Paleozoic recyclants is more diverse and considerably less abundant and tends to be more poorly preserved (ornamentation is either reduced or missing), as well as darker brown to amber in color. Both sets of redeposited Paleozoic spores are fairly easy to distinguish from the younger recyclants, because of their distinct morphology. Also, neither group accepts stain.

Although there was no attempt to divide this rather broad group of redeposited grains into finer "age" categories, many of the recyclants are probably Devonian and/or Carboniferous. The stratigraphic ranges of the genera *Calamospora*, *Densosporites*, *Lycospora*, *Knoxisporites* and *Punctatisporites*, are generally thought to be restricted to the

Devonian and/or Carboniferous (Tschudy and Scott, 1965; Barss, 1967; Felix and Burbridge, 1967). *Murospora* peaked in the Mississippian, although several species have been described from the Mesozoic, and *Florinites* ranges from the Pennsylvanian (peak abundance) to the Permian (Tschudy and Scott, 1965).

Upper Jurassic/Lower Cretaceous Group

Recycled Upper Jurassic/Lower Cretaceous assemblages include:

Alisporites bilateralis Rouse
Appendicisporites spp.
Callialasporites dampieri (Balme) Dev
Cerebropollenites mesozoicus (Couper) Nilsson
Cicatricosporites augustus Singh
C. hallei Delcourt & Sprumont
C. mohroides Delcourt & Sprumont
Classopollis classoides (Pflug) Pocock & Jansonius
Concavissimisporites sp.
Exesipollenites tumulus Blame
Foveotriletes sp.
Hamulatisporites sp.
Leptolepidites verrucatus Couper
Matonisporites sp.
Osmundacidites wellmanii Couper
Podocarpidites biformis Rouse

Many of the species represented in this category are generally long-ranging, with ranges extending from the Upper Jurassic to the Lower Cretaceous (Couper, 1958; Brenner, 1963; Dettmann, 1963; Singh, 1971; Brideaux and McIntyre, 1975; and Srivastava, 1977). Even though a few species have ranges that reportedly extend up into the Cenomanian, they were placed within this group. The recyclants are, for the most part, non-marine and fairly easy to distinguish

taxonomically from Paleozoic and Upper Cretaceous redeposited palynomorphs. Their preservation is generally fair, they are medium to dark brown in color and they do not accept stain.

Although the age of this group of redeposited grains must be considered to range from the Late Jurassic to Early Cretaceous, it is very likely Early Cretaceous. None of the taxa in this category are restricted to the Jurassic. Also, Jurassic sediments have not been found during drilling along the continental shelves of the Labrador Sea. The oldest Mesozoic sediments reported to date belong to the fluvial-deltaic, Lower Cretaceous Bjarni Formation.

Upper Cretaceous Group

Recycled Upper Cretaceous assemblages include:

Aquilapollenites spp.
A. quadrilobus Rouse
Balmeisporites/Ghoshispora sp.
Cyathidites minor Couper
Gleicheniidites senonicus Ross
Proteacidites thalmanii Anderson
Wodehouseia spinata Stanley

Alterbia spp.
Chatangiella spp.
Cyclonephelium distinctum Deflandre & Cookson
Dinogymnium spp.
Odontochitina operculata (O. Wetzel) Deflandre
Oligosphaeridium complex (White) Davey & Williams

The Upper Cretaceous recyclants are comprised of both marine and non-marine palynomorphs. They are generally well preserved and can usually be identified down to species level. The pollen and spores may accept some stain and are generally medium yellow-brown in color. The dinoflagellates and acritarchs, on the other hand, are usually clear and may or may not pick up stain. A Late Cretaceous age has been assigned to this group based upon the well documented age ranges of many of its constituents from North America (Srivastava, 1969 and 1972; Harland, 1973; McIntyre, 1974; May, 1980; and Nichols and Jacobson, 1982. Those species (e.g., *Cyclonephelium distinctum*, *Oligosphaeridium complex* and *Odontochitina operculata*) that have range bases that extend down into the mid and/or Early Cretaceous and that show no variation in color, preservation or stain acceptance were assigned to the younger category.

RESULTS AND DISCUSSION

The relative abundance of the Paleozoic, Upper Jurassic/Lower Cretaceous and Upper Cretaceous groups of recyclants, and their distribution in selected intervals from the seven study wells, are shown in Figure 4. For most samples, counts of 200 in-situ and recycled palynomorphs (including pollen, spores and dinoflagellates) were made. An attempt was made to identify the "relative" age of all specimens.

		KANGA-MIUT 1			KARL-SEFNI A-13			SKOLP E-07			SNORRI J-90			HERJOLF M-92			ROBER- VAL K-92			CARTIER D-70		
		1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
TERTIARY	LATE-MIDDLE MIOCENE																□	●	○			
	EARLY MIOCENE				□	●	○										■	□	●			
	EARLY OLIGOCENE	●	○	—										□	●	●	●	○	▲			
	EARLY OLIGOCENE/ LATE EOCENE				■	●	●							□	●	○	□	●	▲			
	LATE EOCENE	□	●	○	□	●	○				□	□	●	■	●	○	□	●	△	□	●	○
	EARLY EOCENE	■	□	○	■	□	○	□	○	—	□	□	●	□	●	○	□	●	●	□	●	○
	LATE-MIDDLE PALEOCENE	■	■	○	□	●	○	□	●	○	□	●	○	□	○	○	□	●	●	□	●	○
	EARLY PALEOCENE		■		△	●	○	□	●	○	■	□	○	■	●	○	△	□	△	□	●	—
CRETACEOUS	MAASTRICHTIAN							■	□	●				□	●	○	□	□	△	■	○	—
	CAMPANIAN-TURONIAN							□	□	●				□	□	—		□	△			
	ALBIAN-CENOMANIAN								■	□					■	□		□	△			
	NEOCOMIAN														□	○		□	●			

Figure 4. Distribution of relative abundances of recycled Paleozoic (3), Upper Jurassic/Lower Cretaceous (2) and Upper Cretaceous (1) palynomorphs in seven Labrador Sea wells. Symbols represent the following relative abundances: — absent; ○ rare; ● sparse; □ uncommon; ■ common; △ very common; and ▲ abundant.

When in doubt about certain long-ranging species, however, the younger age was assigned. Because of the uncertainties involved with identifying and determining the age of recyclants, relative frequencies (i.e., rare = 1, scarce = <5, uncommon = 4-9, common = 10-20, very common = 21-30 and abundant = >30) are used in the following discussion.

The greatest overall concentration of redeposited palynomorphs is found in the Eocene sections of the wells. There is no apparent latitudinal control over the distribution and species composition of the recyclants from north to south. Cartier D-70, the most southerly well, and Skolp E-07 both have fairly low numbers of recycled grains, whereas Roberval K-92, and Herjolf M-92 have the greatest concentrations.

The dark brown to amber, fairly poorly preserved population of recycled Paleozoic spores previously described were generally sparse to rare. In the Albian-Cenomanian sections of Skolp E-07 and Herjolf M-92, however, they do show a slight increase in number. Reworked Carboniferous spores were also reported in four other offshore West Greenland wells (Rolle, 1985) in addition to Kangamiut 1. The species composition of the redeposited Carboniferous grains is comprised of taxa that are found represented in in-situ Carboniferous spore assemblages recovered from Roberval K-92 and Gudrid H-55 (also located along the southern edge of the Labrador shelf). Although many of the

spores have broad geographical ranges, the similarity in taxa may indicate that the recycled Paleozoic grains were derived from local Carboniferous-aged strata. Another possible source of Paleozoic recyclants might have been highlands associated with the Appalachian system, located south to southwest of the Labrador Sea. According to McMillan (personal communication) the Paleozoic sediments penetrated in Roberval K-92 and Gudrid H-55 along the southern Labrador shelf could possibly represent Appalachian outliers.

In Roberval K-92, there is an anomalous occurrence of a group of very abundant, medium yellow-brown Paleozoic (Carboniferous?) recyclants, dominated almost exclusively by the three genera *Lycospora*, *Triquitrites* and *Punctatisporites*. The origin and distribution of this set of redeposited grains is very difficult to interpret. Although it is possible that they were introduced into Roberval K-92 as contaminants during drilling, Paleozoic mud and other palynomorph enriched additives were reportedly not used (McMillan, personal communication). Also, the cuttings samples were thoroughly washed and, in some instances, carefully picked.

This group of recyclants has a bimodal distribution in Roberval K-92, with peaks of abundance in the Late Cretaceous and in the latest Eocene to early Oligocene. They reach their greatest concentration in the lower Oligocene section of the well. At first glance, it would appear as though a *Lycospora-Triquitrites-Punctatisporites* spore-rich

rock of probable Carboniferous age was extensively eroded over a very substantial period of time. Temporary physical changes in the source area or shifts in paleocurrent directions, could help account for fluctuations in relative abundances. The sediments from the well, however, do not show any significant breaks or changes in the relative frequency of other recyclants or in clay mineral composition (Hiscott, 1984) during the late Paleocene and early Eocene, a period of time during which the anomalous Paleozoic spores are greatly reduced in number.

Another possible explanation for the distribution of this anomalous assemblage in the Roberval K-92 well is that the Upper Cretaceous sediments in which the spores were initially redeposited, were subsequently eroded and redeposited into the younger sediments by multiple, recycling events. Perhaps even more likely is that the spores found in the Cretaceous sections of the well represent cavings contamination from the upper Eocene to lower Oligocene portions of the well. Sidewall cores and the caliper curve (useful for helping to identify severely caved sections in a borehole) from the well would have been useful for resolving this problem, but neither were available for study. If concentrations of the *Lycospora-Triquitrites-Punctatisporites* dominated assemblage are real, they likely represent a very local phenomenon, because of their restriction to the Roberval K-92 well. However, it is difficult to reconcile the abundance of this group of recyclants in Roberval K-92 with

its absence (and the overall low number of recyclants in general) in nearby Cartier D-70.

As in the other wells, only sparse to rare occurrences of the other group of Paleozoic recyclants were noted in Roberval K-92. These recyclants are not only darker and more degraded than the anomalous, three genera dominated group, but also they have no fluorescent properties. The *Lycospora-Triquitrites-Punctatisporites* assemblage, on the other hand, is characterized by a very low, dark reddish-brown fluorescence, indicating different thermal histories for the two groups and, therefore, separate sources.

Upper Jurassic/Lower Cretaceous recyclants are fairly uncommon throughout the studied intervals. They reach their peak abundance in the mid-Cretaceous sections of Skolp E-07 and Herjolf M-92 and are uncommon to rare in the younger sediments. Because most of the grains in this group of recyclants found in the Cretaceous sections of the wells are non-marine and resemble the Lower and mid-Cretaceous pollen and spore assemblages found in the Bjarni Formation, many of the recyclants may have been derived locally from the erosion of the Bjarni Formation.

Although they are never abundant, the greatest concentration of Upper Cretaceous recyclants is found in the lower Paleocene in Snorri J-90 and Roberval K-92 and in the Eocene in Herjolf M-92. Karlsefni A-13

has increased numbers of Upper Cretaceous recyclants in both the lower Paleocene and Eocene. In Skolp E-07 and Cartier D-70, Upper Cretaceous grains redeposited into Tertiary strata are not very common.

Some of the taxa (e.g., *Aquilapollenites* spp.; *Wodehouseia spinata* and *Balmeisporites*) represented in the group of Upper Cretaceous recyclants were not found as part of the in-situ Late Cretaceous pollen and spore assemblages from the Labrador Sea. They are, however, common palynofloral constituents with well-documented occurrences in the western interior and Arctic regions of Canada. Their presence in the Tertiary Labrador Sea sediments suggests the possibility that these recyclants were transported for long distances from sources located in the Canadian western interior and Arctic.

In addition to the presence of the pre-Tertiary groups of recyclants, recycled Paleogene palynomorphs were also noted throughout the Tertiary sections of the wells (see CHAPTER 4). The Paleogene recyclants are comprised primarily of pollen and spores and reach peak abundance in the late Eocene and up into the early Oligocene. In Karlsefni A-13, the most northerly of the study wells, the relative number of Paleogene recyclants increases upwards from the late Paleocene to the Miocene, where it reaches its greatest abundance. In Roberval K-92, Herjolf M-92 and Snorri J-90, Paleogene recyclants are most numerous in the middle to late Eocene. In the Eocene sections of Cartier D-70

and Skolp E-07, Paleogene recycled clasts are fairly common but never abundant.

Petrologic studies by Higgs (1977) and Hiscott (1984) indicate that the provenance of sediments in the Labrador Sea during the Cretaceous was local. Higgs examined Cretaceous and lower Paleocene sands from the continental shelf of the Labrador Sea and onshore western Greenland. The mineralogical and textural immaturity of the grains indicated local sources that underwent rapid erosion and short transportation. The sediment source rocks were comprised predominantly of acidic plutonics and amphibolite-facies metamorphics. These results were supported by Hiscott, who studied the clay mineralogy of fine-grained Cretaceous and Tertiary sediments from six Labrador Sea wells (including Roberval K-92). He found that the middle and Upper Cretaceous marine shales of the Labrador Sea were characterized by a predominance of locally sourced smectite.

Palynological evidence for determining the provenance of sediments for the Cretaceous is not very conclusive, because many of the species in question are rather common forms that have fairly broad geographical distributions. However, the general similarity in composition, preservation and color of many of the recycled Carboniferous and Cretaceous taxa in the Cretaceous Bjarni and Markland formations to in-situ Carboniferous (in the Roberval K-92 and Gudrid H-44 wells) and

Cretaceous palynomorph assemblages suggest that the source of the recyclants may have been relatively local.

The great thickness of Tertiary sediments, if derived from strictly local sources, would require adjacent highlands and a high rate of uplift to keep pace with sediment infilling the offshore basins. To the south along the Atlantic coastal plain of eastern North America, there are also thick sequences of sediments, however, their source can be traced to the Appalachians (Mathews, 1975). Unfortunately, the almost virtual absence of Mesozoic and Tertiary outcrops in the circum-Labrador Sea region makes it difficult to determine if relatively local strata provided the preponderance of sediment delivered offshore.

The apparent random distribution and mixed composition of recyclants in the Lower Tertiary Cartwright and Kenamu formations (as well as Ikermiut and Nukik formations from offshore West Greenland) also makes it difficult to determine provenance. Provenance interpretations for these strata are further complicated by the redistribution and mixing of recyclants on the ocean floor by turbidity currents. Nevertheless, the detailed palynological study of in-situ and redeposited Paleogene pollen and spores from the Labrador Sea by this author suggests that the sediment (including the palynomorphs) source area may have encompassed parts of the western interior and Arctic regions of Canada (see CHAPTER 4).

Hiscott (1984) found that the Lower Tertiary sediments were characterized by a mixed smectite-illite-kaolinite assemblage of clay minerals. The composition and homogeneity of this polycyclic clay suite is also indicative of a multiple source, such as would be expected from a large, intercontinental drainage basin, encompassing thousands of square kilometers. The existence of such a large river drainage system covering much of interior Canada and parts of the Canadian Arctic during the Tertiary was suggested by McMillan (1973), in order to account for the great volume of sediment accumulated along the continental margins of the Labrador Sea. This river system would be akin to the modern Mississippi and Mackenzie rivers in that in each of these regimes not only is the volume of sediment considerable but also the percentage of redeposited palynomorphs is very high.

If the drainage basin of the proposed Tertiary river system carrying sediment to the Labrador Sea is as vast as postulated by McMillan, then it is difficult to determine the actual sources from which the recycled palynomorphs were eroded. In addition, the different relative age populations of recyclants could represent mixtures of either first-cycle and/or multiple cycles of redeposition.

SUMMARY

1. The relative abundances of Paleozoic, Upper Jurassic/Lower Cretaceous and Upper Cretaceous recycled palynomorphs were determined for Tertiary and Cretaceous aged sediments from seven Labrador Sea wells. Recyclants were identified and categorized whenever possible on the basis of their taxonomic identification, otherwise, the degree of maturation, state of preservation and acceptance of stain were used for identification.

2. With the exception of Roberval K-92, Paleozoic recyclants are low in number and fairly evenly distributed among each of the wells. In Roberval K-92, however, there are anomalously high percentages of a three genera-dominated group of Carboniferous? spores in the Upper Cretaceous and upper Eocene to lower Oligocene sections of the well. The number of Upper Jurassic/Lower Cretaceous recyclants is fairly low except for a slight increase in Kangamiut 1 at the top of the upper Paleocene. Skolp E-07, Herjolf M-92 and Roberval K-92 also have slightly higher proportions of Upper Jurassic/Lower Cretaceous redeposited grains in the mid and lower Cretaceous sections of the wells. Moderate to relatively high frequencies of Upper Cretaceous reworks are fairly common throughout the Upper Cretaceous and Tertiary

sections of the wells, but generally show no particular overall pattern of concentration when compared between wells.

3. Within the Upper Jurassic/Lower Cretaceous population of reworked palynomorphs, some of the redeposited taxa can be identified as Lower Cretaceous rather than Jurassic. The remaining recyclants within this group have ranges that extend across the Upper Jurassic and Lower Cretaceous boundary and can not be definitively classified. Due to certain physical characteristics (e.g., color and preservation), however, they are considered of probable Early Cretaceous age. Because of the lack of recycled palynomorphs with restricted Jurassic ranges and the absence of reported Jurassic sediments in any of the Labrador Sea wells drilled to date, it appears unlikely that Jurassic aged strata are present in the offshore Labrador and West Greenland subsurface.

4. Recycled palynomorphs recovered from Cretaceous sediments in Skolp E-07, Herjolf M-92 and Roberval K-92 were probably derived from local sources. There is a similarity in species composition between the recycled Upper Jurassic/Lower Cretaceous palynomorph assemblages in the middle and Upper Cretaceous strata in these wells and the taxa indigenous to the Lower Cretaceous Bjarni Formation. Mineralogical studies by Higgs (1977) and Hiscott (1984) also indicate local sources for the Cretaceous sediments.

5. Hiscott's clay mineralogy and this author's study of contemporaneous and recycled Paleogene pollen and spores from the Labrador Sea indicate distant sources of sediment during the Tertiary. Therefore, the apparent random distribution and relative abundances of recycled Paleozoic, Upper Jurassic/Lower Cretaceous and Upper Cretaceous palynomorphs in the Tertiary sections of the study wells can be explained as a result of multiple sediment sources and long-distance transport, perhaps via a large river system draining much of the Canadian interior.

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EXPLANATION OF PLATES

All specimens were recovered from offshore Tertiary sediments from the Labrador Sea. The photomicrographs were photographed in transmitted light under Nomarski differential interference contrast. Figure captions contain information of the well, sample depth and type of sample (i.e., cuttings or sidewall core) from which specimens were recovered. The magnification and photo number (i.e., negative number, year and frame number) of the photomicrographs are also included.

PLATE 1

FIGURE 1: *Wodehouseia spinata*. Recycled Upper Cretaceous pollen recovered from late Eocene strata. Karlsefni A-13; 7482 ft. (cuttings); 1000x; KARL A:80:18.

FIGURE 2: *Aquilapollenites amplus*. Recycled Upper Cretaceous pollen recovered from late Eocene strata. Cartier D-70; 4500 ft. (cuttings); 800x; CAR C:81:9.

FIGURE 3: *Balmeisporites* sp. Recycled Upper Cretaceous spore recovered from middle-late Eocene strata. Cartier D-70; 4590-4600 ft. (cuttings); 800x; CAR C:81:10.

FIGURE 4: *Gleicheniidites senonicus*. Recycled trilete spore assigned to Upper Cretaceous group of recyclants. Recovered from middle-late Paleocene strata. Kangamiut 1; 3447 m. (cuttings); 800x; KANG E:79:32.

FIGURE 5: *Cicatricosisporites* cf. *C. hughesii*. Recycled Lower Cretaceous spore recovered from late Eocene strata. Kangamiut 1; 2700 m. (cuttings); 800x; KANG E:79:20.

FIGURE 6: *Hamulatisporites* sp. Recycled Lower Cretaceous spore recovered from late Paleocene strata. Kangamiut 1; 3099 m. (cuttings); 800x; KANG E:79:28.

FIGURE 7: *Podocarpidites biformis*. Recycled Lower Cretaceous spore recovered from middle-late Paleocene strata. Kangamiut 1; 3447 m. (cuttings); 800x; KANG E:79:33.

FIGURE 8: *Leptolepidites* cf. *L. verrucatus*. Recycled Lower Cretaceous spore recovered from late Paleocene strata. Kangamiut 1; 3099 m. (cuttings); 800x; KANG E:79:22.

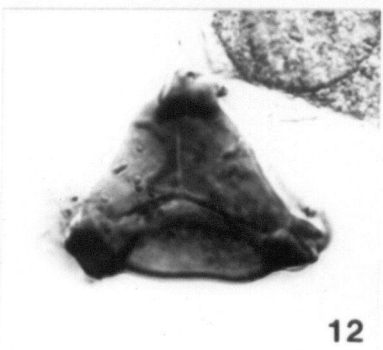
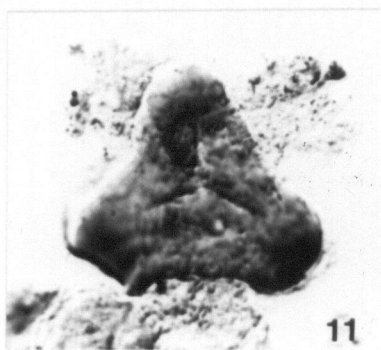
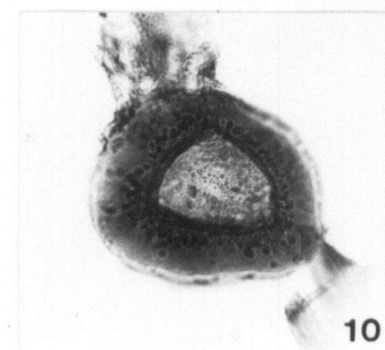
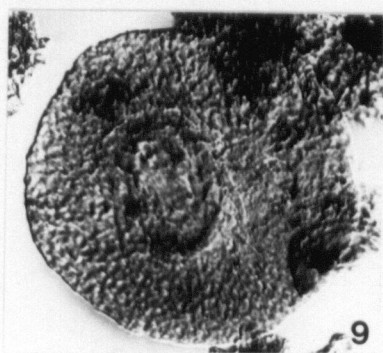
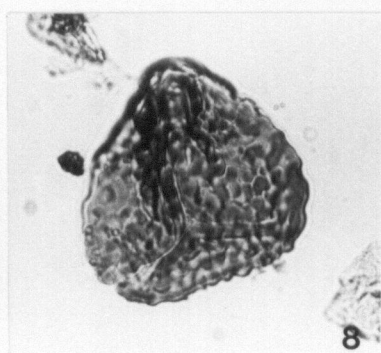
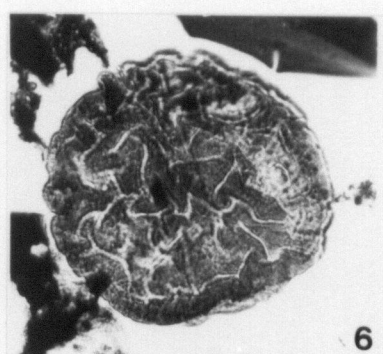
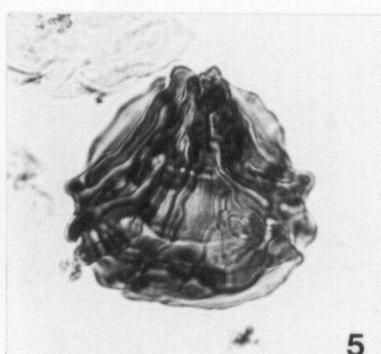
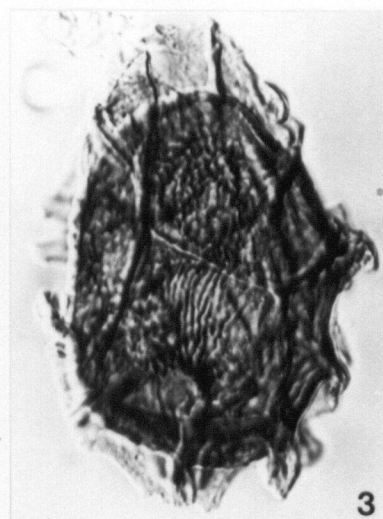
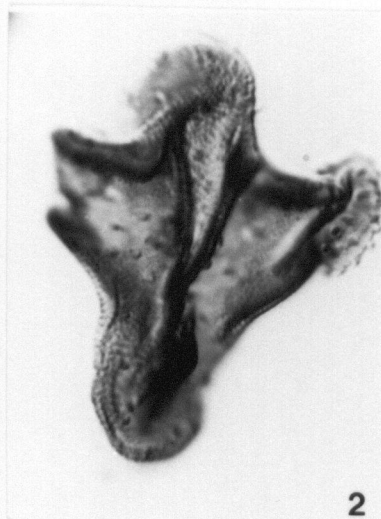
FIGURE 9: *Florinites* sp. Recycled Paleozoic (Carboniferous?) spore recovered from late Eocene strata. Herjolf M-92; 5400 ft. (cuttings); 800x; HERJ A:81:27.

FIGURE 10: *Densosporites* cf. *D. subtriangularis*. Recycled Paleozoic (Carboniferous?) spore recovered from middle-late Paleocene strata. Kangamiut 1; 3201 m. (cuttings); 800x; KANG E:79:14.

FIGURE 11: *Triquitrites* sp. Recycled Paleozoic (Carboniferous?) spore recovered from late Eocene/early Oligocene strata. Roberval K-92; 1870 m. (cuttings); 1000x; ROB E:81:8.

FIGURE 12: *Triquitrites* sp. Recycled Paleozoic (Carboniferous?) spore recovered from late Eocene/early Oligocene strata. Roberval K-92; 1930 m. (cuttings); 1000x; ROB E:81:2.

PLATE 1



CHAPTER 4. PROVENANCE OF IN-SITU AND RECYCLED PALEOGENE PALYNOMORPHS OF THE LABRADOR SHELF

INTRODUCTION

The Paleogene continental shelf sediments of seven Labrador Sea wells were studied in detail for the purpose of relating the composition and relative abundances of recycled and in-situ Paleogene palynomorphs to their sediment source. The wells used in the study are: Kangamiut-1, from offshore Western Greenland; Hekja O-71, from offshore southern Baffin Island; and Karlsefni A-13, Snorri J-90, Herjolf M-92, Roberval K-92 and Cartier D-70, from offshore Labrador. Their location is shown in Figure 1.

This study is an outgrowth of a project, sponsored by Aquitaine of Canada (now Canterra), to determine the distribution of Cretaceous and older recycled palynomorphs in the shelf sediments of the Labrador Sea. During that study, a relatively large number of recycled Paleogene palynomorphs were found in association with the other recyclants. In two of the wells (Hekja O-71 and Roberval K-92), they actually dominate the total late Eocene palynomorph assemblage. Although a few dinoflagellates are represented, almost all of the Paleogene recyclants are pollen and spores. They are also very similar in species composition to the in-situ or contemporaneous Tertiary pollen and spore assemblages recovered from the wells.

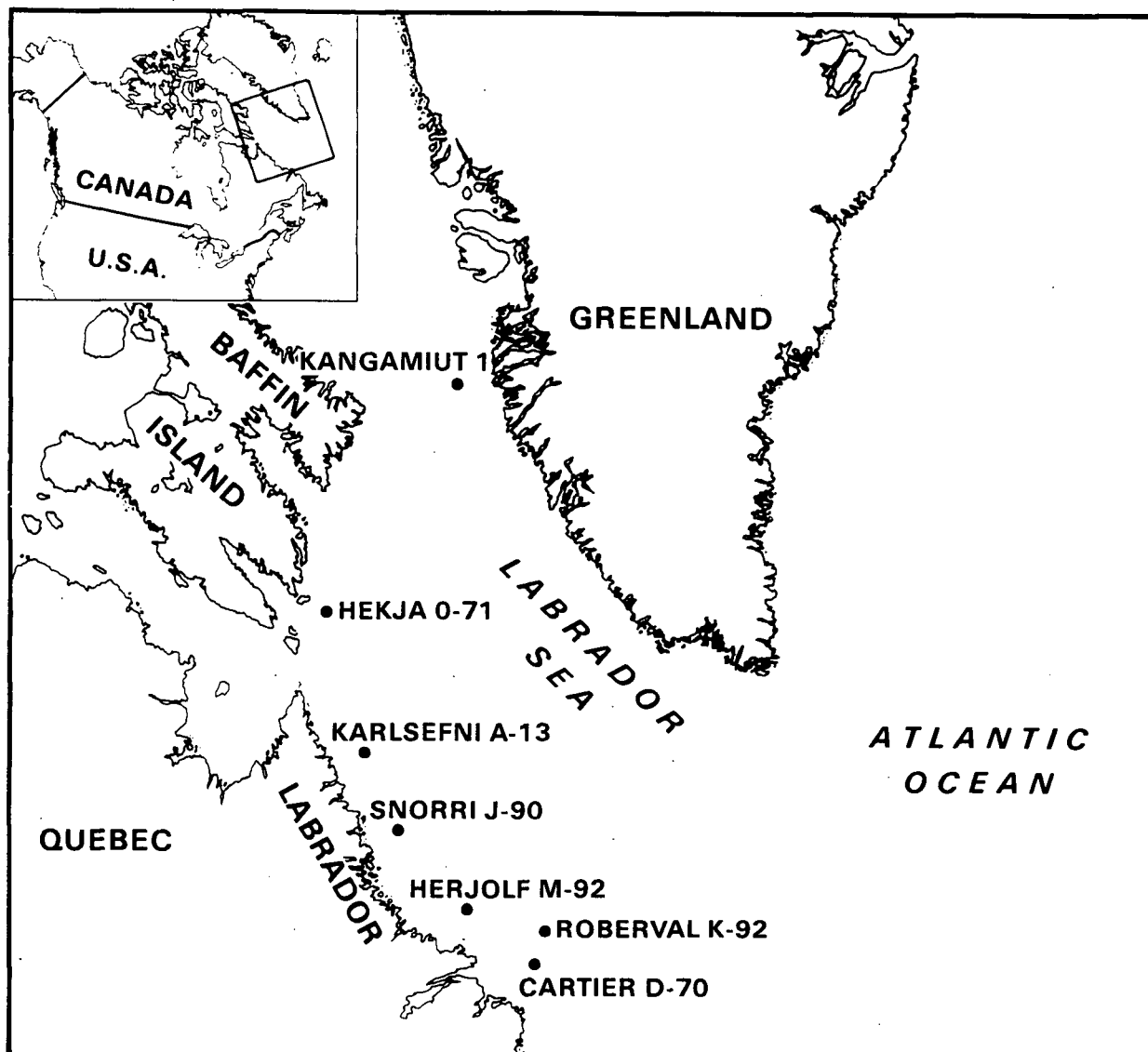


Figure 1. Location map of the Labrador Sea and the seven offshore wells used in this study.

The Paleocene and Eocene depositional history of the Labrador Sea was influenced by a major marine transgression that began in latest Cretaceous time and came to an end during the late Eocene. The shelf sediments are characterized by thick sequences of predominantly brown mudstones with silty and sandy partings and rare, thin dolomitic limestone beds, which generally represent distal turbidites that were reworked downslope by turbidity currents (McWhae, 1981). Sediment accumulation curves for the Labrador Sea (uncorrected for compaction) indicate that shelf sedimentation rates during this time period were in excess of 10 cm/1000 years (Gradstein and Srivastava, 1980). Kerogen analyses show that much of the sediment was terrestrially derived (Bujak and Williams, 1977a and 1977b) and, in places, is characterized by a maximum organic carbon content of from 2-4 percent (Rashid et al., 1979). Foraminiferal assemblages also indicate bathyal to neritic water depths throughout much of the Paleocene and Eocene with a shallowing towards the end of the Eocene (Gradstein and Berggren, 1981). With the onset of marine regression, little or no deposition took place for much of the Oligocene and, perhaps, the early Miocene (Gradstein and Srivastava, 1980).

Based primarily upon deep seismic reflection profiles, McWhae and Michel (1975) and Cutt and Laving (1977) suggested that considerable differential relief existed over the Labrador and Newfoundland shelves

during late Cretaceous and early Paleogene time. Erosion of these topographic highs was suggested as the main source of the terrigenous sediments deposited into the subsiding offshore grabens.

In contrast, McMillan (1973) proposed that, in addition to some input of sediments from local sources, large portions of the Tertiary marine sediments were derived from the erosion of outcrops in the southern Arctic and central and western interior of Canada by a large "super river" system, which entered the Labrador Sea through what is now Hudson Strait. Hiscott (1984) also suggested an Arctic and western Canadian source for the Paleogene sediments of the Labrador Sea, based upon the presence and abundance of a homogeneous, polycyclic suite of clay minerals. The palynofloral composition of the Paleogene contemporaneous and recycled pollen and spore assemblages from the Labrador Sea continental shelf sediments help support both McMillan's and Hiscott's model of a distant source for much of the sediment delivered to the Labrador Sea during the Early Tertiary.

RECYCLED PALYNOMORPHS AS INDICATORS OF PROVENANCE

Palynomorphs and other organic matter are an integral part of the sedimentary environment and are carried as part of the suspended sedimentary load along with inorganic clay and silt sized particles. As such, they can be very useful for helping to determine the

provenance of sediments. Stanley (1966) suggested that recycled pollen and spores and other organic matter in marine sediments could be used to help determine sediment source areas. Groot and other workers also made the same observation based upon their investigation of Quaternary sediments in the Argentine Basin (Groot, 1966).

Askin and Elliot (1982) examined recycled Permian and Triassic palynomorphs in the Tertiary Seymour Island Group of the Antarctic Peninsula, and concluded that a non-marine, topographic high in the forearc terrain of the late Paleozoic-early Mesozoic Gondwana plate margin was the source of the sediment. The pattern of distribution of recycled Paleozoic, Late Cretaceous and Early Tertiary palynomorphs in surficial glacio-marine sediments of the Ross Sea, Antarctica, led Truswell and Drewry (1984) to suggest that separate inputs of ice into the Ross Sea came from West and East Antarctica.

An abundance of recycled Tremadocian (Early Ordovician) acritarchs led Richardson and Rasul (1978) to recognize four different Paleozoic sediment source areas for the Lower Devonian Old Red Sandstone of southern England. Turner (1982) also used redeposited acritarchs to determine sediment source in the type Caradoc Series (Late Ordovician) in Shropshire, England, which was interpreted to have been derived from Tremadoc and Arenig/Llanvirn-aged sediments (Early Ordovician) from the Midland Platform.

Based upon the presence of recycled Jurassic and Lower Cretaceous palynomorphs, McLean (1968) proposed that the sediment source for the upper Paleocene Naheola Formation of Wilcox County, Alabama, was located in central Alabama. Multiple recycling events and a local Late Devonian source of sediment to Lower Cretaceous rocks of the Moose River Basin in Ontario were identified by Legault and Norris (1982). Scott and Srivastava (1984) showed that the Upper Cretaceous Mancos Shale was an important source of sediment to the Late Quaternary deposits in the Alkali Basin of central Colorado in the western interior of the United States.

There are some problems associated with using contemporaneous and, particularly, recycled palynomorphs to determine sediment sources. For example, multiple recycling events can often obscure the primary source of the sediment. Also, sampling and the state of preservation of the organic matter can bias the sample and misrepresent palynomorph concentration. Furthermore, it is often very difficult to identify as recycled, those palynomorphs that have been redeposited in sediments of nearly the same age. Many of the forms are long-ranging and are similar in color and morphology. By understanding these problems and making careful observations, however, it is possible to recognize recycling trends that can be used to help determine the provenance of sediments. Relative abundances of the redeposited grains, especially in intervals where there is good stratigraphic control, can be determined. Also, there are a number of methods that can be used in con-

junction with one another to help identify the recyclants (see CHAPTER 4). These include the taxonomic identification of key diagnostic species with limited ranges, as well as the monitoring of color and stain acceptance characteristics of the grains. It is also useful to qualitatively measure the different fluorescing properties of the palynomorphs.

RESULTS

The palynofloral composition and relative abundance of redeposited (as well as contemporaneous) Paleogene palynomorphs from the Labrador Sea were determined for the purpose of helping to identify their likely provenance. Sample depths and the Lower Tertiary sections from each of the seven study wells are illustrated in Figure 2. Lithostratigraphic nomenclature is based on the work by Umpleby (1979), McWhae et al. (1980) and Rolle (1985), and the relative ages of the sediments are based on palynological work by this author. The relative abundances were determined by counting 300 palynomorphs (in-situ and recycled) per sample. Only those palynomorphs that could be reasonably identified as recycled were counted as such. Other age groups (i.e., Late Cretaceous, Early Cretaceous-Late Jurassic and Paleozoic) of recycled palynomorphs found within the study wells, with the exception of Hekja 0-71, were also included in the counts (see CHAPTER 3).

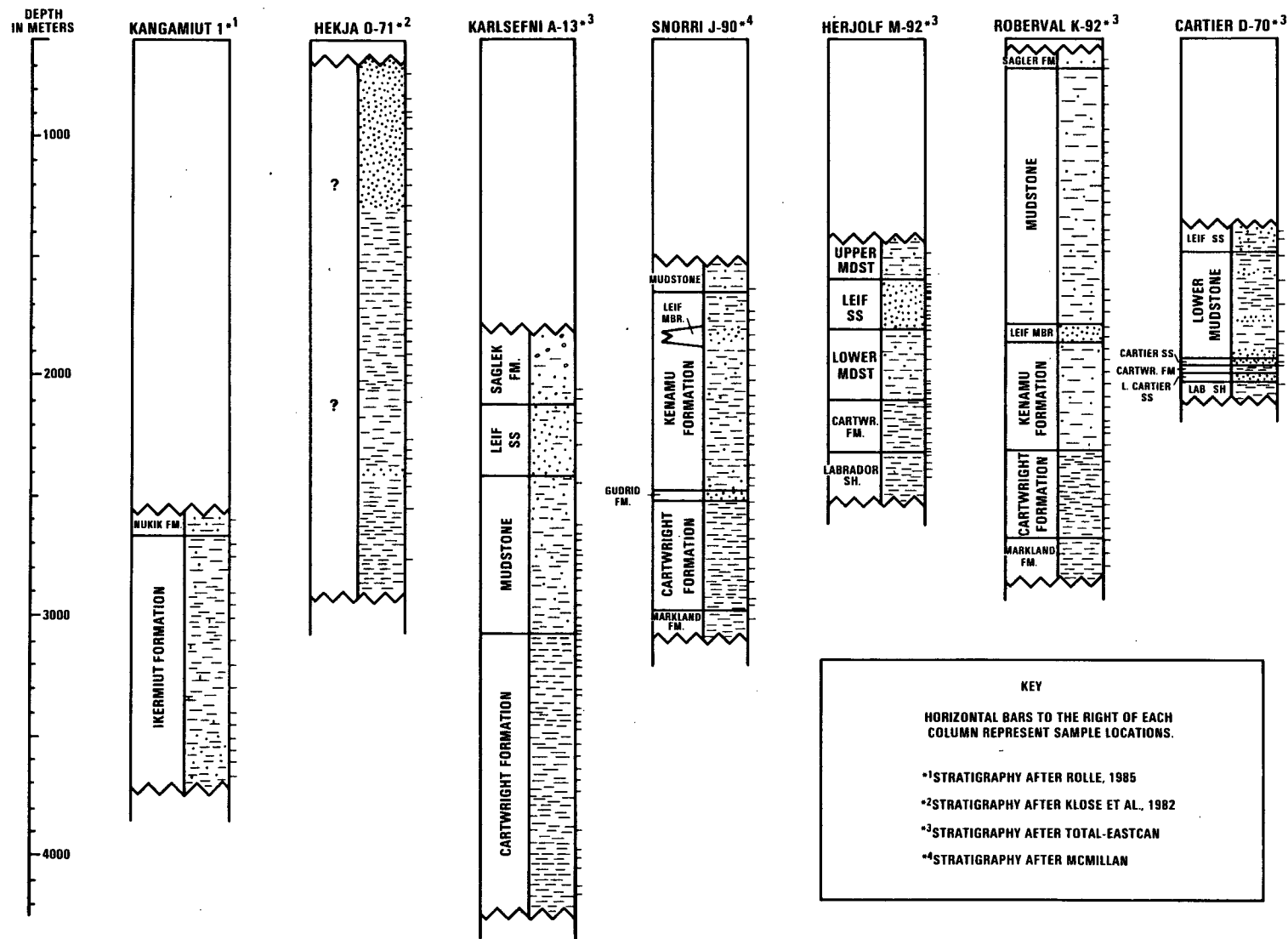
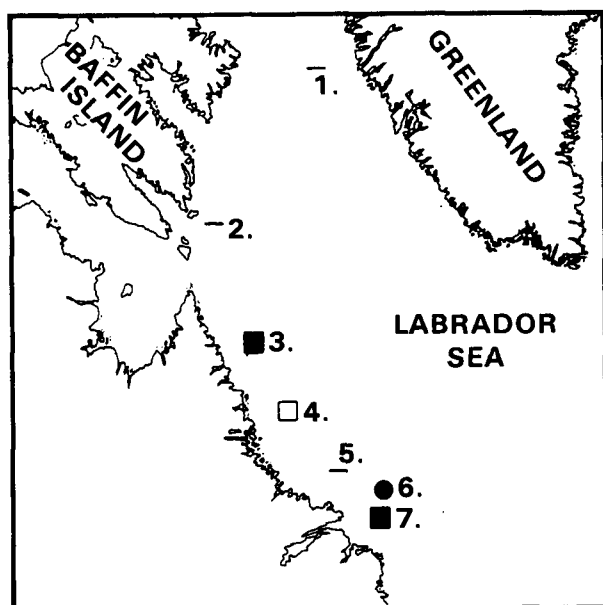


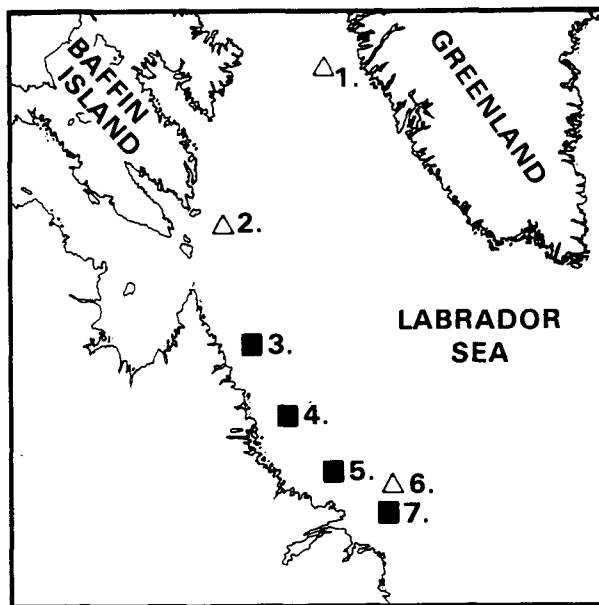
Figure 2. Generalized lithostratigraphic columns of the Tertiary sections of the seven study wells.

The distribution and relative abundances of recyclants in each of the study wells for the middle to late Paleocene, early Eocene, late Eocene, and late Eocene-early Oligocene strata are illustrated in Figure 3. Although Upper Cretaceous dinoflagellate and pollen and spores were found redeposited in the lower Paleocene samples, early Paleocene aged recycled grains could not be identified. A combination of factors made them impossible to recognize. For example, the age difference between the redeposited and in-situ material was too close to be able to distinguish them apart from one another. Also, the diversity of pollen and spores is generally low and, of those species present, many are fairly long-ranging.

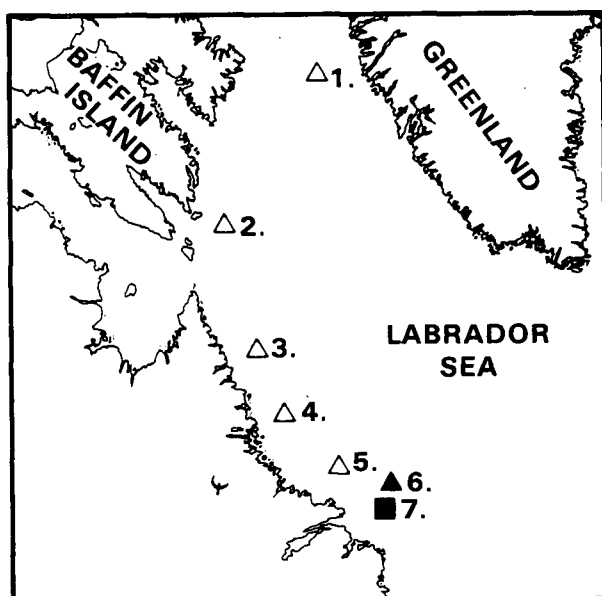
During the middle to late Paleocene, the number of recognizable older Paleocene-aged recyclants is moderately low (Figure 3a), whereas Upper Cretaceous redeposited grains are a fairly common component of the total number of recyclants. By early Eocene time, however, the number of Paleocene recyclants increases (Figure 3b), but the percentage of recycled Late Cretaceous palynomorphs remains approximately the same. Data on the relative abundance of recycled Paleocene palynomorphs for the northern part of the study area was not determined. The Paleocene interval in Hekja 0-71 was not studied because of the difficulty of determining reliable range tops. In Kangamiut 1, it was not possible to separate Paleocene assemblages into different populations.



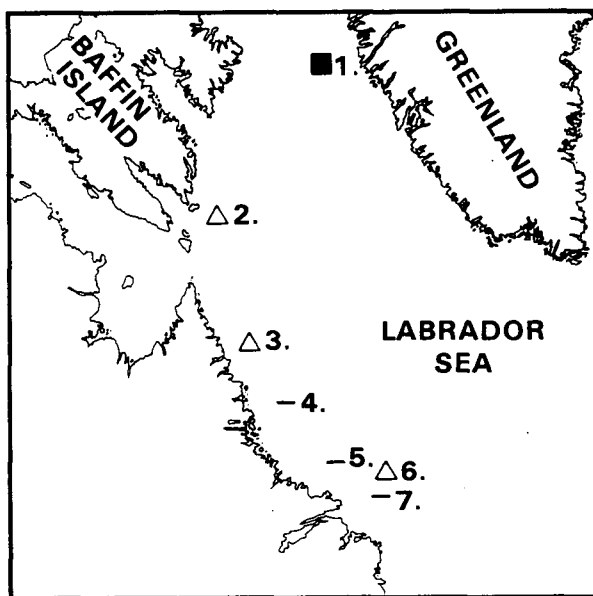
3a. LATE-MIDDLE PALEOCENE



3b. EARLY EOCENE



3c. LATE EOCENE



3d. LATE EOCENE -
EARLY OLIGOCENE

Figure 3. Distribution of relative abundances of Paleogene recycled palynomorphs in the Paleogene sediments of the Labrador Sea. Key to numbers: 1 - Kangamiut 1; 2 - Hekja 0-71; 3 - Karlsefni A-13; 4 - Snorri J-90; 5 - Herjolf M-92; 6 - Roberval K-92; and 7 - Cartier D-70. Symbols represent the following relative abundances: - no data; ● sparse; □ uncommon; ■ common; △ very common; and ▲ abundant.

The Paleogene recyclants reach their greatest abundance in the late Eocene, where they are very common components of the overall palynomorph assemblage (Figure 3c). Similar abundances are found in the late Eocene/early Oligocene sediments from offshore Labrador and Southern Baffin Island. In the northeastern corner of the Labrador Sea basin off West Greenland, however, the number of Paleogene recyclants decreases slightly (Figure 3d).

The most common constituents found within the Paleogene group of recyclants appear to be middle to late Paleocene and early Eocene in age. They include the following species:

Insulapollenites rugulatus,

Maceopolipollenites amplius,

Momipites spp.

Paraalnipollenites alterniporus,

Pistillipollenites mcgregorii,

Plicatopollenites sp.

There are also large numbers of Paleocene tricolporate and tricolpate pollen with uneven staining characteristics, that are especially common in the late Eocene and late Eocene/early Oligocene strata. In Roberval K-92, interpreted Paleocene recyclants generally exhibited a more medium to darker orange color of fluorescence than did palynomorphs considered indigenous to the sediments.

There is a possibility that some of the Paleocene pollen and spores identified as recycled represent mud contamination. One of the more common types of mud additives used in drilling is a pollen-rich Paleocene lignite from North Dakota. Interpretations of the Paleogene stratigraphy in some of the Beaufort Sea and offshore eastern Canada wells have been complicated by these drilling mud contaminants (Bujak, personal communication). However, the physical appearance and species composition of the Paleocene pollen and spores (indigenous and redeposited grains), as well as limited sidewall core control in Kangamiut 1, Karlsefni A-13 and Herjolf M-92 indicate that the majority were not introduced during drilling. Furthermore, an inquiry made into the types of drilling additives used in the offshore study wells suggested that Tertiary muds were not likely used (McMillan, personal communication).

DISCUSSION

In order to help account for the high rate of sedimentation and resulting thick sequences of predominantly Tertiary sediment found along the continental margins of the Labrador Sea, McMillan (1973) proposed the existence of a large river system that drained much of the Canadian interior during latest Cretaceous and Tertiary time. This

"super river" entered the Labrador Sea through the graben structure of what is now the Hudson Strait (see Figure 4). Included within its drainage basin were parts of the Northwest Territories, Alberta, Saskatchewan, Manitoba and the northwestern edge of Quebec. Such great volumes of sediment were being deposited into the Labrador Sea, that in some places, sediment thickness exceeds 3 to 4 kilometers. The uplift and erosion of the Canadian Cordillera helped control the amount and type of sediment being discharged into this ancestral river system. McMillan also discusses the probable locations of other important river systems in the region. One of these probably brought sediment to offshore Labrador through the the Strait of Belle Isle, and another through the Churchill River drainage, which enters Lake Melville at Goose Bay, Labrador. Along the west coast of Greenland (including Disko Island), the Tertiary sand and shale sequences were probably derived from the deposition of sediments carried by rivers draining the Greenland landmass.

The almost complete absence of Cretaceous and Tertiary outcrops on adjacent land masses makes it difficult to determine, however, if the local palynoflora in the area was actually representative of that found in the offshore sediments. A number of studies have shown that pollen and spore assemblages found incorporated into marine sediments do tend to represent the regional flora of the entire drainage basin of the river system responsible for transporting the grains offshore

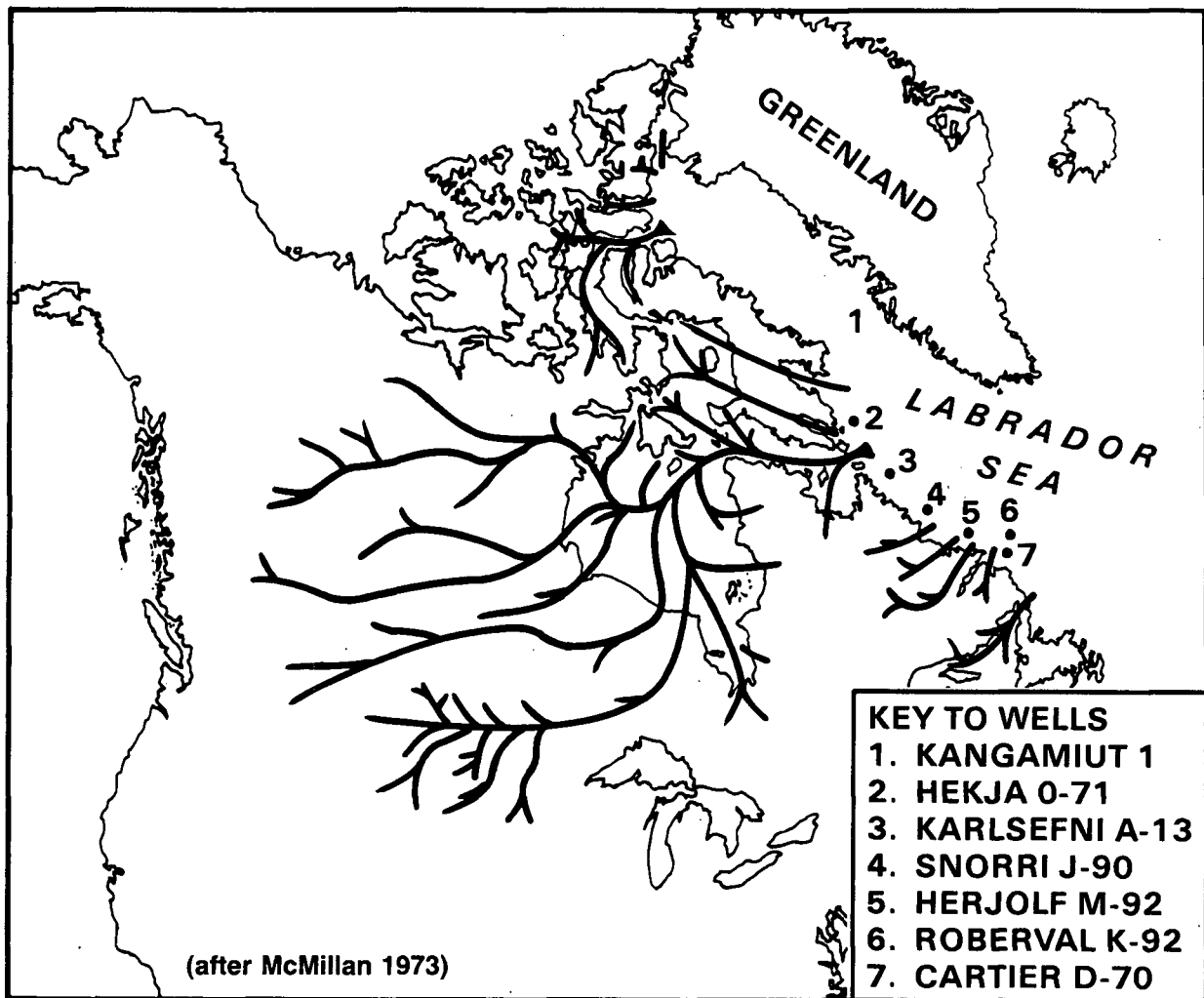


Figure 4. Schematic diagram showing possible drainage patterns of river systems supplying sediments to the Labrador Sea during the Tertiary as proposed by McMillan, 1973.

(Muller, 1959; Koroneva, 1968 and 1971; Heusser and Florer, 1973; Heusser and Balsam, 1977). Therefore, if McMillan's "super river" did exist, a similarity in palynofloral composition between western and interior Canada and the Canadian Arctic and the Labrador Sea would be expected.

A large number of pollen and spore species recovered from the Labrador Sea Paleogene sediments also have well documented occurrences in similarly aged sediments from a broad area encompassing parts of the Canadian Arctic and western Canada. Shared components include *Gothanipollis cockfieldensis*, *Momipites* spp., *Maceopolipollenites* spp., *Pistillipollenites mcgregorii*, *Parviprojectus* sp., *Boisduvalia clavatites*, *Jussiaea* sp. and *Insulapollenites rugulatus*. *Araliaceoipollenites*, *Cupuliferoipollenites*, *Rhoipites* and *Verrutricolporites* pollen species and fungal spores (e.g., *Fusiformisporites*, *Pesavis* and *Ctenosporites*) are also common elements among the several regions.

Although many of these palynomorphs have broad geographical ranges on the North American continent, some appear restricted to the Canadian Arctic and the western and interior regions of Canada and the United States. *Parviprojectus* is found in late Eocene to early Oligocene sediments from the Canadian Arctic (Staplin, 1976, Rouse, 1977) and British Columbia (Rouse, 1977). Similar pollen is also reported from Alaska (Wiggins, personal communication). *Pistillipollenites*

mcgregorii is reported from late Paleocene to middle Eocene strata from British Columbia (Rouse et al., 1971; Rouse, 1977; Rouse and Mathews, 1979; Mathews and Rouse, 1984), the Canadian Arctic (Staplin, 1976; Rouse, 1977; Ioannides and McIntyre, 1980; Norris, 1986) and the northwestern United States (Newman, 1981; and Wingate, 1983). *Insulapollenites rugulatus* occurs in Paleocene sediments from the western interior of the United States (Leffingwell, 1971) and Canada (Sweet, 1978; this author, unpublished technical report).

Some of these elements are conspicuously absent from published palynological reports from immediately south of the Labrador Sea in the Grand Banks, the Scotian Shelf and the northeastern Atlantic coast of the United States (Williams and Brideaux, 1975; Barss et al., 1979; Bebout, 1980). See CHAPTER 2 for a more detailed discussion of the geographic distribution of taxa.

Although the contemporaneous Paleogene assemblages show greater diversity, the species composition of both the recycled and in-situ palynofloral assemblages is very similar. For example, key diagnostic pollen used to identify late Paleocene and early Eocene sediments, such as *Pistillipollenites mcgregorii* and *Momipites coryloides*, are found recycled in late Eocene and younger sediments. This homogeneity of composition suggests that the Paleogene recycled and contemporaneous pollen and spore floras were both derived from similar sources.

That a river system, such as the one proposed by McMillan, is capable of carrying great volumes of sediments, including palynomorphs and other organic debris, for such long distances and then depositing the material into offshore marine environments, is well documented. Muller (1959) examined the distribution of detrital organic matter (e.g., pollen, spores, cuticle and woody material) in the deltaic and shelf sediments of the Orinoco River in northeastern Venezuela. He found that the pollen and spore assemblages associated with these sediments were representative of the regional mountain and plains vegetation growing within the river's drainage basin (an area of over 900,000 square kilometers). Recycled Cretaceous and Tertiary pollen and spores and tracheal fragments from the headwaters of the Orinoco in the Andean foothills were also noted. His results show that swamp and marsh palynofacies of the Orinoco are characterized by local sources whereas the offshore and prodelta palynofacies are composed of mixed assemblages of not only marine but also terrestrially derived contemporaneous and reworked organic matter. There is also a general overall decrease in the amount of land-derived organic matter with increasing distance offshore. The hydrodynamic properties of the organic debris as well as the marine currents are responsible for their distribution.

Contemporaneous and recycled terrestrially derived organic matter, including pollen and spores, were also found in the Amazon submarine fan (Tissot and Pelet, 1981). The organic debris, representing the river's vast drainage basin, was carried by the river and offshore currents out onto the continental shelf and slope.

One of the best analogues of McMillan's proposed "super river", with regards to volume of sediment transported, is the Mississippi River, which has a large drainage basin than spans more than 3 million square kilometers. It deposits, on the average, 500,000,000 tons of sediments per year into the Gulf of Mexico. Its suspended sediment load includes a high percentage of contemporaneous and recycled organic matter (Hart, personal communication).

In order to determine the effective distance of transport of certain pollen and spore types by water in deltaic environments, Piel (1965) examined the pollen and spore flora in six shallow cores of Recent pond and marsh sediments from the Mississippi River Delta. His results show not only a broad spectrum of contemporaneous pollen and spores representing the Mississippi's vast drainage basin, but also a relatively high percentage of Tertiary and Quaternary recycled arboreal pollen and bryophyte and fern spores deposited rather uniformly in each of the six study cores. In addition, he found fairly abundant occurrences of *Aquilapollenites*, which were probably derived from the erosion of Late Cretaceous sediments in the Rocky Mountain

western interior region of North America. Similar Campanian and Maastrichtian pollen (e.g., *Aquilapollenites* spp., *Wodehouseia spinata* and *Balmeisporites* sp.), with well documented occurrences in the Canadian western interior, were also found in the Labrador Sea Tertiary sediments.

The importance of the Mississippi River with regards to sediment distribution offshore is documented by Urban and Newport (1975), who report recycled Devonian through Tertiary aged palynomorphs in Recent sediments approximately 100 miles offshore in the Gulf of Mexico. The broad dispersal of fluvial sediments discharged into marine waters is further demonstrated by the fact that the offshore portions of the modern Mississippi River form a sediment platform out into the Gulf of Mexico covering an area of approximately 700 square miles (Smith, 1978).

In a study of palynomorph distribution in the Gulf of California (Cross et al., 1966; and Cross, 1975), it was found that accumulations of pollen and spores and other land derived plant matter were distributed in banded gradients near the mouths of the larger rivers. The hydrodynamic properties of the different grains tends to cause them to be selectively concentrated in bands. In addition, recycled palynomorphs were associated with bottom sediments in the northern third of the Gulf. These redeposited grains were eroded from older

sediments by the ancestral Colorado River and discharged into the Gulf of California where they underwent later submarine reworking.

Heusser and Balsam (1977), in their study of the distribution of pollen and spores in the Recent offshore sediments off the mouth of the Columbia River and off San Francisco Bay, conclude that fluvial transport is the predominant factor controlling contemporaneous pollen influx in the northeastern Pacific Ocean. They found high concentrations of pollen and spores from 50 to 100 kilometers offshore in water depths ranging from 50 to 3000 meters. In contrast, Mudie (1982) reports that wind transport is the major mechanism of dispersal of Recent pollen and spores in offshore eastern Canada. She found that fluvial transport is subordinate in this region where river runoff volumes are presently small and winds are predominantly offshore. Although wind transport can be an important factor in pollen and spore transport, the large number of recyclants mixed in with in situ assemblages suggests that the primary controlling mechanism of transport was fluvial.

The aforementioned studies all emphasize the importance of marine currents for distributing sedimentary organic matter offshore. Although the paleocirculation of surface waters in the Labrador Sea from Campanian to early Oligocene time may have been poleward (Gradstein and Srivastava, 1980), its northward movement does not appear to have significantly affected the distribution pattern of the recycled and

contemporaneous palynomorphs. In spite of minor differences in relative abundance, the composition and frequency of the two assemblages appear to be fairly evenly distributed at any one time.

Another factor controlling the distribution of the organic matter is the movement and reworking downslope of the sediments by turbidity currents. The Cartwright Formation from offshore Labrador and the Nukik Formation from offshore West Greenland represent, for the most part, turbidite deposits. Recycled grains are a common constituent in turbidites, where they may represent multiple cyclic events (Whitman, 1985). Although the reworking by turbidity currents has undoubtedly affected the overall distribution as well as mixing of assemblages, a detailed examination of the palynomorphs indicates that the species composition of the palynoflora has not been overly biased.

The mineralogical composition of the Cretaceous and early Paleocene continental shelf strata of the Labrador Sea was studied by Higgs (1977) for the purpose of determining the provenance of the sediments. Higgs examined the mineral and lithic fragments of 44 Cretaceous and early Paleocene sand samples from offshore Labrador and onshore West Greenland. Based on his findings, he concluded that the Cretaceous and early Paleocene sediments of the Labrador Sea were derived from local sources. Palynological results from these same intervals do not contradict this conclusion, because of the relatively low percentage

of recycled palynomorphs and the low diversity and abundance of in-situ pollen and spores in the early Paleocene.

Although Hiscott (1984) also supports a local source for Cretaceous and possibly early Paleocene Labrador Sea sediments, his detailed study of the clay mineralogy of both the Cretaceous and Tertiary sediments, from five offshore Labrador wells (including Roberval K-92) and Hekja O-71 from offshore southern Baffin Island, indicates a Canadian Arctic-western North American source for a large portion of the Paleogene sediments. Data from other wells (including Karlsefni H-13, Snorri J-90 and Cartier D-70) were also incorporated into his results. He found that, although the pre-Tertiary marine shales were characterized by an abundance of locally derived smectite, the Paleogene sediments were characterized by a predominately mixed smectite-illite-kaolinite clay assemblage. The homogeneity of this polycyclic clay suite indicates a multiple source such as would be expected from a large, intercontinental drainage basin encompassing thousands of square kilometers. In fact, the volume of the long-distance transported material was so great that it diluted clays derived from local sources.

CONCLUSIONS

1. The similarity of Paleogene in-situ and recycled palynomorphs (primarily pollen and spores) between the shelf sediments of the Labrador Sea and the Canadian Arctic and western interior of Canada indicate that at least a portion of the assemblages may have been transported from distant sources. The method of transport, as proposed by McMillan (1973), was probably via a "super river" system that drained much of the Canadian interior during the Tertiary. The results of Hiscott's (1984) clay mineralogical study supports this conclusion.

2. A Canadian Arctic and western interior sediment source to the Labrador Sea during the Tertiary has important implications regarding the interpretation of not only the sedimentology of the region but also the paleoclimatology.

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CHAPTER 5. PALEOGENE PALEOCLIMATIC TRENDS OF THE LABRADOR SEA REGION

INTRODUCTION

Pollen and spore assemblages recovered from six wells drilled along the continental shelves of the Labrador Sea (Figure 1) help support a large body of data indicating that warm temperatures were prevalent at high latitudes during the Paleogene. During parts of the Early Tertiary, tropical to subtropical conditions extended into Arctic and Antarctic latitudes (Rouse, 1977; Wolfe, 1978). Paleomagnetic studies and paleogeographic reconstructions indicate that paleopole positions in the Tertiary were not significantly different from their present positions (Donn and Shaw, 1977). Although paleontological and isotope geochemical studies (including Rouse, 1977; Savin, 1977; Wolfe, 1978, 1980; Gradstein and Berggren, 1981) from around the world document a general decline in global temperatures since late Cretaceous times, there were several important temperature fluctuations superimposed on the overall cooling trend.

Savin (1977) plotted oxygen isotopic paleotemperature data for North Pacific planktic and benthic foraminifera through the Cenozoic. The isotope data from the benthic foraminifera represents surface water temperatures at high latitudes where cool bottom waters are formed.

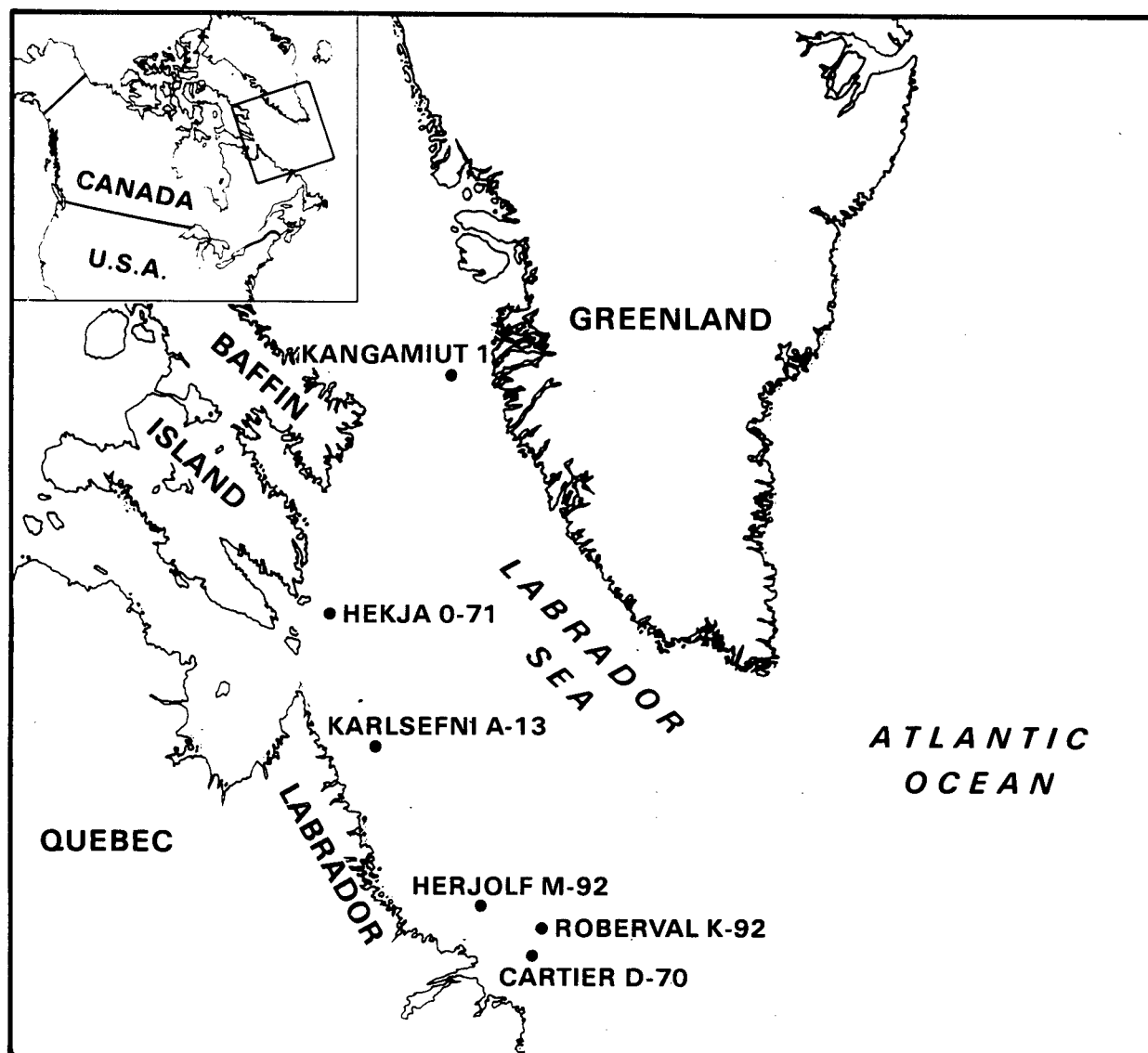


Figure 1. Location map of the Labrador Sea and the six offshore wells used in this study.

The benthic isotopic paleotemperature curve shows a period of climatic cooling at the Cretaceous/Tertiary boundary and early Paleocene, which was followed by a warming phase that reached optimum conditions in the early Eocene. The middle and late Eocene saw gradual cooling until at the end of the Eocene and early Oligocene, there was a dramatic decline in temperature. With the exception of several warming events in the late Oligocene and middle Miocene, there was a deterioration of climate through the Neogene and an increased development of latitudinal temperature gradients.

STUDY AREA

Paleogene sediments were studied in wells from offshore West Greenland (Kangamiut 1), offshore southern Baffin Island (Hekja 0-71) and offshore Labrador (Karlsefni A-13; Herjolf M-92, Roberval K-92 and Cartier D-70). Their location is shown in Figure 1. The ages of the sediments are based upon work by this author and the lithostratigraphy for offshore Labrador is after McWhae et al. (1980) and for offshore Greenland after Rolle (1985). The generalized lithostratigraphy of the Paleogene sections of each of the study wells is illustrated in Figure 2. Sample depths are indicated by horizontal lines to the right of each column.

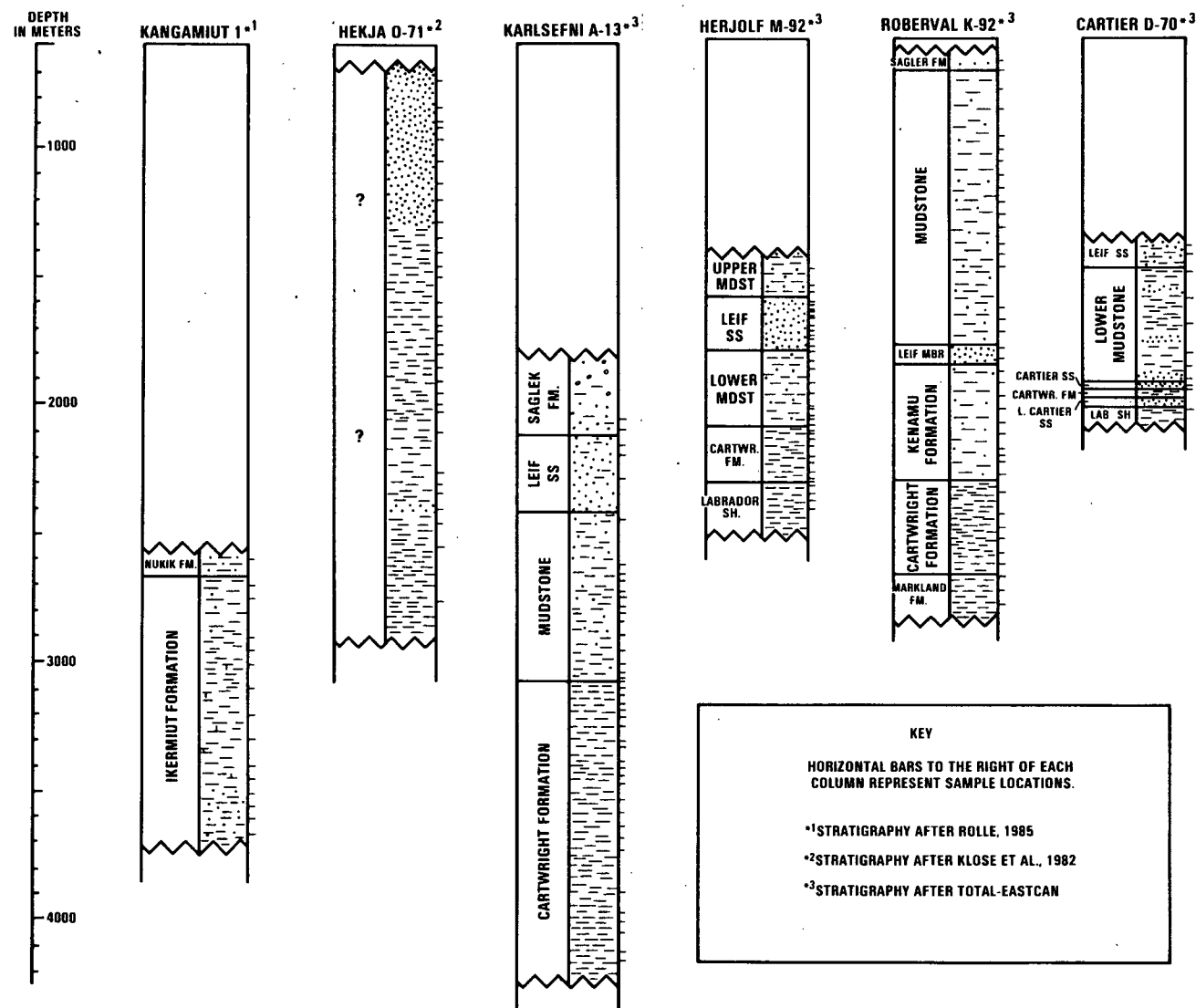


Figure 2. Generalized lithostratigraphic columns of the Tertiary sections of the six study wells.

The Labrador Sea was formed by the breakup of Labrador and Greenland. Based upon dinoflagellate occurrences, the incursion of marine waters into the newly forming basin probably began during the early Senonian (Barss et al., 1979). The modern configuration of the Labrador Sea was established by the latest Eocene/earliest Oligocene with the cessation of sea-floor spreading just prior to Anomaly 13 time (Gradstein and Srivastava, 1980).

During the Paleogene great volumes of sediment, which in places reach up to ten kilometers in thickness (McMillan, 1980 and 1982), were deposited along the continental margins of the Labrador Sea. The sediments are characterized by thick sequences of shales, mudstones, siltstones and sandstones. McWhae et al. (1980) interpret the brown to gray shales and mudstones of the Carwright Formation to represent turbidite deposits. Based upon foraminiferal studies from six offshore Labrador wells (including Karlsefni A-13, Herjolf M-92 and Cartier D-70), Gradstein and Williams (1981) interpret both the Cartwright and Kenamu Formations (roughly equivalent to the Ikermiut and Kangamiut Formations, respectively, from offshore West Greenland) to have been deposited under bathyal to deep neritic conditions. Maximum transgression in the Labrador Sea occurred during the early Eocene (Gradstein and Srivastava, 1980).

RESULTS AND DISCUSSION

The pollen and spores found in the marine sediments of the Labrador Sea represent allochthonous terrestrially derived assemblages, which were selectively delivered offshore mainly by fluvial transport. Although wind transport of palynomorphs can be an important mechanism of delivery of contemporaneous pollen and spores into marine depositional basins, as demonstrated by Mudie (1980 and 1982) in Recent offshore eastern Canada, fluvial transport tends to be the major contributor of pollen and spores and other terrestrial organic matter in marine sediments of warmer climatic regions where fluvial sediments by-pass infilled coastal basins or where rivers are extraordinarily large (Muller, 1959; Cross et al., 1966; Frederiksen, 1969; McAndrews and Powers, 1973; Heusser and Balsam, 1977).

The clay mineralogy of Lower Tertiary Labrador Sea sediments is predominantly characterized by a mixed smectite, illite and kaolinite assemblage which is interpreted by Hiscott (1984) to indicate long distance fluvial transport of the sediments into the Labrador Sea. In order to account for the great thicknesses of sediment, McMillan (1973) proposed the possible existence of several rivers that drained into the Tertiary Labrador Sea basin. One of these was a major river that drained much of the Canadian interior and southern Arctic regions. The composition and distribution of in-situ and recycled Paleogene pollen and spores in the Labrador Sea are also compatible

with a Canadian trans-continental and Arctic provenance (see CHAPTER 4).

Fluvially transported grains tend to reflect the general regional vegetation represented in the drainage basins of the rivers carrying sediments to the sea (Muller, 1959; Cross et al., 1966; Balsam and Heusser, 1976). Therefore, the Labrador Sea pollen and spore assemblage is very likely representative of the gross regional flora of not only the general area surrounding the Labrador Sea but also much of the Canadian interior and parts of the Canadian Arctic.

The general geographic distribution of modern vegetation is climatically controlled. A knowledge of the regional vegetation, therefore, can be used to help interpret paleoclimatic trends, by determining the probable affinities of fossil palynomorphs to modern plants. It is often difficult, however, to relate fossil pollen and spores to their modern antecedents. The further back in time the more difficult it is to reliably determine relationships. A number of workers have made comparisons between fossil pollen and spores and Recent palynofloras (Frederiksen, 1969; Rouse, 1977). The most up to date treatment is by Frederiksen (1985) who discusses in some detail the botanical affinities between various fossil and modern taxa in his review of the paleoecology of Early Tertiary pollen and spores.

Other problems associated with using fossil pollen and spores in marine sediments to interpret paleoclimates include 1) biased assemblages resulting from selective transport of palynomorphs, 2) types of samples used (e.g., cuttings or sidewall cores) and 3) stratigraphic spacing of samples through a section.

The diversity and relative abundance of pollen and spore taxa in the Labrador Sea samples varies considerably from the lower Paleocene sediments where they are at their lowest, to the Eocene and early Oligocene where they are generally high. Another factor controlling the overall composition and distribution of the palynomorphs is the effect of turbidity currents. In-situ and recycled terrestrially derived palynomorphs and other organic matter in the Cartwright Formation were carried and redeposited downslope, where they became mixed with marine assemblages. In addition, mostly cuttings samples were used in the study, thereby, introducing possible downhole contamination by cavings. Paleoecological interpretations are further hampered by the use of fairly wide sampling intervals in Kangamiut 1, Karlsefni A-13, Herjolf M-92 and Cartier D-70.

Because of these problems, therefore, it is not possible to provide a detailed paleoecological analyses of the Labrador Sea Paleogene pollen and spore assemblages. However, it is possible to identify some very broad, general climatic trends that existed in the Labrador Sea and

very likely the Canadian interior and Arctic regions during the Early Tertiary.

Early to Middle Paleocene

Early to middle Paleocene sections were studied in all the wells with the exception of Hekja 0-71. The pollen and spore assemblage recovered from this interval has a low diversity and is characterized by abundant bisaccate and taxodiaceous conifer pollen, as well as monolete and trilete fern spores. Triporate pollen of the Betulaceae-Myricaceae-Casuarinaceae complex and reticulate, scabrate and psilate tricolpate pollen are also present but never abundant. Similar assemblages are also reported from Saskatchewan (Sweet, 1978), Alberta (Sweet, 1983; this author, unpublished technical report) and further to the south in the western interior of the United States (Leffingwell, 1971; Nichols et al., 1985).

Rouse (1977), who reports the same type of assemblage from the Canadian Arctic, interprets it to be indicative of cool and probably wet climatic conditions. Early to middle Paleocene foraminifera assemblages from the Labrador Sea and West Greenland also indicate temperate climatic conditions (Gradstein and Srivastava, 1980).

Schweitzer (1980) interprets a lower Paleocene coastal mixed conifer and broad-leaved deciduous megafloral assemblage from Spitsbergen to

represent a warm temperate environment with occasional light frosts, corresponding to the lowlands of southern China and Taiwan. Based upon physiognomic data and comparisons between fossil and extant floras, Wolfe (1980) considers the early Paleocene Spitsbergen megafloreal assemblages, as well as those from West Greenland, Alaska and Siberia, to be indicative of a mesothermal climate with mean annual temperatures of around 14-15°C.

The evolution of terrestrial vertebrates from the Rocky Mountain western interior of the United States indicates climatic cooling across the Cretaceous/Tertiary boundary. The transitional composition of environmentally restricted faunas corresponds to gradual changes in the physical environment as a result of declining continental paleotemperatures (Clemens, 1982).

Frederiksen (1985) indicates that pteridophyte fern spores are found in a variety of climates today and that a fern-dominated assemblage does not necessarily have to indicate climatic deterioration so much as an ecologically disruptive event. One such event, as proposed by Alvarez and others (1977, 1980), invokes a catastrophic asteroid impact at the end of the Cretaceous. They base their theory on the presence of a geographically widespread, iridium enriched clay layer found at the Cretaceous/Tertiary boundary. The terminal Cretaceous mass extinction and climatic cooling events are interpreted by many (including Alvarez et al., 1980, 1984; Smit and Hertogen, 1980; Hsü,

1981; Smit, 1982; and Pollack et al., 1983) to have resulted from a major impact of an extraterrestrial body.

Early Paleocene fern-dominated palynomorph assemblages have been reported from Colorado, New Mexico and Montana just above the anomalous iridium enriched clay layer. (Tschudy et al., 1984; Nichols et al., 1985). The dominance of fern spores gives way to an increase in angiosperm pollen approximately 15 centimeters above the clay layer. The composition of the new flora is much different from that of the late Maastrichtian.

Other theories to explain the iridium anomaly at the Cretaceous/Tertiary boundary and the decline in global temperatures include excessive volcanism over a prolonged period of time, such as the Deccan traps in India (McLean, 1984; Officer and Drake, 1985) and physio-chemical and paleocirculation changes in the world's oceans (Gartner and Keany, 1978; Tappan, 1982).

Late Paleocene

Continued climatic warming in the middle to late Paleocene is indicated by an increase in diversity and relative abundance of angiosperm pollen in all of the study wells. Tricolporate and juglandaceous pollen are important constituents of the assemblage. The *Momipites* complex (Juglandaceae family) is similar morphologically to the modern

genus *Englehardtia* which is now found in the wet tropical mountains and lowland forests of Southeast Asia (Frederiksen, 1985), Mexico and Central America (Leopold and MacGinitie, 1972).

Climatic warming in the late Paleocene at high latitudes is also indicated by fossil leaf assemblages from Alaska, which are characterized by a dominance of broad-leaved evergreens including palms and cycads (Wolfe, 1971, 1980). Foliar physiognomic characteristics of the flora suggest a mean annual temperature of 17° to 18° C (Wolfe, 1978).

Early to Early-Middle Eocene

Climatic warming reached its maximum during the early to early middle Eocene as evidenced by the high diversity and composition of the pollen and spore palynoflora from offshore Labrador and West Greenland. Similar palynological assemblages are reported from similarly aged sediments from British Columbia (Rouse, 1977; Rouse and Mathews, 1979; Mathews and Rouse, 1984) and the Canadian Arctic (Staplin, 1976; Rouse, 1977; Norris, 1986). Many of the same palynological elements are also reported from more southerly locations in Washington State (Newman, 1981; Reiswig, 1983) and the western interior of the United States (Cushman, 1983; Newman, 1983; Wingate, 1983).

Three of the palynofloral constituents in the assemblage are interpreted as climatically diagnostic. They are *Pistillipollenites mcgregorii*, *Platycarya* sp. and *Rhoipites latus*. *Pistillipollenites*, which makes its first stratigraphic appearance in the late Paleocene, has a widespread occurrence in the late Paleocene to early middle Eocene of North America and Europe (Frederiksen, 1985). According to Rouse (1977), it has a probable affinity with the modern herbaceous family Boraginaceae. He compares it to the modern genus *Tournefortia*, which is native to tropical Central America. Boulter and Hubbard (1982) also associate it with the Eocene paratropical rain forests of southern Britain. The early to middle Eocene *Platycarya* (Juglandaceae) is very similar in appearance to the extant genus *Platycarya*, which is now restricted to the tropical evergreen broadleaved and mixed mesophytic forests of China and Japan (Frederiksen, 1985). *Rhoipites latus* resembles the modern genus *Triumfetta* which is a tropical member of the Tiliaceae family (Rouse, 1977).

Faunal assemblages along the Labrador and Newfoundland continental shelves show a maximum incursion of low-latitude planktic foraminifera in the early and middle Eocene. Gradstein and Srivastava (1980) use the occurrence of *Morozovella*, to indicate the northernmost limit of Paleogene tropical waters in the Labrador Sea. The poleward extent of its geographic range was around 50°N.

Although early and middle Eocene fossil leaf assemblages from northern Alaska and the Canadian Arctic are not very well known, in middle Eocene assemblages from south Alaska they indicate boreo-tropical conditions with a mean annual temperature of around 22°C (Wolfe, 1980). Further south, Leopold and MacGinitie (1972) correlate early Eocene leaf and pollen assemblages from the Rocky Mountain western interior with the broad-leaved evergreen forest of Southeast Asia.

Mammalian (including primates, rodents and a type of "flying" lemur, Dermoptera) and reptilian (including turtles, lizards and an alligator-like species) fossil evidence from the Eureka Sound Formation on Ellesmere Island in the Canadian Arctic also indicate warmer climatic conditions during the early and middle Eocene (Dawson et al., 1976; West et al., 1975; Estes and Hutchison, 1980). Modern Dermoptera are currently restricted to Southeast Asia and alligators are not found north of the Gulf Coast and North Africa (McKenna, 1980).

An isolated oxygen isotope determination of a marine mollusc (scaphopod shell) from the Eureka Sound Formation indicates marine surface temperatures of 17°C (Donn, 1982). The Eureka Sound Formation fossil sites are currently at latitude 79°N. McKenna (1980) calculated the position of the Ellesmere Island sites in the early Eocene as approximately 77.5°N.

Late Eocene to Early Oligocene

The late Eocene to early Oligocene Labrador Sea pollen and spore flora is also characterized by a fairly diverse and abundant assemblage. Triporate and tricolporate pollen predominate. Common elements include *Liquidambar*, *Fagus*, *Corylus/Carpinus*, *Pterocarya* and *Quercus*. Onagraceous pollen (e.g., *Boisduvalia* and *Jussiaea*) are also present. Similar pollen and spore assemblages are also reported from British Columbia (Rouse, 1977; Piel, 1977).

Most of the above genera have broad geographic ranges today that extend from subtropical to temperate climatic zones (Frederiksen, 1969). The modern distribution of *Pterocarya* is in the deciduous broad leaved forests of eastern China and Japan and in the Caucasus Mts. of eastern Europe (Leopold and MacGinitie, 1972). However, because *Pterocarya* has a well documented stratigraphic range extending from the late Paleocene to the Miocene in western Canada and parts of the Canadian Arctic, it is likely that it had a much broader climatic tolerance than it does today. Nevertheless, an absence of the more tropical to paratropical genera *Platycarya* and *Pistillipollenites* suggests cooler temperatures.

Physiognomic characteristics of leaf floras from western Washington State indicate that by late Eocene times paratropical rainforests had given way to mixed mesophytic forests, representing as much as a 10° C

drop in mean annual temperature (Wolfe, 1978). Subtropical paleofloral elements had also disappeared from the Rocky Mountain region by early Oligocene times (Leopold and MacGinitie, 1972). Along the Pacific coast of the United States, marine gastropods with warm-water affinities preferentially disappeared (Hickman, 1980). Climatic cooling during the latter part of the Eocene is also reflected by macrofloral assemblages from southern England (Collinson et al., 1981).

Oxygen isotope studies from the sub-Antarctic (Kennett and Shackleton, 1976), the north Atlantic (Vergnaud-Grazzini et al., 1978), south Atlantic (Boersma and Shackleton, 1977) and the Pacific (Savin et al., 1975) all indicate a cooling trend that extended from middle Eocene to early Oligocene times. The most dramatic drop in isotopic paleotemperatures occurred at the Eocene/Oligocene boundary. Kennett and Shackleton (1976) estimate as much as a 4 C drop in bottom water isotopic paleotemperatures in the sub-Antarctic over a period of 75,000 to 100,000 years. The pronounced Eocene/Oligocene cooling event also coincides with the development of the psychrosphere.

A quantitative analysis of planktic foraminiferal assemblages from six DSDP sites in the Atlantic, Pacific and Indian Oceans indicates that the sharp drop in temperature at the Eocene/Oligocene boundary was marked by an increase in abundance of cool water species (Keller,

1983). The faunas also indicate that the cooling trend began in the middle Eocene before the development of the psychrosphere.

Labrador Sea foraminiferal faunas show a change near the Eocene/Oligocene boundary from a predominance of agglutinated to calcareous forms. Although the change may be attributable to climatic or physical oceanographic changes, it was certainly affected by the marine regression that also occurred at the same time (Gradstein and Berggren, 1981).

CONCLUSIONS

The Paleogene pollen and spore assemblages of the Labrador Sea reflect the general climatic trends found at high latitudes during the Early Tertiary. These trends have been well documented by oxygen isotope paleotemperature analyses as well as by floral and faunal distribution patterns. During the early Paleocene, there was a period of climatic cooling followed by a general warming trend in the late Paleocene and early Eocene. The combined presence of the genera *Pistillipollenites* and *Platycarya*, in the early to early middle Eocene sections of the six study wells, indicate that maximum high latitude paleotemperatures for the Tertiary were reached at that time. The interpreted modern relatives of these two taxa are now restricted to tropical climatic zones. Late Eocene and early Oligocene Labrador Sea pollen and spores

are suggestive of a return to cooler climatic conditions. Oxygen isotope data indicate as much as a 4°C drop in high latitude surface water paleotemperatures near the Eocene/Oligocene boundary.

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CHAPTER 6. SUMMARY

The results of this dissertation are the product of a detailed palynological study of seven Labrador Sea wells (Kangamiut 1, Hekja O-71, Karlsefni A-13, Herjolf M-92, Roberval K-92 and Cartier D-70) from 1978 to 1981. An eighth well, Snorri J-90, was cursorily examined for recycled palynomorphs. The initial purpose of the study was to determine the relative abundance of redeposited Upper Jurassic/Lower Cretaceous recyclants, in order to establish if whether or not reworked palynomorphs could be used to indicate the location of subsurface Jurassic rock units. From detailed examination of the first well, Kangamiut 1, it became immediately apparent that other groups of recyclants, including Paleozoic (Carboniferous?), Upper Cretaceous and Paleogene palynomorphs, were also present in the samples. In addition to the recyclants, relatively abundant and diverse contemporaneous pollen and spore assemblages were found associated with the indigenous offshore flora of dinoflagellates and other marine algae. In the upper Eocene and younger sections of the wells the terrestrial palynomorphs were the dominant component of the overall palynological assemblage.

As a result of these observations, it was decided that a preliminary zonation for the Tertiary of the Labrador Sea based on pollen and spores be established. In addition, the relative abundance and distribution of the four different age-categories of recyclants through

time were determined. The composition of the palynological flora and the recycling trends in the wells permitted several general observations to be made regarding the provenance of the sediments of the Labrador Sea and the Paleogene paleoclimatology of the overall region. The results are briefly summarized below.

Provisional Pollen and Spore Zonation of the Tertiary Sediments of the Labrador Sea

The Tertiary pollen and spore assemblages from six Labrador Sea wells were used to establish eight preliminary biostratigraphic interval zones. Because cuttings samples were used almost exclusively in the study, zonal boundaries were defined by extinction events (range tops). Ages were assigned to the intervals based primarily upon the well-documented ranges of age-diagnostic dinoflagellate species found in association with the pollen and spore assemblages. The zonation represents a good biostratigraphic framework that can be used in conjunction with marine assemblages to characterize and correlate Tertiary rock units in the Labrador Sea and perhaps other offshore locales in northern and western Canada.

The Identification and Classification of Redeposited Palynomorphs from the Labrador Sea

Pre-Tertiary recycled palynomorphs recovered from the shelf sediments of the Labrador Sea were divided into three main categories:

Paleozoic (Carboniferous?), Upper Jurassic/Lower Cretaceous and Upper Cretaceous. Criteria used to identify the redeposited grains included taxonomy, color, stain acceptance, state of preservation and fluorescence intensity and color. The relative percentage of Paleozoic recyclants is generally very low, however, in Roberval K-92 they are very abundant in the Upper Cretaceous and upper Eocene to lower Oligocene sections of the well. The Upper Jurassic/Lower Cretaceous group of reworked palynomorphs is also characterized by fairly low percentages. Although redeposited Upper Cretaceous grains are fairly common in the uppermost Cretaceous and Tertiary sections of the study wells, they do not show any particular pattern of concentration when compared among wells. The recycled palynomorphs associated with the Cretaceous sections of the wells were very likely locally derived, whereas a large percentage of the redeposited grains found in the Tertiary sections were probably delivered to the Labrador Sea from distant sources.

Provenance of Paleogene Shelf Sediments of the Labrador Sea

The recycled and contemporaneous pollen and spore assemblages recovered from the Paleogene shelf sediments of the Labrador Sea show a remarkable similarity to assemblages reported from the Canadian Arctic and western interior of Canada. Due to the composition and relatively high abundance of these grains, it is suggested that they were delivered to the Labrador Sea over long distances via a large river system. It is well documented that pollen and spores can be fluvially trans-

ported for hundreds of miles from their source to their eventual site of deposition. The existence of a large river capable of such long-distance transport was proposed by McMillan (1973). The proposed river would have entered the Labrador Sea through what is now the Hudson Strait. A clay mineralogy study of the Labrador Sea sediments by Hiscott (1985) supports the palynological data by also suggesting a Canadian interior/Arctic Canada sediment source.

Paleogene Paleoclimatic Trends of the Labrador Sea Region

Pollen and spore assemblages recovered from marine sediments are often good indicators of broad regional paleoclimatic trends. Based on this assumption, the Paleogene palynoflora of the Labrador Sea helps support other paleofloral and faunal evidence that warm temperatures prevailed at high northern latitudes during the Lower Tertiary. Climatically diagnostic pollen indicates that the early Paleocene was characterized by a cooling period which gave way to an overall warming trend that persisted into the middle Eocene. Subtropical to tropical conditions are indicated at the peak of the trend in the early to early-middle Eocene. By late Eocene to early Oligocene time, there was a return to overall cooler climatic conditions. Though punctuated by several warming cycles, the cooling trend continued through the Tertiary and Pleistocene.

In conclusion, this study demonstrates the utility of integrating both pollen/spore and dinoflagellate data in palynological studies of marine sediments. The pollen and spores can provide valuable biostratigraphic input as well as important paleoecological information. The results from the examination of recyclants, on the other hand, have important implications with regards to geological and biostratigraphic interpretations. Whereas redeposited palynomorphs can be used to benefit and help in the determination of sediment source areas, they can also cause confusion in dating unless the criteria for their recognition, such as used here, are carefully applied. This can be especially critical when working with well cuttings, because recycling can artificially extend the range tops of some species. In fact, the younger and more abundant the redeposited grains are the more difficult they are to recognize and, therefore, the more potential they have for concealing in-situ assemblages.

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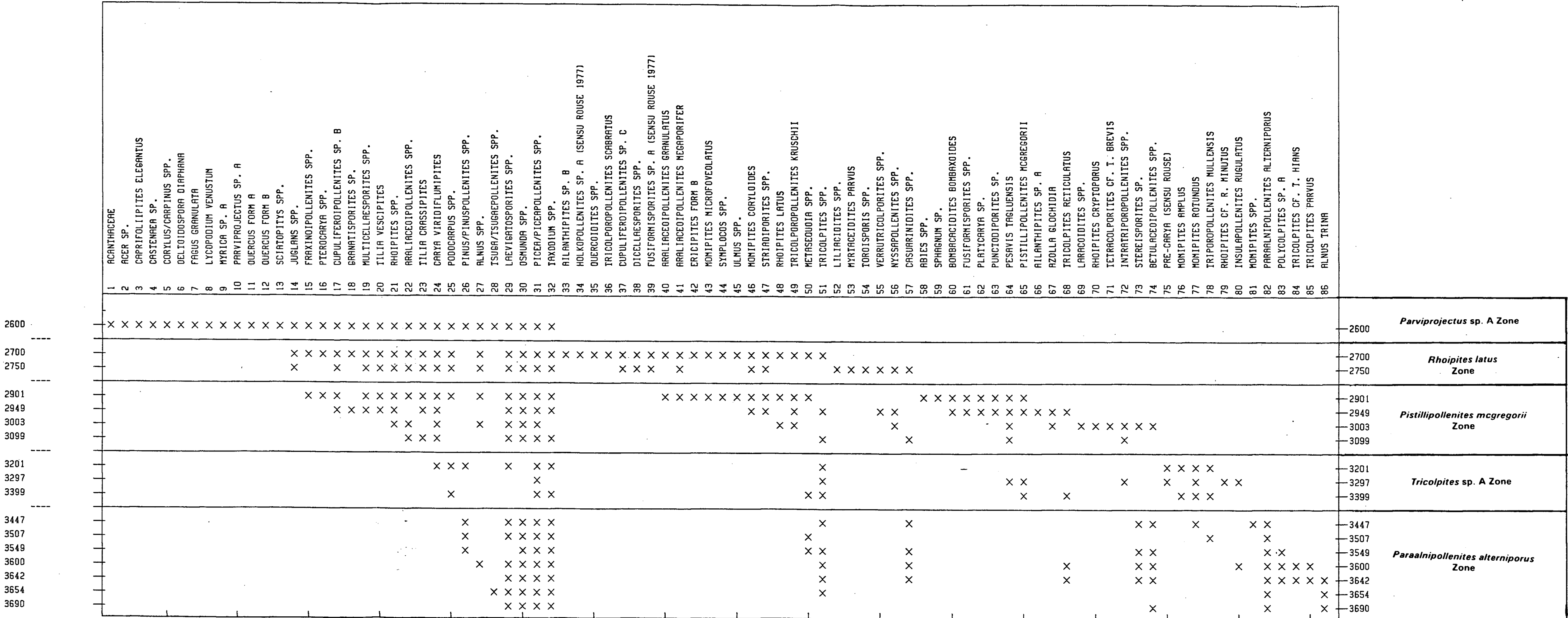
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APPENDIX

TERTIARY POLLEN AND SPORE RANGE CHART: KANGAMIUT 1 WELL

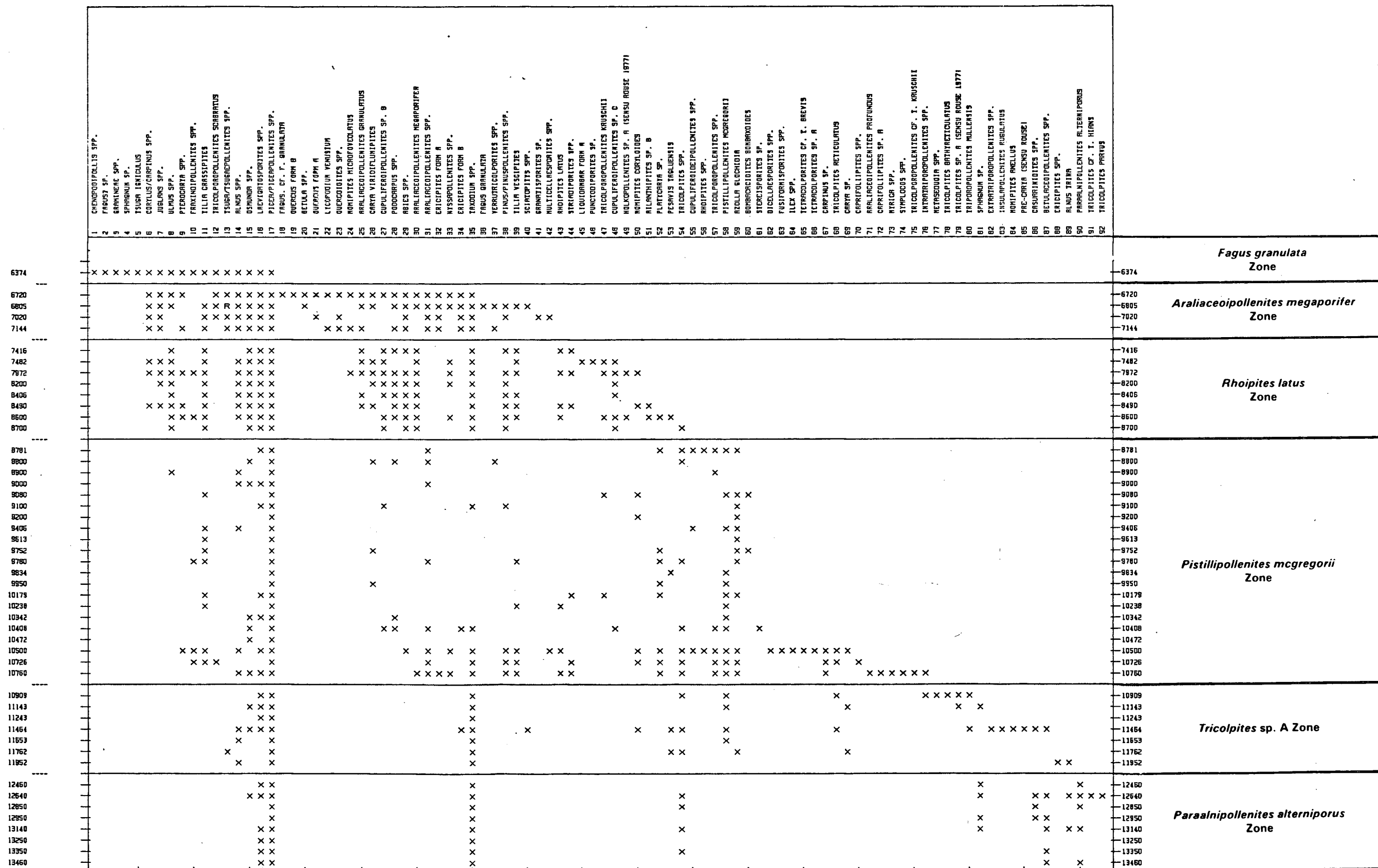


SORTED BY DESCENDING RANGE TOP.

740	X	1	COMPOSITAE SP.
855	X	2	CHENOPODIOPOLLIS SPP.
910	X	3	GRAMINEAE SPP.
935	X	4	TSUGA IGNICULUS
	X	5	BETULA CLARIPITES
	X	6	QUERCUS FORM B
	X	7	ABIES SPP.
	X	8	PINUS/PINUSPOLLENITES SPP.
	X	9	ALNUS SPP.
	X	10	LAEVIGATOSPORITES SPP.
	X	11	OSMUNDA SPP.
	X	12	PICEA/PICEAPOLLENITES SPP.
	X	13	SALIXPOLLENITES SPP.
	X	14	TILIA SP. A
	X	15	TSUGA VIRIDIFLUMINIPITES
	X	16	ACER SP.
	X	17	MYRICA SP. A
	X	18	PSEUDOTSUGA SP.
	X	19	JUGLANS SP. B
	X	20	LARACOIDITES SPP.
	X	21	SPHAGNUM SP.
	X	22	FAGUS GRANULATA
	X	23	LIQUIDAMBAR FORM B
	X	24	QUERCUS FORM A
	X	25	LIQUIDAMBAR FORM A
	X	26	SCIATOPITYS SPP.
	X	27	FAGUS, CF. F. GRANULATA
	X	28	CORYLUS/CARPINUS SPP.
	X	29	ILEX SPP.
	X	30	METASEQUOIA SPP.
	X	31	ULMUS SPP.
	X	32	CAPRIFOLIIPITES SPP.
	X	33	CARYA VIRIDIFLUMIPITES
	X	34	PTEROCARYA SPP.
	X	35	TAXODIUM SPP.
	X	36	TILIA CRASSIPITES
	X	37	NUPHUR? SP.
	X	38	CYRILLACEAPOLLENITES SP.
	X	39	ERICIPITES FORM B
	X	40	ERICIPITES FORM A
	X	41	METASEQUOIA SPP.
	X	42	CEDRUS SP.
	X	43	JUSIACA SP.
	X	44	PARVIPROJECTUS SP. A
	X	45	POLYPODIISPORITES SP.
	X	46	CUPRESSACEOUS SPP.
	X	47	FRAXINUS SP.
	X	48	ONAGRACEOUS SP.
	X	49	TRICOLPATE SP. (VERRUCATE)
	X	50	TSUGA/TSUGAPOLLENITES SPP.
	X	51	PERIPORATE SP.
	X	52	PODOCARPUS SPP.
	X	53	JUGLANS SPP.
	X	54	NYSSAPOLLENITES SPP.
	X	55	DIERVILLA ECHINATA
	X	56	LYCOPODIUM VENUSTUM
	X	57	LILIACOIDITES SPP.
	X	58	MONIIPITES VENTIFLUMINIS
	X	59	TRICOLPOROPOLLENITES SCABRATUS
	X	60	MYRICA SPP.
	X	61	POLLENITES PSEUDOLAESUS
	X	62	ACANTHACEAE
	X	63	DROSERIA SP.
	X	64	ROUSEA MONILIFERA
	X	65	ROUSEA ARANEOSA
	X	66	BOISDUVALIA CLAVITITES
	X	67	EPHEDRA CF. E. CLARICRISTATA
	X	68	SIGNOPOLLIS SP.
	X	69	CYRILLACEAPOLLENITES SPP.
	X	70	TOROSPORIS SPP.
	X	71	ARALICEIDIPOLLENITES PROFUNDUS
	X	72	CUPULIFEROIPOLLENITES SPP.
	X	73	VERRUTRICOLPORITES SPP.
	X	74	ARALICEIDIPOLLENITES GRANULATUS
	X	75	MYRICIPITES SPP.
	X	76	ROUSEA SP.
	X	77	ARALICEIDIPOLLENITES SPP.
	X	78	MILFORDIA? SP.
	X	79	VERRUTRICOLPORITES CRUCIATUS
	X	80	TETRACOLPORITES CF. T. BREVIS
	X	81	ARALICEIDIPOLLENITES MEGAPORIFER
	X	82	TILIA VESCIPTES
	X	83	TRICOLPOROPOLLENITES CF. J. KRUSCHII
	X	84	TRICOLPOROPOLLENITES SPP.
	X	85	VERRUTRICOLPORITES SP. C
	X	86	ARALICEIDIPOLLENITES SP. A
	X	87	CASSIA SPP.
	X	88	TETRACOLPORITES BREVIS
	X	89	TRIPOROPOLLENITES SPP.
	X	90	SYMPLOCOIDIPOLLENITES SP. A
	X	91	TETRACELLACSPORITES SPP.
	X	92	ARALICEIDIPOLLENITES MICROPORIFER
	X	93	TETRACOLPORITES SPP.
	X	94	TRICOLPITES SP. C (SENSU WMS & BR 1975)
	X	95	PSILATRICALPORITES SP. Z (SENSU WMS & BR)
	X	96	STRIADIPORITES SPP.
	X	97	VERRUTRICOLPORITES SP. B
	X	98	VERRUTRICOLPORITES SP. A
	X	99	MONIIPITES MICROFOVEOLATUS
	X	100	AILANTHIPITES SP. B
	X	101	MULTICELLACSPORITES SPP.
	X	102	FRAXINIDIPOLLENITES SPP.
	X	103	QUERACOIDITES SPP.
	X	104	CUPULIFEROIPOLLENITES SP. B
	X	105	LONICERA SP.
	X	106	HORNIELLA SPP.
	X	107	MONIIPITES CORYLOIDES
	X	108	RHOIPITES LATUS
	X	109	RHOIPITES SPP.
	X	110	MONIIPITES SPP.
	X	111	PESAVIS PARVUS
	X	112	SYMPLOCOIDIPOLLENITES SP. B
	X	113	AILANTHIPITES SP.
	X	114	PESAVIS TAGLUENSIS
	X	115	CAPRIFOLIIPITES SP. A
	X	116	FUSIFORMISPORITES SPP.
	X	117	MYRTACIDITES PARVUS
	X	118	FUSIFORMISPORITES SP. A (SENSU ROUSE 1977)
	X	119	HOLKOPOLLENITES SP. A (SENSU ROUSE 1977)
	X	120	TRICOLPOROPOLLENITES KRUSCHII
	X	121	DICELLACSPORITES SPP.
	X	122	GRAMATISPORITES SP.
	X	123	CAPRIFOLIIPITES INDEQUANTUS
	X	124	GOTHANIPOLLENITES SP.
	X	125	GOTHANIPOLLIS COCKFIELDENSIS
	X	126	SYMPLOCOS SP. A
	X	127	SYMPLOCOS SP. B
	X	128	TRICOLPITES SPP.
	X	129	VERRUTRICOLPORITES SP. D
	X	130	CUPULIFEROIPOLLENITES SP. C
	X	131	TETRACOLPORITES SP. A
	X	132	TRICOLPITES SP. XX (SENSU WMS & BR 1975)
	X	133	PLATYCARYA SP.
	X	134	RHOIPITES ANGUSTUS
	X	135	AILANTHIPITES SP. A
	X	136	PUNCTODIPORITES SP.
	X	137	BOMBACACOIDITES BOMBACOIDES
	X	138	CTENOSPORITES WOLFEI
	X	139	SYMPLOCOS SPP.
	X	140	INTRATRIPOROPOLLENITES SPP.
	X	141	AZOLLA GLOCHIDIA
	X	142	CASUARINIDITES SP.
	X	143	CASUARINIDITES SPP.
	X	144	PISTILLIPOLLENITES MCGREGORII
	X	145	SAGENOPOLLIS ARANEOSA
	X	146	TRICOLPITES SP. ZA (SENSU WMS & BR 1975)
	X	147	CUPULIFEROIDIPOLLENITES SPP.
	X	148	SILTARIA SPP.
970	X		
1065	X		
1145	X		
1205	X		
1290	X		
1350	X		
1405	X		
1455	X		
1505	X		
1605	X		
1650	X		
1685	X		
1710	X		
1775	X		
1805	X		
1860	X		
1905	X		
1950	X		
1990	X		
2020	X		
2065	X		
2105	X		
2270	X		
2305	X		
2335	X		
2405	X		
2455	X		
2505	X		
2555	X		

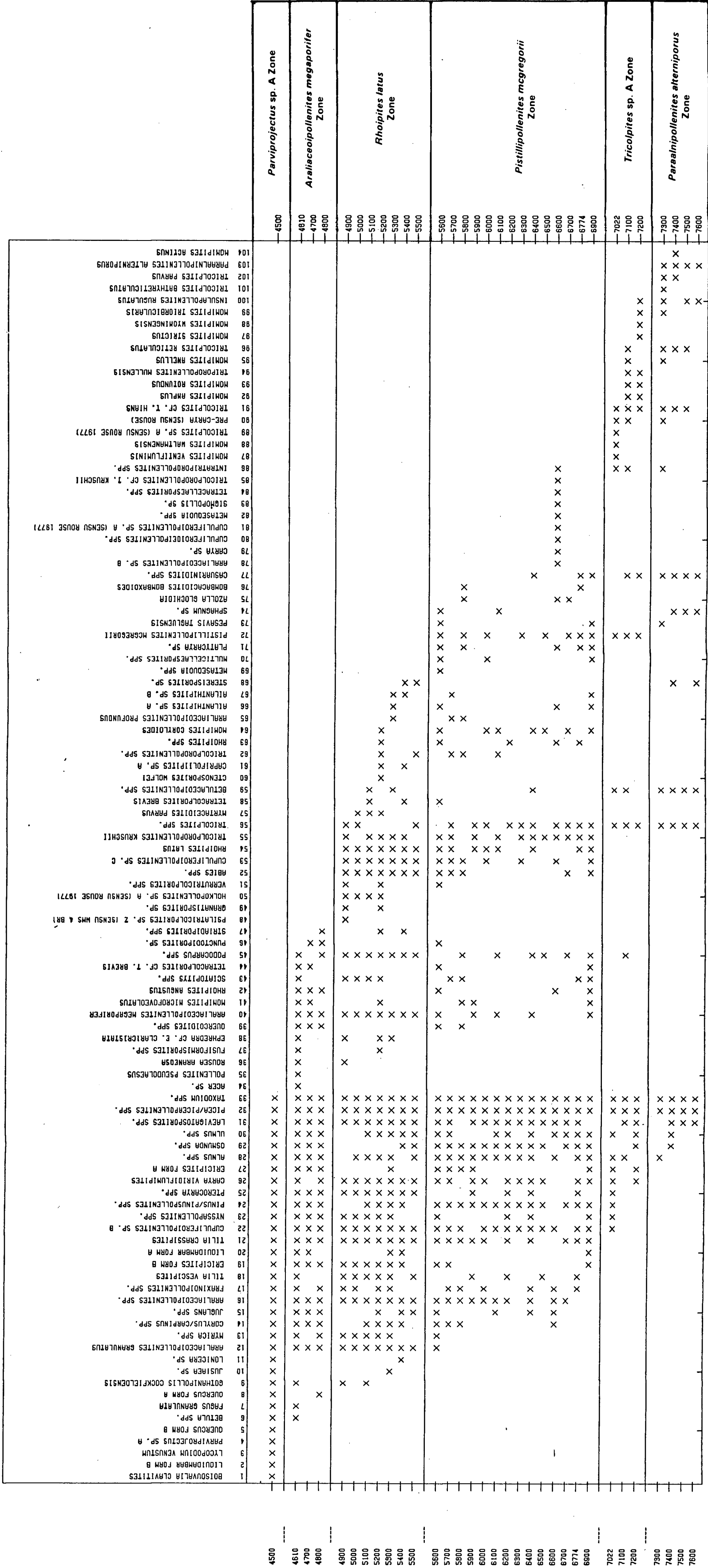
SORTED BY DESCENDING RANGE TOP.

TERTIARY POLLEN AND SPORE RANGE CHART: KARLSEFNI A-13 WELL



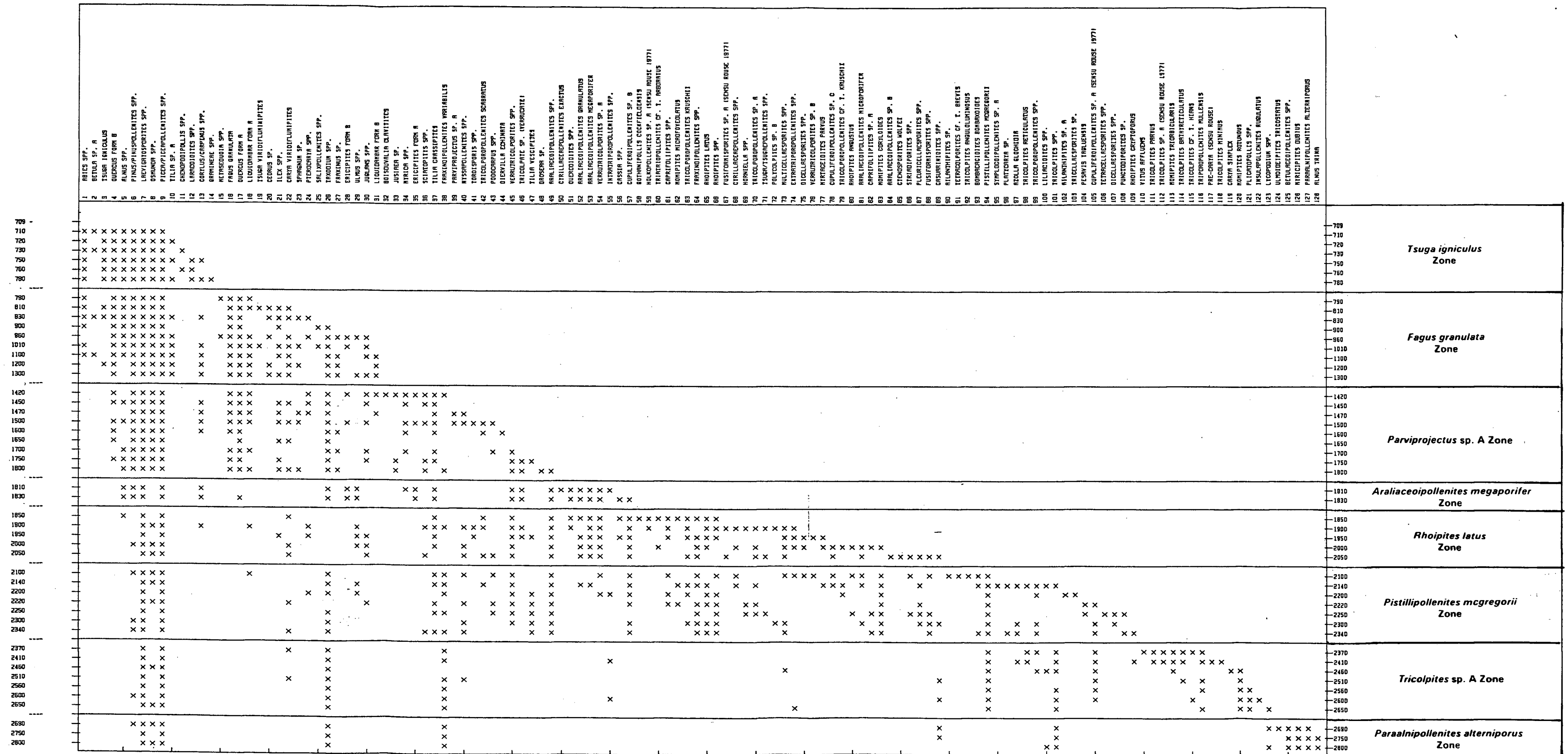
SORTED BY DESCENDING RANGE TOP.

TERTIARY POLLEN AND SPORE RANGE CHART: HERJOLF M-92 WELL



SORTED BY DESCENDING RANGE TOP.

TERTIARY POLLEN AND SPORE RANGE CHART: ROBERVAL K-92 WELL



SORTED BY DESCENDING RANGE TOP.

4500	4800	5100	5480	5500	5600	5720	5810	5860	6130
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SORTED BY DESCENDING RANGE TOP.