Tertiary Stratigraphy and Paleobotany of the Cook Inlet Region, Alaska

GEOLOGICAL SURVEY PROFESSIONAL PAPER 398-A

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By JACK A. WOLFE, D. M. HOPKINS, *and* ESTELLA B. LEOPOLD

TERTIARY BIOSTRATIGRAPHY OF THE COOK INLET REGION, ALASKA

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Discussion of stratigraphic significance of fossil plants from the Chickaloon, Kenai, and Tsadaka Formations

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TERTIARY BIOSTRATIGRAPHY OF THE COOK INLET REGION, ALASKA

TERTIARY STRATIGRAPHY AND PALEOBOTANY OF THE COOK INLET REGION, ALASKA

By Jack A. Wolfe, D. M. Hopkins, and Estella B. Leopold

ABSTRACT

The nonmarine sedimentary rocks of Tertiary age in the Cook Inlet region, once thought to be entirely of Eocene age, are shown by paleobotanical evidence to be mostly of Paleocene, Miocene, and Pliocene age. Our study of Chickaloon floras confirms the Paleocene age of the Chickaloon Formation, as suggested by Barnes and Payne (1956). The Wishbone Formation has not yielded fossil plants, but its conformable and gradational relationship to the underlying Chickaloon Formation indicates that it is at least partly of Paleocene age, although some rocks of Eocene age may be included. Our study of Kenai floras, shown to be mostly of Miocene and probable Pliocene age, confirms the suggestion of Barnes and Payne that two different coal-bearing rock sequences of disparate age may be represented by the Chickaloon Formation of the Matanuska Valley and the Kenai Formation of the Cook Inlet-Susitna Lowlands. The Tsadaka Formation, which rests unconformably upon the Chickaloon and Wishbone Formations, represents a marginal conglomeratic facies of the Kenai Formation; the fossil floras indicate that the Tsadaka Formation was deposited during the first half of the Miocene Epoch.

Three new provincial time-stratigraphic units—the Seldovian, Homerian, and Clamgulchian Stages—are proposed. These units encompass all plant-bearing strata in Alaska and in adjoining parts of the same ancient floristic provinces that are of approximately the same age as those parts of the Kenai Formation represented in the type and reference sections designated in this report. Rocks belonging to these three stages are recognized and distinguished from one another primarily by fossil plants.

The Seldovian Stage is characterized by a rich and diversified warm-temperate flora containing many elements that are now exotic to Alaska but that were widespread during the Miocene. At least 23 fossil plant species appear to be restricted to the Seldovian Stage. Comparisons of different floras suggest that lower and upper subdivisions of the Seldovian Stage may be recognized. Paleobotanical correlations indicate that the Seldovian Stage corresponds approximately to the lower half of the Miocene Series as recognized in northwestern conterminous United States and Japan, but some upper Oligocene rocks may also be included.

The Homerian Stage is characterized by a less diversified and relatively provincial flora in which many of the exotic elements are lacking. At least 11 fossil plant species appear to be restricted to the Homerian Stage. The provincialism of the flora makes correlation in traditional Epoch-Series terms difficult, but some paleobotanical evidence indicates that the Homerian Stage corresponds at least in part to the upper half of the Miocene Series; some lower Pliocene rocks may also be included.

The Clamgulchian Stage is characterized by an extremely provincial flora that is depauperate in species of woody plants. Nearly all the warm-temperate exotic genera have disappeared. Three species of willow and one species of alder seem to be restricted to the Clamgulchian Stage; all seem to be ancestral to living Alaskan species. The extreme provincialism of the flora makes correlations with deposits outside of Alaska imprecise at the present time; we think, however, that the Clamgulchian Stage corresponds to at least part of the Pliocene Series.

INTRODUCTION

The low-lying areas adjoining upper Cook Inlet and the lower courses of the Susitna and Matanuska Rivers in southern Alaska (fig. 1) are underlain by a thick and complex sequence of nonmarine sedimentary rocks of Tertiary age that are of considerable economic importance because they contain coal, petroleum, and natural gas. These nonmarine sedimentary rocks contain abundant fossil plants, but other kinds of fossils are extremely rare. Any attempt to establish the ages of individual formational units in the Tertiary sequence of the Cook Inlet-Susitna Lowlands and of the neighboring Matanuska Valley must be based upon fossil plants. Because the fossil plants are abundant and varied, they can also provide the basis for understanding the time-stratigraphic sequence of the Tertiary rocks.

This report sets forth new conclusions concerning the ages of the Chickaloon, the Tsadaka, and the Kenai Formations of the Cook Inlet-Susitna Lowlands and the Matanuska Valley, based on the fossil floras they contain, and it names and describes three time-stratigraphic units based on fossil floras that can be recognized within the Kenai Formation and correlative stratigraphic units.

The report is based primarily on a study by Wolfe of about 50 collections of fossil leaves and fruits obtained by Wolfe and Hopkins in various parts of the

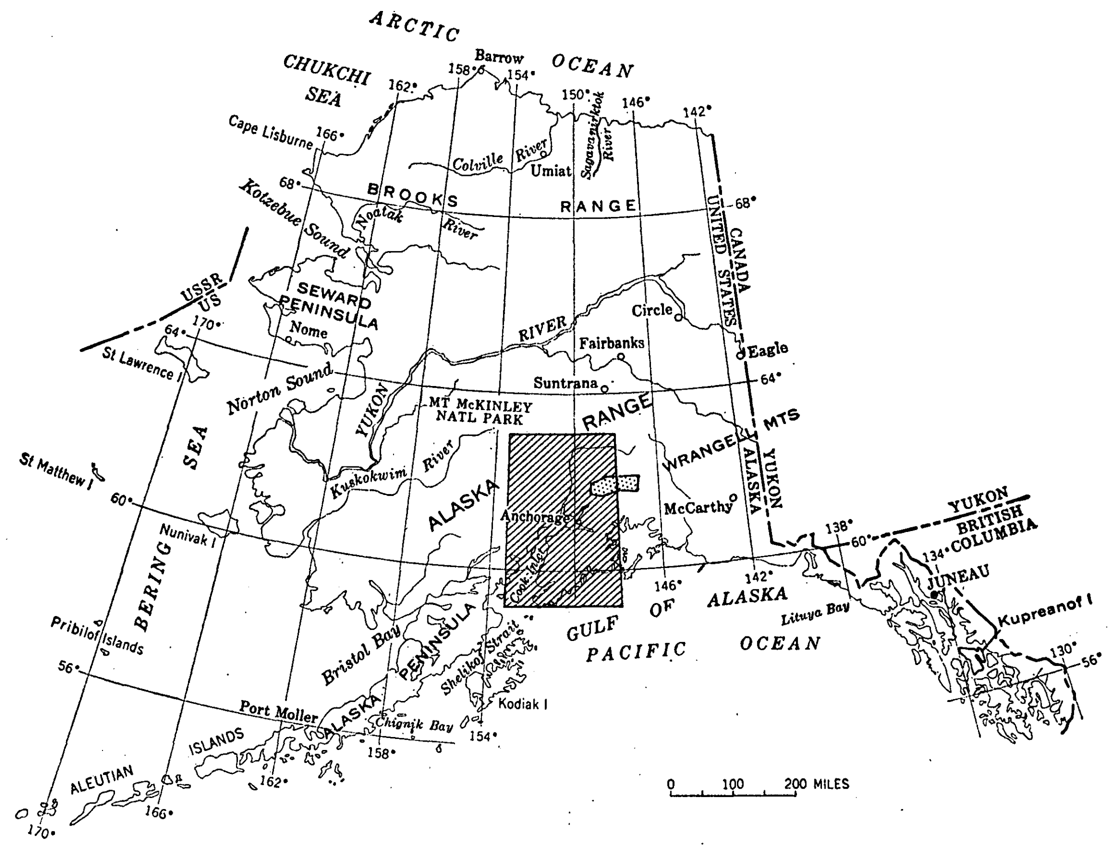

FIGURE 1.—Location of the Cook Inlet region (diagonal lines) and the Matanuska Valley (stippled), Alaska.

Cook Inlet-Sustina Lowlands and the Matanuska Valley during the summer of 1962 as well as upon examination of many small collections obtained from the region by other geologists. A companion paper (Wolfe, 1966) discusses the systematic relationships of these plant fossils and their floristic significance. The study of the fossil leaves is supplemented by preliminary palynological studies by Leopold and Wolfe of 17 outcrop samples and several samples from well cuttings; the palynological studies of the subsurface samples confirm the results of study of pollen samples and megafossil collections from surface exposures, but only the surface pollen samples are discussed individually here. The stratigraphic and geologic discussion is based primarily on the publications cited in this report, but it is supplemented by observations made by Hopkins and Wolfe while collecting fossil plants in 1962.

PREVIOUS GEOLOGIC STUDIES

The Tertiary sedimentary rocks of the Cook Inlet region attracted interest very early in the geological exploration of Alaska because of the coal deposits that they contain. Prior to the 1950's, attention was focused chiefly on the coal-bearing Tertiary rocks exposed along the east shore of Cook Inlet and in the Matanuska Valley because these are in areas relatively accessible to water, rail, and highway transportation. The results of early studies in these areas are summarized in Martin, Johnson, and Grant's account (1915) of the geology of the western part of the Kenai Peninsula and in Martin and Katz' description (1912) of the geology and coal fields of the Matanuska Valley (fig. 2). A more detailed description of the stratigraphy of the Tertiary rocks exposed in the Wishbone Hill district in the western part of the Matanuska Valley is given by Barnes and Payne (1956); maps of various parts of the Matanuska Valley and Cook Inlet area are given in Waring (1936), Tuck (1937), Barnes (1962a, b; 1966), Barnes and Sokol (1959), Hazzard, Moran, Lian, and Simonson (1963), and Davison (1963). The stratigraphy of the Tertiary rocks exposed along the north shore of Kachemak Bay and the east shore of Cook Inlet is described by Barnes and Cobb (1959).

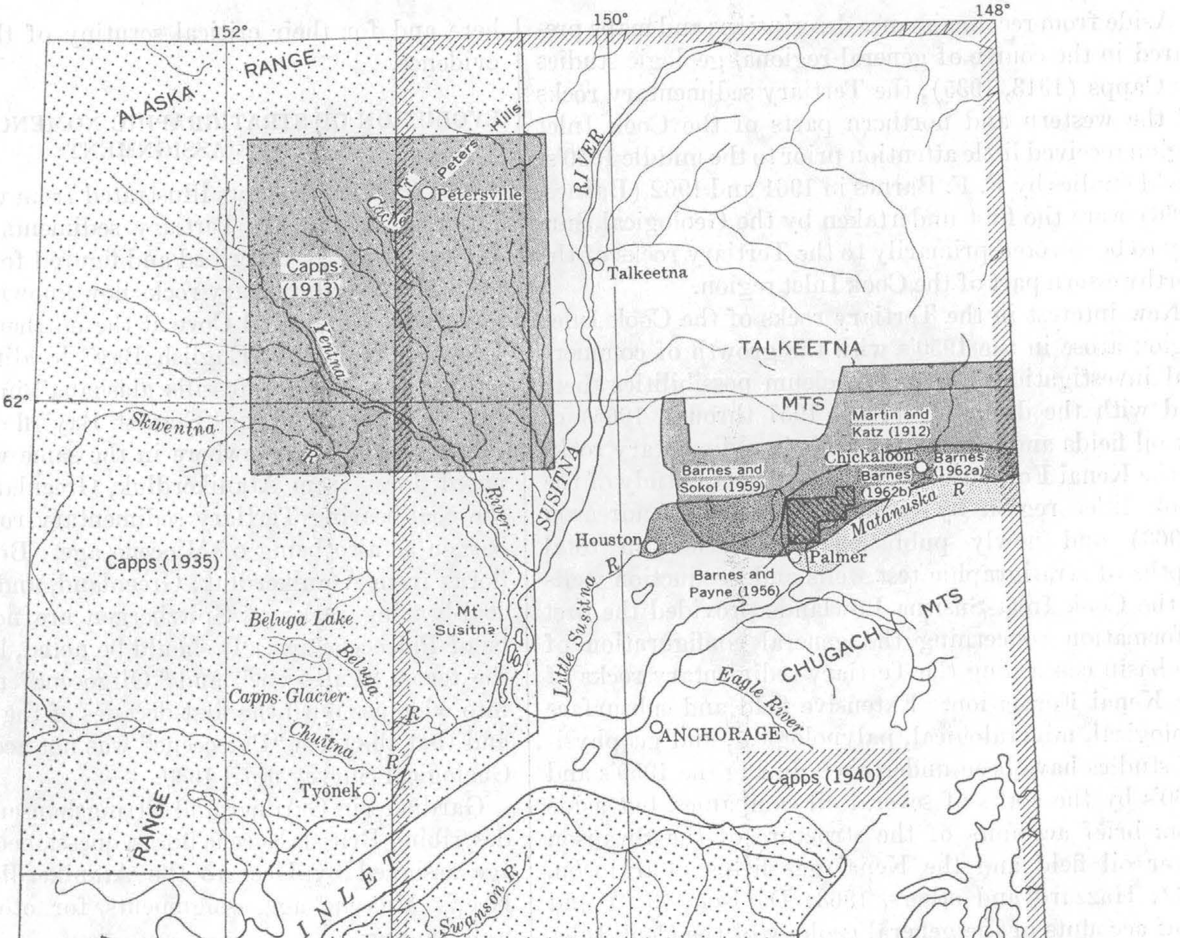

FIGURE 2.—Map of Cook Inlet region, showing areas covered by previous reports.

Aside from reconnaissance descriptions and maps prepared in the course of general regional geologic studies by Capps (1913, 1935), the Tertiary sedimentary rocks of the western and northern parts of the Cook Inlet region received little attention prior to the middle 1950's. Field studies by F. F. Barnes in 1961 and 1962 (Barnes, 1966) were the first undertaken by the Geological Survey to be devoted primarily to the Tertiary rocks of the northwestern part of the Cook Inlet region.

New interest in the Tertiary rocks of the Cook Inlet region arose in the 1950's with the growth of commercial investigations of the petroleum possibilities there and with the discovery (from 1957 through 1965) of six oil fields and several gas fields in sedimentary rocks of the Kenai Formation. An aeromagnetic study of the Cook Inlet region by Grantz, Zietz, and Andreason (1963) and newly published information on total depths of stratigraphic test wells and production wells in the Cook Inlet-Susitna Lowlands provided the first information concerning the general configuration of the basin containing the Tertiary sedimentary rocks of the Kenai Formation. Extensive field and subsurface geological, mineralogical, palynological, and geophysical studies have been undertaken during the 1950's and 1960's by the staffs of several oil companies, but aside from brief accounts of the structure of the Swanson River oil field and the Kenai gas fields (Parkinson, 1962; Hazzard and others, 1963; Davison, 1963) and brief accounts of the general geology of the Cook Inlet region (Kelly, 1963; Hill, 1963 and in press), results of these studies remain unpublished.

ACKNOWLEDGMENTS

In this investigation, we have been greatly assisted by discussions with the geologists of several of the oil companies that have been engaged in petroleum exploration in the Cook Inlet region. We have also benefited by the opportunity to examine a number of fossil plant collections that these geologists submitted to us from areas that we were unable to visit personally and especially from the opportunity to compare ideas and observations concerning the palynology of the Tertiary rocks of the Cook Inlet region with Paul Wesendunk, of Standard Oil Co. of California; with John Browning, of Shell Oil Co.; and with H. Tate Ames and Walter Riegel, of Pennsylvania State University. Dwight Taylor, of the U.S. Geological Survey, kindly furnished determinations of fossil fresh-water mollusks and data concerning their possible paleoecological and paleogeographic significance.

We are especially indebted to Arthur Grantz and Farrell F. Barnes, of the U.S. Geological Survey, for their discussion and criticism of the concepts presented here and for their critical scrutiny of the supporting evidence.

EVOLUTION OF STRATIGRAPHIC NOMENCLATURE AND AGE ASSIGNMENTS

The first fossil plants illustrated from western North America came from Tertiary sediments in the Cook Inlet area. Heer described and figured fossil plants obtained from sedimentary rocks now known as the Kenai Formation from Coal Cove at the northern entrance to Port Graham (his "English Bay" locality) and from Ninilchik in "Flora fossilis alaskana" in 1869. Heer correctly diagnosed the "English Bay" flora as being of Miocene age, but elsewhere in the same work he diagnosed floras from Atanikerdluk, Greenland, and from the coal-bearing Tertiary sedimentary rocks of Spitzbergen as also being of Miocene age. Both the upper floras from Atanikerdluk, Greenland, and those of the coal-bearing rocks of Spitzbergen are now known to be of Paleocene age. It should be noted, however, that the terms "Paleocene" and "Oligocene" did not come into wide use until the first decades of the 20th century and that the term "Paleocene" was not accepted by the Geological Survey until 1939.

Gardner (in Gardner and Ettingshausen, 1879, p. 8), describing British Eocene floras, questioned the Miocene age assigned by Heer to the Atanikerdluk beds and Heer's Miocene age assignments for other floras, as well, saying:

> There is no great break in passing from one to the other [Eocene to Miocene floras]; when we compare them over many latitudes, and but little change beyond that brought about by altered temperature or migration. But if Tertiary floras of different ages are met with in one area, great changes on the contrary are seen, and these are mainly due to progressive modifications in climate, and to altered distribution of land. Imperceptibly, too, the tropical members of the flora disappeared; that is to say, they migrated, for most of their types, I think, actually survive at the present day, many but slightly altered. Then the subtropical members decreased, and the temperate forms, never quite absent even in the Middle Eocenes, preponderated. As decreasing temperature drove the tropical forms south, the more northern must have pressed closely upon them. The Northern Eocene, or the temperate floras of that period, must have pushed, from their home in the far north, more and more south as climates chilled, and at least, in the Miocene time, occupied our latitudes. The relative preponderence of these elements, I believe, will assist in determining the age of Tertiary deposits in Europe more than any minute comparisons of species. Thus it is useless to seek in the Arctic regions for Eocene floras, as we know them in our latitudes, for during the Tertiary period the climate conditions of the earth did not permit their growth there. Arctic floras of temporate, and therefore Miocene aspect, are in all probability of Eocene age, and what has been recognized in them as a newer or Miocene facies is due to their having been first studied in Europe in latitudes which only became fitted for them in Miocene times.

Dall and Harris (1892, p. 234–249) named the beds at Coal Cove and Ninilchik, Alaska, the Kenai Group (and on p. 249, the Kenai Series) and proceeded to extend this name to all beds of suspected Tertiary age throughout Alaska. Thus, the names "Kenai Group," and "Kenai Formation" came for some years to be synonymous with nonmarine beds of suspected Tertiary age in Alaska, and "Kenai flora" to be applied to any Alaskan flora of suspected Tertiary age. Thus defined, the name "Kenai" was applied to beds now known to range in age from Albian to Pliocene. Although Dall and Harris discussed the Alaskan Tertiary sequence under the heading "Miocene of the Kenai Group," they acknowledged Gardner's view that the Atanikerdluk beds were of Eocene age and concluded (p. 252) that "it must be conceded that the view that the [Kenai Group] is of Eocene age does not seem unreasonable."

Two years later, in a review of the fossil floras of Alaska, Kowlton (1894), was prepared to agree that those floras to which he assigned a Tertiary age represented the "Arctic Miocene" of Gardner (1879, p. 8) and that they corresponded to the Eocene of Europe as well as to floras of Fort Union age in the United States. In 1904, he placed a fossil plant collection from Kukak Bay on the Alaska Peninsula (and by implication all other "Kenai floras") in the upper Eocene.

The stratigraphic concept of the Kenai Formation was refined by Martin, Johnson, and Grant (1915), who presented the first systematic description of the Tertiary sedimentary rocks exposed on Kenai Peninsula. In the meantime, Martin and Katz (1912) mapped the Tertiary sedimentary rocks of part of the Matanuska Valley, subdividing them into the Chickaloon Formation and the Eska Conglomerate (of former usage). Floras from the Chickaloon Formation were diagnosed by Hollick (in Martin and Katz, 1912, p. 49–52) as "Arctic Miocene (Eocene)" and "probably Kenai." On this basis, Martin and Katz stated (p. 52): "The Chickaloon Formation is shown by its flora to be certainly Tertiary and probably Eocene. It is the local equivalent of at least part of the Kenai Formation of Cook Inlet and is the approximate equivalent of the Tertiary coal-bearing beds which are present in many parts of Alaska." Martin and Katz found no diagnostic fossils in their Eska Conglomerate; they stated (p. 54) that "the only conclusion that can be drawn regarding its age is that it is certainly Tertiary and is possibly the equivalent of the Miocene conglomerates that have been recognized at several places along the Pacific coast of Alaska."

The name "Kenai flora" continued for many years to be applied to Tertiary floras far beyond the limits of the Kenai Peninsula, but the name "Kenai Formation" gradually became restricted to Kenai Peninsula. Smith (in Hollick, 1936, p. 28) stated, for example, that "the name Kenai has been restricted to its more usual formational sense and limited to beds directly connected with the Kenai beds in the type area [on Kenai Peninsula]."

Hollick, in 1936 in his exhaustive monograph on the Tertiary floras of Alaska, continued to treat all Alaskan floral material as though it were synchronous in age, saying (p. 21, 23):

> The most obvious fact in connection with the general facies of the flora is its unmistakable identity with the so-called Arctic Miocene flora of British America (Northwest Territory), Greenland, Iceland, Svalbard (Spitsbergen), New Siberia, Sakhalin, and elsewhere in the holarctic region. This flora is now recognized as Eocene and is believed to be approximately equivalent to the flora of the Fort Union and allied formations in the United States and the Canadian Provinces.
>
> * * * * *
>
> In view of the facts above set forth the general similarity of the Alaska Tertiary flora to that of the Eocene in the States proper would appear to be demonstrated; but it may be objected that certain of the listed species also occur in strata more recent than the Eocene, that this fact has been ignored in the discussion of distribution and stratigraphy, and that these species might indicate a later than Eocene age for the flora. Inasmuch, however, as such species are relatively few, and as certain of the Eocene species apparently persisted throughout Tertiary time and are represented in our existing flora, it would be logical to infer that many species persisted into later Tertiary time before becoming extinct and would therefore be recognized as elements in Oligocene, Miocene, and Pliocene floras.

Doubts were expressed as early as 1906 (Brooks, p. 238) that rocks containing the so-called Kenai flora were all of the same age:

> At the type locality the Kenai is made up of only slightly indurated or entirely unconsolidated beds. The same terrane has, however, been identified in much more highly altered rocks which carry plant remains and also coal, such as those of Controller Bay, Matanuska River, and Cantwell River. These facts are difficult to reconcile, and it appears that the deciphering of the Alaska Tertiary stratigraphy must await further investigations. It seems at least possible that the Kenai series of the Pacific littoral may include horizons younger or older than the Upper Eocene, and in any event that all the coal-bearing beds of the Pacific coast province are not synchronous deposits.

Brooks' doubts in 1906 were eventually confirmed by Barnes and Payne (1956) in a detailed study of the Tertiary sedimentary rocks exposed in the Wishbone Hill district of the Matanuska Valley. Their careful mapping showed that the Eska Conglomerate of Martin and Katz (1912) actually consists of two units separated by an angular unconformity and having contrasting degrees of lithification and structural complexity. Barnes and Payne (1956) proposed the name Wishbone Formation for the lower unit, which rests unconformably upon the Chickaloon Formation, and the name Tsadaka Formation for the less consolidated and less deformed upper unit; the name Eska Conglomerate was abandoned. They reasoned on structural and paleogeographic grounds that the Chickaloon and Wishbone Formations are probably of Paleocene age. The Tsadaka Formation was thought to be Eocene or younger and to be correlative with the Kenai Formation.

Knowlton evidently had come to have some reservations around the turn of the century about the homogeneity of the so-called Kenai flora and about the equation "Arctic Miocene=Eocene." This doubt is shown by the presence of the word "Oligocene" in his handwriting on the labels of some of the Alaskan Tertiary fossil plant collections in the U.S. National Museum. R. W. Brown, U.S. Geological Survey paleobotanist from 1929 to 1959, also had occasionally expressed his belief, in conversations, that floras of other than Eocene age probably were included in the collections. However, Brown never undertook the thorough restudy of the Alaskan Tertiary fossil floras that would have been required to revise and refine their age assignments. Consequently, the Kenai Formation was still assigned to the upper part of the Eocene Series by Barnes and Cobb (1959) in their careful restudy of the stratigraphy of the Tertiary rocks in the Homer district.

Wolfe began a systematic reconsideration of the Alaskan Tertiary floras in 1960; some preliminary results were announced by MacNeil, Wolfe, Miller, and Hopkins (1961). They noted that the dating of plant-bearing Tertiary beds in Alaska has been hampered by Gardner's old and still unproven concept of the "Arcto-Tertiary" flora and said, (p. 1802):

> However, evaluation by Wolfe of new and old plant collections from Alaskan rocks whose age is determined by marine invertebrates clearly shows that floras of the same age in Alaska and in Oregon or Washington are similar on the specific level. In fact, except for the ubiquitous and long-ranging conifers such as *Metasequoia*, there is not one species known in both the Eocene flora of Alaska and the Miocene flora of Oregon. Even on the generic level, there is little resemblance between these two floras. Nearly all of the so-called "Arcto-Tertiary" genera are typical of the Oligocene and Miocene Alaskan floras rather than the Eocene.

The preliminary study of the floras reported by MacNeil, Wolfe, Miller, and Hopkins (1961) led to the conclusion that floras from Port Graham and Cache Creek (representing the Seldovian Stage of the present paper) are "no older than late Oligocene." Studies of Hollick's illustration led to the tentative conclusion that floras from the Kenai Formation at Homer (representing the Homerian Stage of this report) were correlative with those found in the *Acila shumardi* zone of the Alaska Peninsula and thus of Oligocene age. Pollen studies by Paul Wesendunk were cited as demonstrating that the Tsadaka Formation is equivalent to some part of the Kenai Formation. The Chickaloon Formation was thought to be of middle and early Eocene and possibly in part of Paleocene age. The preliminary conclusions reached in 1961 are revised and refined in the present report.

Recent exploration for petroleum and natural gas has shown that the Tertiary sequence reaches thicknesses probably exceeding 18,000 feet and possibly reaching 25,000 feet in some parts of the Cook Inlet lowland (Kelly, 1963; Hill, 1963, 1966; Hazzard and others, 1963). Petroleum geologists commonly apply the name "Kenai Formation" to the entire Tertiary sequence in the Cook Inlet-Susitna Lowlands and the part of the Matanuska Valley that lies west of Moose Creek, although the sequence is said to contain at least two unconformities (Hazzard and others, 1963), to include at least five thick sedimentary sequences of contrasting lithology (Kelly, 1963), and to include basal beds thought to be of Paleocene age (Hazzard and others, 1963; Hill, 1966).

In this report, we shall follow the current practice of applying the name Kenai Formation to all beds in the Cook Inlet region that are or were probably once physically continuous with the beds of the Kenai Formation exposed in the type area. The name Tsadaka Formation is, however, retained for those beds in the Wishbone Hill district to which the name Tsadaka Formation was given by Barnes and Payne (1956). We wish to emphasize that other workers (Kelly, 1963; Hill, 1963, 1966; Barnes, 1966) have recognized several thick and distinctive lithologic units within the Kenai Formation. Further stratigraphic studies will probably result in the naming of several of these lithologic units as formations and thus in raising the Kenai Formation once again to group status. The paleobotanical studies reported here demonstrate that the Tsadaka Formation is equivalent to only a part of the present Kenai Formation; thus the Tsadaka Formation probably will eventually become a formation within a "Kenai Group."

The floras reported here from the Kenai and the Tsadaka Formations indicate that the enclosing beds are mostly of Miocene and Pliocene age, although some beds of latest Oligocene age may be included. Floras from the Chickaloon Formation indicate that the enclosing beds are of Paleocene age. The Chickaloon and Wishbone Formations lie unconformably below the Tsadaka Formation and contrast sharply with the Tsadaka in degree of lithification and complexity of structure. We suggest, therefore, that any beds in the subsurface that can be demonstrated to be of Paleocene or Eocene age should be referred either to the Chickaloon or the Wishbone Formations unless they can be shown to lie conformably and gradationally beneath those parts of the Kenai Formation that contain Neogene (Miocene and Pliocene) floras.

GEOLOGY

Most of the Cook Inlet region is underlain by igneous, volcanic, and sedimentary rocks of Mesozoic age; these rocks constitute the basement upon which the Tertiary sediments were deposited. The Matanuska Formation, the youngest part of the Mesozoic sequence, ranges in age from Albian to Maestrichtian(?) (Grantz and Jones, 1960); it consists mostly of clastic marine sediments. The Arkose Ridge Formation, which crops out in the southern Talkeetna Mountains just north of the Matanuska Valley, consists of coarse-grained clastic nonmarine sedimentary rocks of Albian or possibly Cenomanian age; it is possibly correlative with mollusk-dated marine beds in the lower part of the Matanuska Formation (Grantz and Wolfe, 1961).

The Tertiary sequence includes two older and more strongly lithified formational units—the Chickaloon Formation and the Wishbone Formation—and two younger and weakly lithified formational units—the Kenai Formation and the Tsadaka Formation. The Wishbone Formation rests conformably upon the Chickaloon Formation; both formations were deformed prior to deposition of the Kenai and Chickaloon Formations. The Tsadaka Formation rests with angular unconformity upon the Wishbone and Chickaloon Formations, and it evidently interfingers laterally with beds that are low in the Kenai Formation.

The Chickaloon Formation is intruded by numerous dikes, stocks, and large sills in the eastern part of the Matanuska Valley. No intrusive rocks have been seen in the Wishbone Formation, but a small dike intrudes the overlying Tsadaka Formation at the eastern end of its outcrop area (Barnes and Payne, 1956, p. 23 and pl. 2). At Castle Mountain basaltic lava flows rest unconformably upon conglomerate customarily correlated with the Wishbone Formation (Barnes, 1962a).

The Tertiary sequence is covered throughout much of the Cook Inlet region by glacial drift of late Pleistocene age. The glacial cover is so extensive that exposures of the Tertiary rocks are largely limited to sea bluffs and to the walls of sharply cut stream valleys.

PALEOGENE STRATIGRAPHY

CHICKALOON FORMATION

The Chickaloon Formation, named by Martin and Katz (1912), consists of a sequence of nonmarine clastic sedimentary rocks at least 5,000 feet thick that is exposed in many places in the Matanuska Valley between Hicks Creek and Moose Creek (fig. 3). The formation is covered by younger Tertiary sediments west of Moose Creek, and the western limits of its distribution are not known.

The Chickaloon Formation appears to rest unconformably upon the Matanuska Formation of Cretaceous age in exposure on Anthracite Ridge (Waring, 1936, p. 11–12, 17) and in the valley of Wolverine Creek (Grantz and Wolfe, 1961, p. 1765); it may lie conformably upon the Matanuska Formation near the mouth of Moose Creek and in the Knob Creek area (Barnes, 1962b). The Chickaloon Formation is conformably overlain by the Wishbone Formation.

Small stocks, large sill-like bodies, and narrow dikes intrude the Chickaloon Formation. These intrusive bodies are especially abundant in the eastern part of the Matanuska Valley; they are rare in the Moose Creek-Eska Creek area (Barnes, 1962a).

The Chickaloon Formation consists of interbedded claystone, siltstone, feldspathic sandstone, and conglomerate and includes many beds of bituminous coal in the Moose Creek, Eska Creek, and Chickaloon areas. Most of the coal beds in the Moose Creek-Eska Creek area are in the upper 1,400 feet of the formation (Barnes and Payne, 1956, p. 14); those in the Chickaloon area appear to lie about midway between the top and bottom of the formation (Capps, 1927, p. 42). Carbonate concretions and thin beds of fresh-water limestone are scattered throughout the formation.

Thick beds of conglomerate are a major component of exposures of the lower part of the Chickaloon Formation near the Chugach Mountain front in the vicinity of Wolverine Creek and along the base of Arkose Ridge northwest of Moose Creek, but conglomerate beds are scarce in the lower part of the Chickaloon Formation adjoining the Castle Mountain fault northeast of Moose Creek (Barnes, 1962a, Barnes and Payne, 1956, p. 15). The basal part of the formation in the Anthracite Ridge area consists of thick-bedded greenish-gray sandstone and a poorly defined pebbly sandstone which may represent a basal conglomerate containing well-rounded pebbles of quartz and chert in some places and angular pebbles of shale presumably derived from the Matanuska Formation in others (Waring, 1936, p. 12–13). Higher parts of the Chickaloon Formation contain only a few lenses of pebble conglomerate that grade laterally into pebbly sandstone. Pebbles in the conglomerate beds consist mostly of quartz, chert, and fine-grained igneous and metamorphic rocks. Pebbles of granitic rocks are scarce or entirely lacking in most exposures; however, some of the conglomerate beds exposed northwest of Wolverine Creek are rich in granitic pebbles

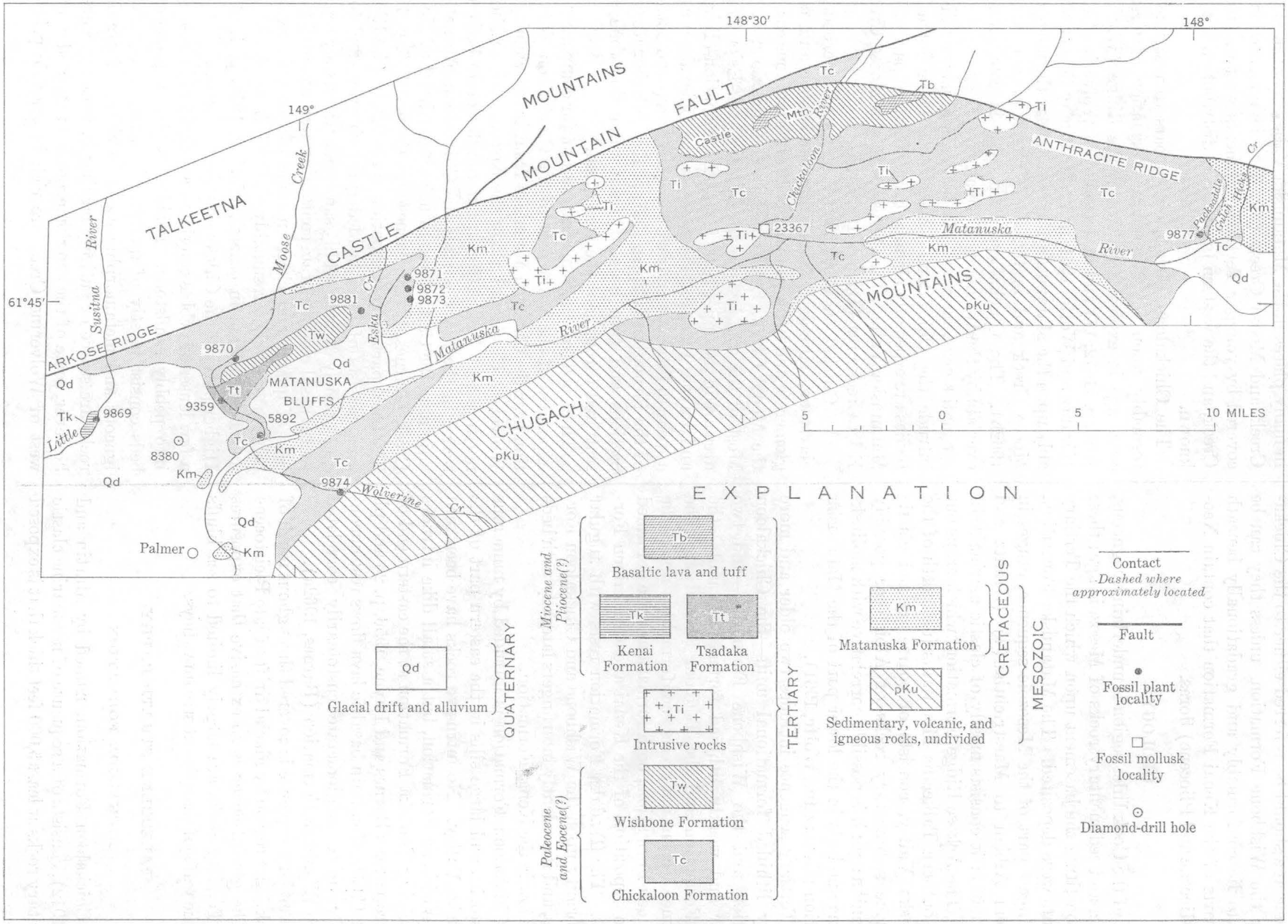

FIGURE 3.—Generalized geologic map of the Matanuska Valley showing approximate extent of Tertiary sedimentary rocks and localities of fossil plants and mollusks. Modified from Capps (1927), Grantz and Jones (1960), Barnes and Payne (1956), and Barnes (1962a).

(F. F. Barnes, unpub. data), and the Tertiary rocks exposed in Fishhook Canyon of the Little Susitna River just south of the Castle Mountain fault consist mostly of conglomerate rich in granitic pebbles and cobbles. Barnes (1962a) mapped the granite-rich conglomerate in Fishhook Canyon as representing a western extension of the Chickaloon Formation. This interpretation is adopted on figure 3, but the granite-bearing conglomerate in Fishhook Canyon may represent the basal part of the Neogene sequence and may be an extension of the Tsadaka Formation.

Barnes and Payne (1956, p. 44) suggested that the Chickaloon Formation was derived from areas far to the north of the present northern margin of the Matanuska Valley. The abundance of coarse-grained conglomerate in exposures of the Chickaloon Formation adjacent to the Chugach Mountain front suggests that the Chugach Mountains may also have been a major source of sediment during Chickaloon time.

FLORA AND AGE

We have obtained megafossil floras from the following locations: the coal-bearing sequence exposed in strip-mining pits in the Moose Creek, Eska Creek, and Knob Creek areas (locs.[1] 9870–9873 and 9881, table 1 and fig. 3); beds exposed in the bluffs along the north bank of the Matanuska River just west of the mouth of Moose Creek (loc. 5892); the canyon of Wolverine Creek (loc. 9874); and beds exposed along the old alinement of the Glenn Highway just west of Packsaddle Gulch (loc. 9877). The flora from locality 9870 was obtained from the Burning Bed coal group, and the flora from locality 9881 is a composite collection from several horizons within and between the Premier and Jonesville coal groups; these floras represent the upper 800 feet of the Chickaloon Formation (Barnes and Payne, 1956, pl. 6). The floras obtained from strip-mining pits at localities 9872–9874 are in a structurally complex area in which individual coal groups cannot be continually traced (Barnes, 1962b), but the floras are thought to represent the same interval. The Matanuska Bluffs flora was obtained at the base of a 1,500-foot sequence that probably lies entirely below the coal-rich upper part of the

[1] All locality descriptions are given under sections on "Fossil-plant localities" and "Fossil-mollusk localities." In this report 4-digit numbers are USGS Paleobotany localities (except locs. 10002 and 10003); 4-digit numbers preceded by the letter "D" are USGS localities, Denver catalog; and 5-digit numbers are USGS Cenozoic localities.

TABLE 1.—*Partial checklist of flora from Chickaloon Formation in Alaska, showing occurrences of species in other selected areas*

[Generic names in quotation marks indicate that the species are invalidly assigned to those genera]

Species	Chickaloon Formation — Locality 9877	9874	5892	9881	9870	9873	9872	9871	Chignik Bay, Alaska Peninsula	Hamilton Bay, Kupreanof Island, southeast Alaska	Fort Union Formation, High Plains	Upper Atanikerdluk flora, Greenland
Anemia elongata (Newb.) Knowl	×										×	
Dennstaedtia americana Knowl						×					×	×
Hymenophyllum confusum Lesq	×										×	
Onoclea hesperia R. W. Br						×	×	×		×	×	×
Osmunda macrophylla Penh				×							×	
Glyptostrobus nordenskioldi (Heer) R. W. Br		×	×	×	×	×		×	×	×	×	×
Metasequoia occidentalis (Newb.) Chan		×	×	×	×	×	×	×	×	×	×	×
Alismaphyllites grandifolius (Penh.) R. W. Br				×				×			×	
Carya antiquora Newb				×	×		×	×	cf.	×	×	
Pterocarya sp					×							
Comptonia sp				×				×				
Corylites fosteri (Ward) Bell		×	×	×							×	cf.
Quercophyllum groenlandicus (Heer) Koch			×						×		×	×
"*Planera*" *microphylla* Newb			×	×		×		×		×	×	
Cocculus flabella (Newb.) Wolfe		×		×	×	×	×	×	×		×	×
Trochodendroides serrulata (Ward) Wolfe					×		×		×		×	cf.
Hamamelites inaequalis (Newb.) R. W. Br				×								
Sinowilsonia sp		×		×	×		×					
Macaranga sp				×								
sp				×								
"*Pterospermites*" sp. cf. "P." *dentatus* Heer				×								
Melanolepis sp				×								
"*Sapindus*" *affinis* Newb			×	×	×	×		×			×	
Acer sp					×							
Decostea sp				×	×	×	×					
"*Piper*" *chapini* Holl				×								
Grewiopsis auriculaecordatus (Holl.) Wolfe		×		×	×	×	×		×	×	×	×
Dicotylophyllum alaskanum (Holl.) Wolfe				×	×		×			×		cf.
Dicotylophyllum flexuosa (Newb.) Wolfe			×	×					×	×	×	cf.
Dicotylophyllum richardsoni (Heer) Wolfe				×	×		×				×	×

Chickaloon Formation represented by the floras from the strip-mining pits (Barnes and Payne, 1956, pl. 6), although the actual height of the horizon above the base of the Chickaloon Formation is unknown. The Wolverine Creek flora was collected in a siltstone bed interstratified with conglomerate and lying about 1,000 feet above the base of the Chickaloon Formation. The stratigraphic position of the Packsaddle Gulch flora is unknown.

The discussion that follows is based on a study of some of the elements in these floras. We also obtained small megafossil floras from several localities in the Chickaloon River area, but these localities have not added any species not recognized in the Matanuska Bluffs and Wishbone Hill material and are not discussed here. Pollen floras recovered from the Chickaloon Formation thus far are small and poorly preserved; they have been given only a cursory examination and are not discussed here.

The most diverse and best preserved floras in the Chickaloon Formation are those that occur in the upper part in the Moose Creek-Eska Creek-Knob Creek area. These floras have many species in common, and some of these species are diagnostic of Paleocene floras in other parts of the world. The Matanuska Bluffs and Wolverine Creek floras do not differ greatly from floras in the upper part of the Chickaloon Formation and also contain some diagnostic Paleocene species. The Packsaddle Gulch flora is considerably different from the other floras, but it contains at least two ferns known from the Fort Union Formation of Paleocene age in the northern Great Plains. Thus, the Chickaloon Formation appears to be entirely of Paleocene age.

Several of the most characteristic species of the Chickaloon flora are listed in table 1. As can be seen from that table, many of these forms are widely distributed in Paleocene rocks. *Dennstaedtia americana*, *Onoclea hesperia*, *Trochodendroides serrulata*, "*Planera*" *microphylla*, *Carya antiquora*, *Quercophyllum groenlandicus*, *Dicotylophyllum flexuosa*, *Anemia elongata*, and *Hymenophyllum confusum* are restricted to beds of Paleocene age outside of Alaska and thus are valuable indices to this epoch.

The Paleocene floras that most resemble the Chickaloon flora are the Fort Union flora of the northern Great Plains (Brown, 1962) and the Upper Atanikerdluk flora of northwestern Greenland (Heer, 1868). The Paleocene age of the Fort Union Formation is well established on the basis of fossil mammals (Wood and others, 1941), and the Atanikerdluk flora is well dated by its stratigraphic relationship with beds containing a rich marine molluscan fauna of early Paleocene age (Koch, 1959, 1963). The general aspect of the Chickaloon and Atanikerdluk floras is similar, and at least 10 species are common to both floras. The resemblance between the Chickaloon and the Fort Union floras is considerably stronger. Of the 36 well-defined species reported here from the upper part of the Chickaloon Formation, 18 are also known from the Fort Union. None of the species that occur in the Chickaloon Formation contradict a Paleocene age.

In the latest correlation chart of the Alaskan Tertiary (MacNeil and others, 1961) rocks of Paleocene age were definitely recognized only in the Sagavanirktok Formation north of the Brooks Range, but the present study has resulted in the recognition of the Paleocene Series in several other areas in Alaska. The fossil floras from Hamilton Bay on Kupreanof Island in southeastern Alaska (locs. 3652, 4389, 4391, 4392, 7474, 7565) and from Chignik Bay (locs. 3519, 3522, 3523) on the south side of the Alaska Peninsula contain several species also found in the Chickaloon Formation (table 1). The Chignik Bay collections came from a series of rocks that rest with an angular unconformity on the Campanian and Maestrichtian (Late Cretaceous) Chignik Formation (C. A. Burk, oral commun., May 1963). Much of the Tertiary sequence in the Eagle-Circle district in east-central Alaska is also probably of Paleocene age (locs. 8680, 8681).

The Chickaloon floras probably grew in a subtropical or warm-temperate climate. Although the questionable familial relationships of many of the Chickaloon genera make it difficult to draw conclusions from Recent distributions, almost 50 percent of the Chickaloon species has entire margins, indicating a warm-temperate or a subtropical climate. *Dennstaedtia*, *Macaranga*, *Melanolepis*, and the fan palms grow today in warm climates. The presence of *Metasequoia*, *Carya*, and *Acer* does not contradict this conclusion; the distributions of both living and fossil species of these genera indicate that all have been represented in subtropical and warm-temperate floras during some part of Cenozoic time.

FRESH-WATER MOLLUSKS

Fossil fresh-water mollusks were found in the Chickaloon Formation in several places, but only those from USGS Cenozoic locality 23367 on the Chickaloon River were preserved well enough for identification. D. W. Taylor determined the following gastropods: *Bellamya westoni* (Tozer) ?; *Campeloma edmontonense* Tozer; Thiaridae?, indeterminate.

The two forms identified to species are previously known only from Maestrichtian beds in western Alberta but, according to Taylor, could well have longer time ranges. Ecologically, the mollusks add little information; both genera have extant species that live in warm-temperate to tropical climates.

WISHBONE FORMATION

The Wishbone Formation, named by Barnes and Payne (1956), consists of a sequence 2,000 to 3,000 feet thick of coarse-grained clastic nonmarine sedimentary rocks exposed at Wishbone Hill (between Moose Creek and Eska Creek) (fig. 3). The Wishbone Formation rests conformably and gradationally upon the Chickaloon Formation. It "consists chiefly of conglomerate, but includes many interbeds of crossbedded feldspathic sandstone, a few lenticular beds of siltstone, and some claystone. The conglomerate consists of firmly cemented pebbles of fine-grained igneous and metamorphic rocks, chert, vein quartz, and jasper in a sandy matrix" (Barnes, 1962a). Pebbles of granitic rocks are scarce. Barnes (1962a) assigned conglomerate beds overlying the Chickaloon Formation at Castle Mountain to the Wishbone Formation, although, because fossils are lacking, the possibility cannot be excluded that these beds are more nearly correlative with the Miocene Tsadaka Formation. At Castle Mountain, the conglomerate assigned to the Wishbone consists of "alternating beds of conglomerate 5 to 50 feet or more in thickness and arkosic sandstones that range from a few inches to 40 feet. The basal portion of the conglomerate is coarse and contains pebbles as much as a foot in diameter. The pebbles consist mainly of igneous materials, including acidic porphyry, fine-grained basic rocks, granite, and diorite, as well as quartz, greenstone, and metamorphic rocks of various types" (Capps, 1927, p. 45).

The Wishbone Formation and the overlying Tsadaka Formation were originally included in the Eska Conglomerate of Martin and Katz (1912), but Barnes and Payne (1956) showed that the two formations differ in degree of lithification and structural complexity, that granitic pebbles are scarce in the Wishbone Formation at Wishbone Hill and abundant in the Tsadaka Formation, and that the two formations are separated by an angular unconformity. The Wishbone Formation has not yielded identifiable fossils; however, it is thought to be at least partly of Paleocene age because it rests conformably and gradationally upon the Chickaloon Formation. Some Eocene rocks may also be included. The Tsadaka Formation is of Miocene (Seldovian) age, as is shown in later paragraphs.

NEOGENE STRATIGRAPHY

KENAI AND TSADAKA FORMATIONS

The Kenai and Tsadaka Formations occupy a roughly elliptical basin (the Shelikov trough of Payne, 1955) extending from the vicinity of the Peters Hills southward to and beyond Seldovia and Cape Douglas (pl. 1). The Kenai Formation consists chiefly of sandstone, siltstone, and claystone in the central part of the basin and also in some marginal areas. Coal or lignite beds are extremely abundant in some parts of the sequence. Beds and lenses of pebbly sandstone or pebble conglomerate are scattered sparsely through the sequence throughout the basin. The Tsadaka Formation consists chiefly of conglomerate and coarse-grained sandstone in the Wishbone Hill district, but Barnes and Payne (1956) also referred to the Tsadaka Formation a 1,000-foot sequence of predominantly sandy-textured rocks containing only a few interbeds of conglomerate found in exploratory holes drilled by the Geological Survey in 1932 about a mile west of the head of Tsadaka Canyon (Waring, 1934). The paleobotanical studies described in this report confirm that the beds found in the Geological Survey drill holes are approximately the same age as the Tsadaka Formation.

The thick conglomerate sequence of the Tsadaka Formation constitutes a major part of the Neogene section at the margin of the basin in the Wishbone Hill district, and thick unnamed sequences of conglomerate are present in the Kenai Formation—possibly at several stratigraphic levels—in a marginal belt extending along the west edge of the Cook Inlet region from the vicinity of the Peters Hills southward to at least the vicinity of Chinitna Bay. Conglomerate beds form a relatively minor part of the Kenai Formation in exposures along the south shore of Kachemak Bay. No published information is available concerning the lithology of the Kenai Formation at the perimeter of the basin in other areas.

The best exposures of the marginal parts of the Kenai Formation are those found in several places along the south shore of Kachemak Bay between Port Graham and a point 5 miles northeast of Seldovia. Sedimentary rocks of the Kenai Formation there bury a rugged topography carved in sedimentary and volcanic rocks of Jurassic age and having a local relief of at least 100 feet. The small exposures of the Kenai Formation between Seldovia and Port Graham consist of places where the present shoreline intersects a narrow, steep-walled northeast-trending canyon cut in the Jurassic rocks and subsequently filled with Neogene clastic sediments (pl. 1); the exposures northeast of Seldovia apparently represent material filling a somewhat larger erosional valley or basin to which the buried canyon may have been tributary. The Neogene clastic sediments in these exposures along the south shore of Kachemak Bay consist of sandstone, siltstone, and claystone with a few thin lignite beds. These grade into masses of conglomerate and taluslike or colluviumlike breccia in zones a few tens to a few hundreds of feet wide adjoining the buried slopes carved in the Jurassic rocks. These relationships are well illustrated in figures 1 and 2 of Martin, Johnson, and Grant (1915) although these authors interpreted as fault breccia the fossil talus or colluvium shown near the left and right margins of their figure 2.

In the western Matanuska Valley and along the west margin of the Cook Inlet region, thick masses of Neogene conglomerate adjoin modern steep mountain slopes underlain by older rocks. The presence of this conglomerate and of rugged topography buried beneath sediments of the Kenai Formation near Seldovia suggests that the original basin in which the Neogene rocks were deposited may not have been much larger than the area presently underlain by the Kenai and Tsadaka Formations.

Kelly (1963) distinguished five lithologic zones in wells penetrating the Kenai Formation in the central part of the basin. From top to bottom, these include his zone 1, about 5,000 feet thick, composed of massive sand beds; zone 2, several thousand feet thick, composed of sandstone, shale, and lignite; zone 3, several thousand feet thick, composed of siltstone, shale, and low-rank coal; zone 4, the "Hemlock producing zone" of local petroleum geologists, composed chiefly of conglomerate and sandstone and having a total thickness of about 700 feet; and zone 5, consisting of several hundred feet of siltstone and shale.

Hill (1963, p. 197) indicated that the upper massive sand sequence (Kelly's zone 1) is characterized by pollen assemblages rich in birch and alder and that the sandstone, shale, and lignite or coal sequence below (Kelly's zones 2 and 3) is characterized by pollen assemblages containing elm and hickory. Kelly's zone 1 of massive sand beds contains several large accumulations of methane gas on both the east and west sides of Cook Inlet (Kelly, 1963); gas has also been obtained in a thick sandstone zone within Kelly's zone 2 (Hill, 1963, p. 197). Kelly's zone 4, the "Hemlock producing zone," yields petroleum in the Swanson River oil field of northwestern Kenai Peninsula and in several newly discovered oil fields on and near the northwest shore of Cook Inlet. Kelly suggested that the "Hemlock producing zone" corresponds to the Chickalon Formation, and Hill assigns a Paleocene(?) age to some part of the Kenai Formation found in the subsurface, but no paleontological substantiation for these age assignments has been published.

Sections of thick sequences of Neogene rocks based on surface exposures have been measured for the Kenai Formation only in the area between Swift Creek and Clam Gulch by Barnes and Cobb (1959). They have described a stratigraphic section approximately 5,000 feet thick in the area extending eastward from Anchor Point along the north shore of Kachemak Bay and another stratigraphic section approximately 2,000 feet thick in exposures along the east shore of Cook Inlet between Cape Starichkov and Clam Gulch. Their Cape Starichkov-Clam Gulch measured section lies mostly above their Kachemak Bay measured section, but the lower part may include some rocks correlative with the highest part of the Kachemak Bay measured section. The Kachemak Bay measured section consists of a lower, predominantly fine-grained sequence in which the clastic beds are strongly lithified and the organic beds consist of subbituminous coal and an upper sandy sequence in which the clastic beds are only weakly lithified and in which the organic beds consist of lignite. Only the weekly lithified sandy and lignitic sequence is represented in the Cape Starichkov-Clam Gulch measured section. Lithologic comparisons, comparisons in the rank of coal beds (Barnes, 1962c), and comparison with the character of the pollen floras summarized by Hill (1963) all suggest that Barnes and Cobb's upper weakly lithified sandy and lignitic sequence corresponds to Kelly's zone 1 and Hill's "birch-alder zone." Barnes and Cobb's lower well-lithified coaly sequence probably corresponds to Kelly's zone 2 and part of his zone 3 and to part of Hill's "elm-hickory zone."

STRUCTURE AND TECTONICS

The boundaries of the area underlain by Tertiary rocks in the Cook Inlet region (pl. 1) appear in most places to represent the outcrop of the unconformity that separates the Neogene sequence from older rocks. However, the basin is bounded by the Castle Mountain fault along the north side of the western Matanuska Valley and by minor faults in several other localities. A major fault may also constitute the south boundary of the basin between Knik Arm and Kachemak Bay. In that area, a nearly linear escarpment that is probably a fault scarp separates the pre-Tertiary rocks exposed in the rugged Kenai-Chugach Mountains from the lowlands to the northwest which are apparently underlain by the Kenai Formation.

The basin containing the Kenai Formation is divided into a deep southeastern segment and a shallow northwestern segment by a major structural discontinuity consisting of the Bruin Bay fault, the Moquawkie magnetic contact, and the part of the Castle Mountain fault that lies east of Theodore River (Grantz and others, 1963). Paleobotanical correlations suggest that areas south and east of this major structural discontinuity were subsiding much more rapidly than areas to the north and west while the Neogene sedimentary rocks were accumulating because the individual provincial stages defined in this report appear to be represented by much thicker stratigraphic sequences south and east of the discontinuity than to the north and west. The Bruin Bay fault and the Moquawkie magnetic contact may no longer be active structural features, but the part of the Castle Mountain fault that lies east of Theodore River has undergone movement within late Quaternary time; its trace across the Susitna valley is marked in many places by scarplets that transect morainal features of the Naptowne ("classical" Wisconsin) Glaciation (Karlstrom, 1964).

Superimposed upon the major basinal structure are several broad, gentle northeast-trending folds having a structural relief of several thousand feet. Dips on the flanks of these folds as seen in surface exposures and in published cross sections of subsurface structural features (Parkinson, 1962; Hill, 1963) are generally less than 10°. The larger folds northwest of the Castle Mountain-Moquawkie-Bruin Bay structural discontinuity are expressed in the landscape by large, rounded mountains such as Mount Susitna and the Peters Hills (pl. 1) that are composed of pre-Tertiary rocks and that represent the exhumed cores of anticlines involving the Neogene rocks. Comparable folds are present in the deeper part of the basin to the southeast of the Castle Mountain-Moquawkie-Bruin Bay structural discontinuity, but their cores remain deeply buried beneath a thick cover of Neogene and Quaternary sediments (Kelly, 1963). Some of these folds were already growing while the Kenai Formation was accumulating. Detailed correlations between development wells in the Swanson River oil field show that individual stratigraphic units thin over the crest of the low anticline there (Kelly, 1963, p. 296; Parkinson, 1962, p. 182). Topographic anomalies on surfaces underlain by sediments of Quaternary age suggest that some of the anticlines may still be active (Kelly, 1963, fig. 9; Hill, 1963).

Smaller folds and small high-angle faults are superimposed upon the larger structural features in some areas. Small, steep, closely spaced folds in the Kenai Formation exposed in Cache Creek valley near localities 9867 and 9868 (pl. 1) may represent landslide masses. Barnes (1966) noted similar small areas of extremely disturbed structural features along the walls of valleys cut deeply into the Kenai Formation northwest of Cook Inlet. Elsewhere, the small faults that cut the Kenai Formation typically have displacements of no more than a few tens of feet. Minor faults in the Swanson River oil field appear to show increasing displacements with increasing depths (Parkinson, 1962, p. 182). This observation suggests that the faults were developing while the Kenai Formation was being deposited as was the major anticline upon which they are superimposed.

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PROVINCIAL STAGES

Surface exposures of the Kenai Formation contain abundant fossil leaf floras of varied character. Some of the differences among the local fossil leaf floras reflect differences in the ecological conditions that prevailed nearby when the enclosing sediments were deposited. For example, fossil floras collected in the central part of the basin are generally poorer in species and genera than fossil floras collected at approximately the same stratigraphic level near the margin of the basin. Floras from the central part of the basin consist largely of taxa whose nearest living relatives thrive in pond, swamp, and flood-plain enviroments; floras collected nearer the basin margin contain a better representation of the taxa that grew best in the varied sites available in a well-drained environment. However, certain consistent differences among the local fossil leaf floras are clearly correlated with differences in stratigraphic position within the Kenai Formation and are thought to reflect differences in the age of the enclosing beds. For example, beds low in the exposed part of the Kenai Formation contain leaves of species of *Alnus* and *Salix*, among other genera, that appear to be ancestral to some of the species of *Alnus* and *Salix* represented by leaves in higher beds of the formation. Beds low in the exposed part of the formation contain varied floras of a generally warm-temperate character, but beds high in the formation contain floras closely related to the present depauperate Hudsonian and Boreal forest of southern and central Alaska.

Pollen floras obtained from the Kenai Formation also show differences that are correlated with approximate stratigraphic position and that therefore reflect evolutionary changes in the regional vegetation, as well as differences that can be correlated with geographic position within the basin. Differences due to geographic position are less conspicuous in the pollen floras than in the leaf floras because some pollen types can be transported long distances by wind; consequently, upland plants are commonly represented by a few pollen grains in samples from positions in the central part of the basin where leaves of upland plants are entirely lacking in the megafossil collections. In spite of this fact, the pollen floras are less useful than the leaf floras for age determination because pollen grains generally can only be distinguished at the generic level, whereas well-preserved leaves can generally be distinguished at the species level. Our age determinations based on pollen samples taken from the Kenai Formation during the present study must depend more upon the abundance and variety of exotic genera than upon the presence or absence of taxa known to have a narrowly restricted stratigraphic range. Furthermore, pollen grains are readily eroded and redeposited, and reworked pollen grains commonly are not distinguishable from grains derived from plants living at the time that the enclosing sediments were deposited. Consequently, the presence at a given stratigraphic level of single grains of pollen of exotic taxa cannot be interpreted confidently as evidence that those taxa were living in the area when the enclosing beds were laid down. In spite of these reservations, our preliminary palynological studies generally have confirmed and amplified the stratigraphic results of our studies of the megafossil floras.

Three time-stratigraphic units can be recognized within the Kenai Formation on the basis of the fossil leaf floras they contain. The lowest of these three units contains widespread floras much like the floras contained in beds of comparable age in Oregon, Washington, and Japan; we can state confidently that this unit includes beds of early or middle Miocene age because its floras include taxa diagnostic of approximately the first half of the Miocene Series. Floras within the two higher time-stratigraphic units become increasingly provincial and are more difficult to place within the framework of Pacific Basin upper Miocene and Pliocene stratigraphy. Nevertheless, Neogene beds in many other areas in Alaska can be correlated with one or another of the three time-stratigraphic units recognized within the Kenai Formation because they contain similar floras. Thus, these three units provide a useful standard on which to base correlations and age assignments within Alaska and probably within adjoining parts of Siberia and northwestern Canada. For these reasons, the three time-stratigraphic units are defined and described on the following pages as the Seldovian (Oligocene? and Miocene), Homerian (Miocene and Pliocene?), and Clamgulchian (Miocene? and Pliocene) provincial stages.

The Tsadaka Formation contains a flora diagnostic of the Seldovian Stage, an indication that the formation is equivalent in age to the oldest part of the Kenai Formation found in surface exposures. The lowest part of the Kenai Formation penetrated in petroleum exploration wells, however, may consist of beds that are not present in any surface exposures from which we have floras and that may be appreciably older than the Seldovian Stage. Our paleobotanical studies indicate that beds belonging to the Seldovian Stage can be distinguished by their contained leaves from beds of Oligocene age on Sitkinak Island and in the Gulf of Alaska, as well as in Oregon and Washington (see Wolfe, 1966). Some of the lowest beds found in subsurface penetrations of the Kenai Formation may be of Oligocene age or older.

Seldovian Stage

DEFINITION

The Seldovian Stage is proposed as a provincial time-stratigraphic unit that encompasses all plant-bearing strata in Alaska and in adjoining parts of the same ancient floristic province that are of approximately the same age as those parts of the Kenai Formation represented in the type section along the Chuitna River and near Capps Glacier and in the reference section near Seldovia Point, 2 miles north of Seldovia. Rocks belonging to the Seldovian Stage are recognized primarily on the basis of the fossil floras that they contain. The stage is named after Seldovia Point because strata of the Kenai Formation exposed in sea cliffs ½ to 3 miles east of Seldovia Point on the south shore of Kachemak Bay contain an especially rich flora that includes most of the elements upon which recognition of the Seldovian Stage is based. These exposures, briefly described by Martin (in Martin and others, 1915, p. 82), do not display either the top or the bottom of the Seldovian Stage; they are therefore designated as a reference section rather than a type section. The type section of the Seldovian Stage is designated as the sequence of strata of the Kenai Formation that is exposed on the flanks of the ridge south of Capps Glacier and along the walls of the upper valley of the Chuitna River downstream to the position of our locality D1949 (pls. 1 and 2.)

The top of the Seldovian Stage is designated in the type section as lying at the level of the coal bed from which our pollen specimen D1949 was collected. This specimen contains a typical Seldovian pollen flora. A calcareous siltstone bed lying stratigraphically about 50 feet above this coal bed and represented by our locality 9844 contains a leaf flora typical of those contained in rocks of the Homerian Stage.

We are not prepared at this time to define the base of the Seldovian Stage with precision. Recognizably older floras are not known below the type section or in any other surface exposures of the Kenai Formation of which we are aware. On Sitkinak Island, however, fossil plants have been collected from a coal-bearing unit that conformably underlies marine rocks of earliest Miocene ("late Blakeley") age (G. W. Moore, written commun., Oct. 19, 1964; F. S. MacNeil, written commun., Sept. 12, 1962). A small collection in the possession of Mr. C. E. Nickles of King Salmon, Alaska, obtained from very near the highest part of the coal-bearing rocks, contains the characteristic lower(?) Seldovian species *Alnus evidens*. Another collection (loc. 10002), from about 2,000 feet stratigraphically below the Nickles locality, contains *Alnus* n.sp. aff. *A. evidens*.

A third collection (loc. 10003) comes from a locality that is thought to be at or below the horizon of locality 10002; this third collection contains *Alnus n.*sp. aff. *A. evidens*, *Carpinus* n.sp. aff. *C. cappsensis*, and *Cercidiphyllum crenatum.* The first two species are related and probably ancestral to species that we consider to be diagnostic of the Seldovian Stage. Thus, the Nickles collection is placed in the lower(?) Seldovian, but the two lower collections (10002, 10003) are considered to be pre-Seldovian. A more precise definition of the position of the base of the Seldovian Stage must await additional collecting.

FLORA

Strata assigned to the Seldovian Stage in various parts of the Cook Inlet region have thus far yielded 76 species of plants based on fossil leaves (table 2) and 25 pollen and spore forms representing at least 14 angiosperm genera and 19 families of tracheophytes. The leaf and pollen floras are typical of the "Arcto-Tertiary" flora and are characterized by taxonomic richness, especially in the deciduous dicotyledon groups such as Salicaceae, Juglandaceae, Betulaceae, Fagaceae, Ulmaceae, and Aceraceae.

The following significant megafossil species appear to be restricted to the Seldovian Stage: *Salix inquirenda*, *Alnus healyensis*, *A. barnesi*, *A. fairi*, *A. largei*, *A. evidens*, *A. cappsi*, *Carpinus seldoviana*, *C. cappensis*, *Quercus* (*Leucobalanus*) *furuhjelmi*, *Q.* (*L.*) *bretzi*, and *Fagus antipofi.* Also restricted in Alaska to the Seldovian Stage are *Zelkova oregoniana* and *Liquidambar mioformosana*, but these species are known to have longer time and stratigraphic ranges in other regions. In addition, the following taxa are abundant or common in the Seldovian Stage but are rare in the Homerian Stage: *Carya bendirei*, *Pterocarya nigella*, and *Cercidiphyllum crenatum.* *Ulmus* is represented by fossil leaves in Seldovian beds and by pollen in some Homerian beds.

The leaf floras of the Seldovian Stage show some individual variation from one locality to another. This floristic variation is undoubtedly due in part to former environmental differences between parts of the Cook Inlet region during Seldovian time. For example, the richness of Seldovia Point flora (locs. 6061, 9856–9858) probably reflects the diversity of the ecological and topographic conditions that prevailed there during Seldovian time, and the strong dominance of Betulaceae in Seldovian beds from many other parts of the region probably reflects the rather monotonous topography and the wide distribution of poorly drained sites that must have prevailed in areas nearer the center of the basin of sedimentation.

However, we think that at least part of the variation among different Seldovian floras reflects difference in age. The floras from Tsadaka Canyon, Little Susitna River, Redoubt Point, and Harriet Point have several similarities that set them somewhat apart from other Seldovian floras. These similarities include the lack of white oaks or other Fagaceae, a scarcity of maples (only one species, *Acer fatisiaefolia*, is known in these floras), and the occurrence of *Alnus evidens* and *Corylus harrimani.* In contrast, the Seldovia Point flora, the Capps Glacier localities, and the Cache Creek localities have white oaks and other Fagaceae (abundant in the Seldovia Point flora), diverse maples, and *Alnus cappsi.* In addition, species of *Salix* that are closely related to Homerian or Clamgulchian forms are known mostly from floras containing white oaks and *Alnus cappsi*, and the predominantly Homerian species *Spiraea weaveri* is known from the Seldovian locality at Houston along with white oaks and *Alnus cappsi.* Although we have not yet found the two types of floras in a single continuous stratigraphic sequence, the floras containing *Alnus evidens* or *Corylus harrimani* and lacking Fagaceae or maples other than *Acer fatisiaefolia* are thought to be older than the floras containing *Alnus cappsi*, Fagaceae, and diverse maples; we therefore designate them tentatively in this paper as lower(?) and upper(?) Seldovian floras, respectively.

The pollen and spore samples of the Seldovian Stage that have been studied come from the type Seldovian section in the Capps Glacier-Chuitna River area (seven samples) and from the referred Seldovian section near Seldovia Point (two samples). Grain counts are based on at least 100 grains except for one sample (D1719) in which only 36 grains were recovered.

The most notable characteristic of all the Seldovian microfossil samples is the large proportion of dicotyledon pollen exclusive of Betulaceae. Most of these dicotyledons represent genera now exotic to Alaska: *Carya*, *Juglans*, *Pterocarya*, *Ulmus-Zelkova*, *Liquidambar*, *Ilex*, *Tilia*, and *Nyssa.* We have not observed all these genera in any one sample, although in various combinations at least four are present in any given sample. *Ulmus-Zelkova* is present in all samples, *Carya* and *Pterocarya* in eight, and *Nyssa* in seven. Two samples have a low (1 and 1.5 percent of grains counted) representation of this exotic dicotyledon element, but the other seven samples have between 7 and 92 percent; locality D1949 (pl. 2), which is taken here as the top of the Seldovian in the type section, has 8 percent.

Pinus pollen is present in all samples and ranges in abundance from 1 to 18 percent. *Picea* is noted, sometimes in abundance (as much as 23 percent) in seven

TABLE 2.—*Checklist of Seldovian megafossil flora*

[Numbers indicate localities]

Species	Lower(?) Seldovian														?	Upper(?) Seldovian													
	Tsadaka Canyon	Little Susitna River				Eagle River		Cape Douglas	Harriet and Redoubt Points						Chinitna Bay	Seldovia Point				Beluga Lake			Capps Glacier			Houston	Cache Creek		Mills Creek
	9359	8380	9364	9865	9866	9863	9864	9761	9885	9886	9945	9887	9760	9884	3505	9856	9857	6061	9858	9848	9849	9850	9845	9846	9937	9365	9867	6063	6066
Equisetum sp		×																							×	×			
Dryopteris sp																			×										
Onoclea sensibilis L																			×										
Osmunda sp		×		cf.																									
Ginkgo biloba L														×	×		×												
Glyptostrobus europaeus (Brong.) Heer	×	×										×	×						×				×			×			
Metasequoia glyptostroboides Hu and Cheng	×	×		×	×			×	×	×	×	×	×		×	×	×		×			×	×	×				×	
Taxodium distichum Rich																×			×										
Sequoia sempervirens Endl																													×
Pinus sp. cf. *P. ponderosa* Laws		×																							×				
Pseudolarix sp																							×						
Chamaecyparis sp																										×			
Potamogeton sp																			×										
Smilax sp																			×										
Cyperacites sp	×							×								×			×				×		×	×			×
Poacites tenuistriatus Heer																×			×										
Populus kenaiana Wolfe					×	cf.							cf.			×			×	×		×	cf.	×		×	×		
sp. aff. *P. latior* Braun																×			×				×					×	
Salix cappsensis Wolfe																							×						
picroides (Heer) Wolfe																×					×	×							
inquirenda Knowl				×															×		×					×	×	×	
sp. aff. *S. confirmata* (Holl.) Wolfe																				cf.	×				×			×	
sp. aff. *S. crassijulis* Trautv																				cf.					×	×			
sp. aff. *S. kachemakensis* Wolfe		×																	×						×				
Comptonia sp. cf. *C. naumani* (Nath.) Endo																							×						
Carya bendirei (Lesq.) Chan. and Axelr																×								×					
Pterocarya mixta (Knowl.) R. W. Br																×			×										
nigella (Heer) Wolfe	×	×														×	×		×	cf.		×	×						
(*Cycloptera*) sp																			×										
Alnus barnesi Wolfe										×													×		×				cf.
cappsi (Holl.) Wolfe																			×					×	×	×	×	×	
evidens (Holl.) Wolfe	×	cf.	×	cf.	×	cf.		×	×	cf.		×	×																
fairi (Knowl.) Wolfe																			×							×			
healyensis Wolfe																×			×			×	×	×		×			
largei (Knowl.) Wolfe						×										×						×							
Carpinus cappsensis Wolfe	×	×	×				cf.			×		×											×	×					
seldoviana Wolfe																×			×										
Corylus harrimani Knowl	×	cf.																											
Betula sublutea Tan. and Suz																				×									
Fagus antipofi Abich														cf.		×	×	×	×										
sp. cf. *F. paleocrenata* Tan																×													
Quercus bretzi Chan																×			×								×	×	
furuhjelmi Heer																×	×		×							×			
Ulmus longifolia Ung																×			×			×				×			
sp. aff. *U. newberryi* Knowl	×	cf.														×			×		×		×						
Zelkova oregoniana (Knowl.) R. W. Br																×			×							×			
Nuphar sp																			×										
Ceratophyllum sp																											×		
Cercidiphyllum crenatum (Ung.) R. W. Br						×										×	×						cf.	×					
Cocculus auriculata (Heer) Wolfe																×			×										
Hydrangea sp																			×										
Liquidambar mioformosana Tan																×	×		×				×						
Platanus bendirei (Lesq.) Wolfe																			×										
Crataegus sp																			×							×			
Prunus sp																×			×										
Spiraea weaveri Holl																										×			
Cladrastis japonica (Tan. and Suz.) Wolfe																							×						
Alchornea? sp. (*Populus delicata* Chan.)																			×										
Mallotus sp																			×										
Rhus sp. aff. *R. glabra*				cf.																						×			
Acer ezoanum Ois. and Huz																			×	×									
fatisiaefolia Huz	×																		×				×						
glabroides R. W. Br																								×	cf.		×	×	
macropterum Heer																×	×		×										
sp. aff. *A. crataegifolium* Sieb. and Zucc																			×										
sp. cf. *A. subpictum* Sap																	×							×	×				
Aesculus majus (Nath.) Tan																								×					
Vitis sp																×													
sp	×																												
Tilia sp																			×										
Nyssa sp. cf. *N. knowltoni* Berry																			×										
Hemitrapa borealis (Heer) Miki																×													
Kalopanax sp																×													
Vaccinium sp											×																		
Fraxinus n. sp. "A"						×																							
n. sp. "B"																×													

samples, but *Abies* and *Tsuga* are never abundant and occur in three and six samples, respectively.

Pollen of Betulaceae is found in all the samples, typically in abundance (as much as 88 percent). Except in two samples, *Alnus* is more abundant than pollen of the *Betula*-type (*Betula*, *Carpinus*, *Ostrya*). Ericales are represented in five samples but do not compose more than 4 percent of any tally.

MOLLUSKS

With one exception, all the identifiable fresh-water mollusks from the Kenai Formation are from beds definitely of Seldovian age. Mayer (in Heer, 1869) described three species of mollusks from the Seldovian beds exposed at Coal Cove, Port Graham. D. W. Taylor has reclassified two of these mollusks as *Plesielliptio onariotis* (Mayer) and *Melanoides furuhjelmi* (Mayer). Taylor considers that the third mollusk, "*Paludina*" *abavia* Mayer, may be one of the Hydrobiidae, perhaps *Lithoglyphus*. Both *Plesielliptio* and *Melanoides* also occur at Houston, Alaska (USGS Cenozoic loc. 23343, same as USGS Paleobotany loc. 9365; see (pl. 1). A fauna from the Eagle River locality (USGS Cenozoic loc. 23368, same as USGS Paleobotany loc. 9864) may also contain *Plesielliptio onariotis*, but the material is too poor to be certain. Fresh-water gastropods, including a new species of *Campeloma* and a probable new species of *Bellamya*, also were obtained at Eagle River.

AGE

The precise age limits of the Seldovian Stage are uncertain. Paleobotanical correlations indicate that the beds from which upper(?) Seldovian floras have been obtained are of late early and (or) middle Miocene age; beds that have yielded lower(?) Seldovian floras probably are of early Miocene age, but some beds of late Oligocene age may also be included.

The upper(?) Seldovian floras contain several species that are restricted to beds of early and middle Miocene age in Oregon and Washington: *Salix inquirenda*, *Alnus fairri*, *A. healyensis*, *Quercus bretzi*, *Cocculus auriculata*, *Platanus bendirei*, *Alchornea*? n. sp., and *Fraxinus* n. sp. "A." Some Seldovian species have an early and middle Miocene age range in Japan: *Fagus antipofi*, *Cocculus auriculata*, and *Acer ezoanum*. None of the other species known from upper(?) Seldovian floras contradict an age assignment to the early half of the Miocene Epoch. Moreover, these floras probably are not of earliest Miocene age; in Washington and Oregon, the lobed oaks and *Cocculus* do not appear in the floras assigned to Wolfe's zone 1 (Wolfe, 1962, table 89.1) representing the basal part of the Miocene Series. The upper(?) Seldovian floras appear to be correlative with the floras of either Wolfe's zone 2 or zone 3, which are considered to be of late early and early middle Miocene age, respectively.

The lower(?) Seldovian floras have not been as extensively collected as have the upper(?) Seldovian floras, and thus their correlation is less certain. Several lower(?) Seldovian species are indicative of a Miocene age: *Ulmus* sp. aff. *U. newberry*, *Acer fatisiaefolia*, and *Pterocarya nigella*. *P. nigella* is especially significant because middle and upper Oligocene rocks in Oregon and Washington contain a related and probably ancestral species. Similarly, on Big Sitkinak Island *Carpinus cappsensis* and *Alnus evidens* are probably descended from closely related species found in the nonmarine beds that lie below beds containing an early Miocene marine molluscan fauna (Wolfe, 1966) and below beds that contain *A. evidens*. An age of earliest Miocene seems most probable for the lower(?) Seldovian floras, but we cannot exclude the possibility that some of them may be of latest Oligocene age.

Pollen of the Compositae is not certainly known in other parts of the world in beds of pre-Miocene age, but it is abundant in some Miocene beds. We have not found Compositae pollen in any Seldovian flora, but we do not feel that any age significance can be attached to its absence.

Homerian Stage

DEFINITION

The Homerian Stage is proposed as a provincial time-stratigraphic unit that encompasses all plant-bearing strata in Alaska and in adjoining parts of the same ancient floristic province that are of the same age as those parts of the Kenai Formation represented in the type section near Homer and in the reference section in the valley of the Chuitna River. Rocks belonging to the Homerian Stage are recognized primarily on the basis of the fossil floras that they contain. The stage is named after the town of Homer.

The type section of the Homerian Stage is designated as the sequence of strata of the Kenai Formation approximately 2,000 feet thick that is exposed in coastal bluffs and in steep gullies and canyons along the east shore of Cook Inlet and the north shore of Kachemak Bay from Troublesome Gulch (loc. 4129, pl. 1) past the town of Homer to Fritz Creek (loc. 9853, pl. 1). A geologic map, geologic sections, and correlated measured stratigraphic sections of the beds included in the type section are given by Barnes and Cobb (1959, pls. 18 and 19).

The base of the Homerian Stage cannot be recognized and may not be represented in the type section. The lowest flora that has been collected there comes from beds exposed at the mouth of Troublesome Gulch; a sequence several hundred feet thick of massive sandstone beds underlies this flora in bluffs that extend northwestward to Anchor Point, but these beds have yielded no fossil plants. The base of the Homerian Stage is represented, however, in exposures at our localities D1949 and 9844 on the lower Chuitna River (pl. 2). These exposures are designated as a reference section for the Homerian Stage, and the base of the stage is defined as lying immediately above the coal bed at locality D1949, which contains a Seldovian pollen flora. Locality 9844, which lies 50 feet higher in the reference section, contains a leaf flora diagnostic of the Homerian Stage.

The top of the Homerian Stage is represented in the type section but cannot yet be closely defined because it lies within a stratigraphic sequence about 1,500 feet thick in which we have not yet sought fossil plants. The highest flora typical of the Homerian Stage was obtained from exposures just west of the mouth of Fritz Creek (loc. 9853). Our next higher flora, collected about 7½ miles to the northeast and just west of the mouth of Cottonwood Creek (loc. 9855) contains species that we consider diagnostic of the Clamgulchian Stage. A more precise definition of the top of the Homerian Stage must await additional collecting within the stratigraphic interval between these two localities.

FLORA

Strata assigned to the Homerian Stage in various parts of the Cook Inlet region have yielded 47 species of plants based on fossil leaves (table 3) and 26 pollen and spore types representing at least 15 vascular genera and 11 families of seed plants. Homerian leaf and pollen floras are much less diversified than Seldovian floras. Most of the warm-temperate elements now exotic to Alaska that characterize Seldovian floras are lacking in Homerian floras. The Homerian leaf floras collected thus far in the Cook Inlet region are dominated by Salicaceae and Betulaceae, but some of the pollen floras are dominated by Pinaceae.

The following megafossil species appear to be restricted to the Homerian Stage: *Salix alaskana*, *S. chuitensis*, *S. kachemakensis*, *S. tyonekana*, *Alnus corylina*, *A. adumbrata*, *Carpinus cobbi*, *Corylus chuitensis*, *Spiraea hopkinsi*, *Rhododendron weaveri*, and *Vaccinium homerensis*. Salicaceae and Betulaceae dominate the Homerian floras both in numbers of specimens and in numbers of species. In addition, Ericaceae form an important element in some individual floras. Most of the warm-temperate exotic elements of the Seldovian floras are lacking in floras from the Homerian Stage; only *Carya*, *Pterocarya*, *Carpinus*, *Cladrastis*, and Taxodiaceae persist as rare elements in the leaf floras. Ulmaceae occur rarely in pollen floras; fossil leaves of this family have not yet been found in Homerian strata in the Cook Inlet region. Fagaceae are lacking from Homerian floras of the Cook Inlet region, and *Acer*, common in Seldovian floras, is rare in Homerian floras. Leaves of *Fagus* sp. cf. *F. sanctieugeniensis* Holl., are associated with a marine molluscan fauna of late Miocene or early Pliocene age (F. S. MacNeil, oral commun., 1961) on Cenotaph Island in Lituya Bay (fig. 1); these beds presumably must lie within the Homerian or Clamgulchian stage.

Early in our investigation, Wolfe (in MacNeil and others, 1961) erroneously placed the type Homerian beds below beds that we now assign to the Seldovian Stage, basing his conclusions on study of published illustrations of a few species from each of these floras. However, study of new leaf and pollen floras from the Capps Glacier and Chuitna River area (pl. 2) and of pollen floras from wells penetrating strata of both stages indicates clearly that the Homerian Stage is younger than and lies stratigraphically above the Seldovian Stage. This conclusion is reinforced by Wolfe's systematic studies (Wolfe, 1966), which show that Seldovian species are consistently morphologically more similar to Oligocene species than are Homerian species. Furthermore, Homerian pollen and leaf floras are more depauperate and more similar to Recent Alaskan floras than are Seldovian floras.

The stratigraphically highest flora in the type section of the Homerian Stage is that obtained at locality 9853 immediately west of Fritz Creek. No fossil plants have been collected from the approximately 1,500 feet of strata between localities 9853 and 9855; the latter is the lowest locality assigned here to the Clamgulchian Stage. We propose that all or part of the beds in this interval should be assigned to the Homerian Stage if they contain *Alnus adumbrata* or to the Clamgulchian Stage if they contain *Alnus schmidtae*.

The pollen and spore flora from the Homerian type section is known from five samples, and we have one sample (D1717, pl. 2) that lies several hundred feet stratigraphically above the beds at locality 9844, which are considered to be the lowest Homerian rocks in the Chuitna River reference section (pl. 2).

In contrast to the richness and abundance of the exotic dicotyledon element in the Seldovian pollen floras, this element is poorly represented in the Homerian pollen floras. Thus far, only three exotic dicotyledon genera are known; *Carya* and *Pterocarya* each have been found in two samples, and *Ulmus*, in three.

TABLE 3.—*Checklist of Homerian megafossil flora*

[Numbers indicate localities]

Species	Cache Creek	Chuitna River		Type section, Homerian								
	9868	9844	4130	9852	4129	9366	5820	5821	9851	9361	4131	9853
Osmunda sp.		×										
Onoclea sp. cf. *O. sensibilis* L.		×										
Glyptostrobus europaeus (Brong.) Heer.	×	×		×		×				×		×
Metasequoia glyptostroboides Hu and Cheng.	×	×	×	×	×	×				×	×	
Taxodium distichum Rich.						×				×		
Typha sp.		×								×		
Cyperacites sp.		×		×						×		×
Populus eotremuloides Knowl.				×								
kenaiana Wolfe.		×		×				×				
washoensis R. W. Br.				×								
Salix alaskana Holl.							×			×		×
chuitensis Wolfe.	×	×								×		×
confirmata (Holl.) Wolfe.							×	×			×	×
cookensis Wolfe.												×
kachemakensis Wolfe.				×	×					×		×
tyonekana Wolfe.		×		×				×				
picroides (Heer) Wolfe.		×										
Myrica sp.										×		
Carya bendirei (Lesq.) Chan. and Axelr.									×			
Pterocarya sp. cf. *P. nigella* (Heer) Wolfe.		×										
Alnus adumbrata (Holl.) Wolfe.	×	cf.	×					×	×	×		×
corylina Knowl. and Cock.	×	×	×	cf.	×				×	×	×	×
sp. aff. *A. healyensis* Wolfe.		×										
Betula sp. cf. *B. thor* Knowl.		×										
Carpinus cobbi Wolfe.			×							×		
Corylus chuitensis Wolfe.	×	×					×			×		
Cercidiphyllum crenatum (Ung.) R. W. Br.	×											
Hydrangea bendirei (Ward) Knowl.						×						
Ribes sp.									×	×		
Prunus sp.										×		
Rubus sp.		×										
Spiraea hopkinsi Wolfe.	×	×			×	×				×	×	×
weaveri Holl.						×			×	×	×	×
Cladrastis japonica (Tan. and Suz.) Wolfe.		×								cf.		
Sophora sp.		×										
Acer sp. cf. *A. glabroides* R. W. Br.									×			
Elaeagnus sp.		×								×		
Cornus sp.	×	×								×		
sp.		×										
Aralia sp.		×										
Arbutus sp.		×										
Rhododendron weaveri (Holl.) Wolfe.		×									×	×
Vaccinium homerensis Wolfe.								×		×	×	×
sp.		×			×					×		
Halesia sp.								cf.		×		
Diervilla sp.		×							×			
Symphoricarpos sp.		×										

Three of the samples contain two of these genera, one sample has only *Ulmus*, and two samples entirely lack the exotic element. *Carya* and *Pterocarya* are also represented by leaflets, but as yet *Ulmus* is represented in the Homerian of the Cook Inlet area only by pollen. The abundance of the exotic elements in the Homerian is low and does not exceed 3 percent in any one sample.

Betulaceae and Pinaceae dominate all the Homerian microfossil floras. Although none of the megafossil floras of Homerian age in the Cook Inlet region are known to contain Pinaceae, leaves and seeds of several genera of this family have been found in late(?) Seldovian or Homerian beds at the base of the Wrangell lavas near McCarthy, Alaska (locs. 9933, 9935) (fig. 1). In all samples, *Alnus* pollen is more abundant than that of the *Betula* type. Total Betulaceae pollen represents between 20 and 80 percent of pollen tallied in each sample. *Pinus* occurs in each sample, and *Picea* in five of the six samples studied. *Abies* and *Tsuga* are somewhat better represented in Homerian than in Seldovian pollen floras; each genus occurs in five Homerian samples. Ericales are also better represented in the Homerian and were noted in five samples; in three samples, Ericalean pollen represents at least 5 percent of the pollen tallied. No Compositae pollen has been found as yet in Homerian strata.

MOLLUSKS

A fresh-water clam has been collected from USGS Cenozoic locality 23396 on the southeast side of the Moquawkie magnetic contact along the Beluga River. Because most exposures of the Kenai Formation on the same side of the contact in the Chuitna Valley about 7 miles to the south are of Homerian age, this clam is probably also of Homerian age. D. W. Taylor has determined the specimen as probably *Hypriopsis*; this genus is today confined to tropical and warm-temperate East Asia.

AGE

The age limits of the Homerian Stage are very uncertain. Although the stratigraphic relationships indicate clearly that the Homerian Stage is younger than the Seldovian Stage and hence younger than the early half of the Miocene Epoch, there is little in the Homerian floras themselves to strengthen this assertion. The general provincialism of the Homerian flora makes correlation difficult with floras in Oregon and Washington or in Japan. The occurrence in Homerian floras of *Pterocarya* cf. *P. nigella* and *Carya bendirei* indicates that at least part of the Homerian Stage can be no younger than late Miocene in age; neither of these species is known above the Miocene in Washington or Oregon. More significantly, *Alnus adumbrata* is known from the late Miocene Stinking Water flora in Oregon (reported there as *Alnus harneyana* Chaney and Axelrod, 1959, p. 158).

Unnamed beds on the west shore of Port Moller on the Alaska Peninsula (loc. 5182, fig. 1) have produced a small Homerian flora containing *Salix kachemakensis* and *S. alaskana*. The age of these beds is not certainly known, but on lithologic and stratigraphic evidence, C. A. Burk (oral commun., May 1963) considers them to be equivalent to marine beds exposed east of Port Moller which contain a molluscan fauna that F. S. MacNeil (oral commun., July 1963) places in the later half of the Miocene Epoch.

The evidence, although not conclusive, indicates that strata of the Homerian Stage represent at least part of the upper half of the Miocene Series. The youngest part of the Homerian Stage may be of early Pliocene age, but we have no evidence to either support or contradict this suggestion.

Clamgulchian Stage

DEFINITION

The Clamgulchian Stage is proposed as a provincial time-stratigraphic unit that encompasses all plant-bearing strata in Alaska and in adjoining parts of the same ancient floristic province that are of approximately the same age as those parts of the Kenai Formation that are represented in the type section on the east shore of Cook Inlet and in the reference section on the north shore of Kachemak Bay. Rocks belonging to the Clamgulchian Stage are recognized primarily on the basis of the fossil floras that they contain. The stage is named for the village of Clam Gulch, near the north end of the type section.

The type section of the Clamgulchian Stage is designated as the sequence of strata of the Kenai Formation at least 2,000 and possibly 3,000 feet thick that is exposed in coastal bluffs along the east shore of Cook Inlet from Happy Creek (loc. 9883, pl. 1) northward to a point 4 miles north of Clam Gulch (loc. 9860). The type section has yielded several good floras, but we do not have large floras from either the top or the bottom of the stage there. Floras from less than 1,500 feet above the base of the stage are present, however, in exposures in sea bluffs and steep gullies and canyons along the north shore of Kachemak Bay between Cottonwood Creek (loc. 9855) and Swift Creek (loc. 9859). Geologic maps, geologic sections, and correlated measured sections are given for the type section and the reference section by Barnes and Cobb (1959, pls. 17, 18, and 19).

The strata definitely assigned to the Clamgulchian Stage in the reference section on the north shore of Kachemak Bay include approximately 1,500 feet of beds that lie above Barnes and Cobb's (1959, pl. 19) coal bed G and that are exposed between Cottonwood Creek and Swift Creek. The upper part of this sequence consists of poorly lithified clastic beds and of lignitic organic beds, as does the sequence that constitutes the type section. The lower part of the strata exposed in the reference section, however, is well lithified. The organic beds consist of subbituminous coal and are similar in general lithologic character to the strata making up the Homerian Stage in the type section.

The lowest flora typical of the Clamgulchian Stage was obtained just above Barnes and Cobb's coal bed G in the Kachemak Bay reference section (loc. 9855). Strata about 1,500 feet thick, which we have not yet searched for fossil plants, separate this typical Clamgulchian flora from our highest Homerian flora obtained near the mouth of Fritz Creek (loc. 9853). Additional collecting within this stratigraphic interval must be done before the boundary between the Homerian and Clamgulchian stages can be precisely defined in the reference section.

The strata assigned to the Clamgulchian Stage may represent the youngest Tertiary rocks exposed in the Cook Inlet region. Consequently we are not prepared to attempt to define the top of Clamgulchian Stage with precision. The Clamgulchian flora is closely related to the modern Alaskan flora; the former contains some species that are still extant in Alaska and others that probably are ancestral to modern species. Nevertheless, the Clamgulchian floras are readily distinguished both by their general floristic composition and by the presence of a few extinct taxa from late Pleistocene and Recent floras in Alaska. Criteria for recognizing the upper limit of the Clamgulchian Stage and selection of a reference section in which the upper limit can be precisely defined must await further study of late Tertiary and early Pleistocene rocks in Alaska and of the floras that they contain.

FLORA

Rocks of the Clamgulchian Stage in the Cook Inlet region have yielded 20 species based on megafossil plants (table 4) and 21 pollen and spore types representing at least 11 angiosperm genera and 16 tracheophyte families. The Clamgulchian floras are depauperate in species of woody plants, and nearly all the warm-temperate elements now exotic to Alaska are absent. The pollen and leaf floras collected thus far from the Cook Inlet region are dominated by Betulaceae. However, we expect that leaf floras from areas that had greater topographic diversity during Clamgulchian times might be dominated by Pinaceae.

The following megafossil species appear to be restricted to the Clamgulchian Stage: *Salix ninilchikensis*, *S. leopoldae*, *S. kenaiana*, and *Alnus schmidtae*. All these species appear to be intermediate between Homerian and Recent species. The exotic element is greatly reduced in Clamgulchian leaf floras and is represented only by *Glyptostrobus* and *Rhus*.

The three pollen samples from the Clamgulchian rocks on the north shore of Kachemak Bay and the two samples from the type section show an even greater

TABLE 4.—*Checklist of Clamgulchian megafossil flora*

[Numbers indicate localities]

Species	Kachemak Bay			Type section, Clamgulchian					
	9855	9854	9859	9883	9360	9763	9862	9861	9860
Equisetum sp					X		X		
Glyptostrobus europaeus (Brong.) Heer				X	X				
Cyperacites sp	X	X		X	X		X	X	X
Carex sp							X		
Potamogeton sp							X		
sp							X		
Populus tacamahacca Mill		X	cf.		X		X		
Salix confirmata (Holl.) Wolfe	X								
cookensis Wolfe					X		X		X
crassijulis Trautv							X		
kenaiana Wolfe			X		X	X	X		X
leopoldae Wolfe	X	X			X	X	X	X	
ninilchikensis Wolfe							X		
Alnus incana (L.) Moench		X		X	X	X	X		
schmidtae Wolfe	X		X		X		X		
Betula papyrifera Michx	X	X							
Malus sp. cf. *M. fusca* (Rafin.) Schn									X
Spiraea weaveri Holl	X			X					
sp. cf. *S. beauverdiana* Schn									X
Rhus sp. aff. *R. glabra* L							X		

decrease than the Homerian pollen floras in the exotic dicotyledon element. Although four samples contained pollen of exotic genera—*Pterocarya*, *Ulmus*, *Liquidambar*, and *Tilia*—each is represented by only a single grain. Because *Pterocarya* and *Ulmus* are represented by foliage and pollen in known Homerian rocks, both of these genera may have survived into the Clamgulchian. *Liquidambar* and *Tilia*, however, are unknown in the Homerian megafossil and microfossil floras, and the occurrence of these genera in the Clamgulchian samples may be the result of redeposition from beds of Seldovian or earlier Tertiary age. The possibility of redeposited pollen in Clamgulchian samples is indicated by the presence of limy cobbles bearing imprints of *Alnus* leaves in a small lens of conglomerate between localities 9860 and 9861. These leaves are too fragmentary for specific determination, but it is clear that some consolidated fossiliferous beds were being eroded during the Clamgulchian.

Betulaceae dominate all our Clamgulchian pollen samples and range in abundance from 45 to 95 percent. Although most of this total consists of *Alnus*, pollen of the *Betula* type is the dominant form in one sample. *Pinus* and *Picea* are present in all samples, but pollen of the former genus is the more abundant of the two. *Abies* has not been found in any sample, and *Tsuga* is present in four samples. Pollen of Ericales is not as common as in the Homerian samples; pollen assigned to this order was seen in only three samples and forms no more than 3 percent in any tally. The only Compositae pollen that we have found in the Kenai Formation consists of a single grain found in sample D1955.

AGE

The Clamgulchian Stage is younger than the Homerian Stage and older than the glacial part of the Pleistocene Epoch; beyond this, we have no strong evidence bearing on the age in traditional epoch terms of the Clamgulchian Stage. If it is accepted that the Homerian Stage is equivalent to at least part of the later half of the Miocene Epoch, it follows that the Clamgulchian Stage cannot be older than late Miocene.

The occurrence of several Recent species and of several other species closely related to Recent species in Clamgulchian floras also indicates that the Clamgulchian Stage falls somewhere within the later Neogene. The only Clamgulchian species known in the Neogene of the northwestern conterminous United States is the extant *Alnus incana*, which, as fossil, is known from the Pliocene Troutdale flora. Because *A. incana* is interpreted by Wolfe (1966) as descended from *A. corylina*, which is known in the latest Miocene of Oregon, the occurrence of *A. incana* in Clamgulchian strata is an indication that this stage is of Pliocene age.

TABLE 5.—*Stratigraphic distribution of significant species*

[●, fossil found at indicated locality. O, determination based on fragmentary material. Dashed range lines indicate a possible

STAGE	Locality	*Alnus evidens*	*Corylus harrimani*	*Carpinus cappsensis*	*Ulmus* sp. aff. *U. newberryi*	*Comptonia* sp. cf. *C. naumani*	*Acer fatisiaefolia*	*Salix inquirenda*	*Salix* sp. aff. *S. confirmata*	*Salix* sp. aff. *S. crassijulis*	*Salix* sp. aff. *S. kachemakensis*	*Populus* sp. aff. *P. latior*	*Alnus barnesi*	*Alnus cappsi*	*Alnus fairi*	*Alnus healyensis*	*Alnus largei*	*Fagus antipofi*	*Quercus bretzi*	*Quercus furuhjelmi*	*Ulmus longifolia*	*Zelkova oregoniana*	*Liquidambar mioformosana*	*Acer ezoanum*	*Acer glabroides*	*Pterocarya nigella*
CLAMGULCHIAN	9860 9861																						+(1)			
CLAMGULCHIAN	9862																									
CLAMGULCHIAN	9360																									+(2)
CLAMGULCHIAN	9859																									
CLAMGULCHIAN	9854																									
CLAMGULCHIAN	9855																									
HOMERIAN	4131 9853																									
HOMERIAN	9361				+(1)																+(1)					+(1)
HOMERIAN	9851				+(4)																+(4)				O	+(1)
HOMERIAN	5820 5821																									
HOMERIAN	9366																									
HOMERIAN	4129 9852																									
HOMERIAN	4130 9844				+(1)																+(1)					O
SELDOVIAN	Upper(?)			●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
SELDOVIAN	Lower(?)	●	●	●	●	●	●	●	●																	●

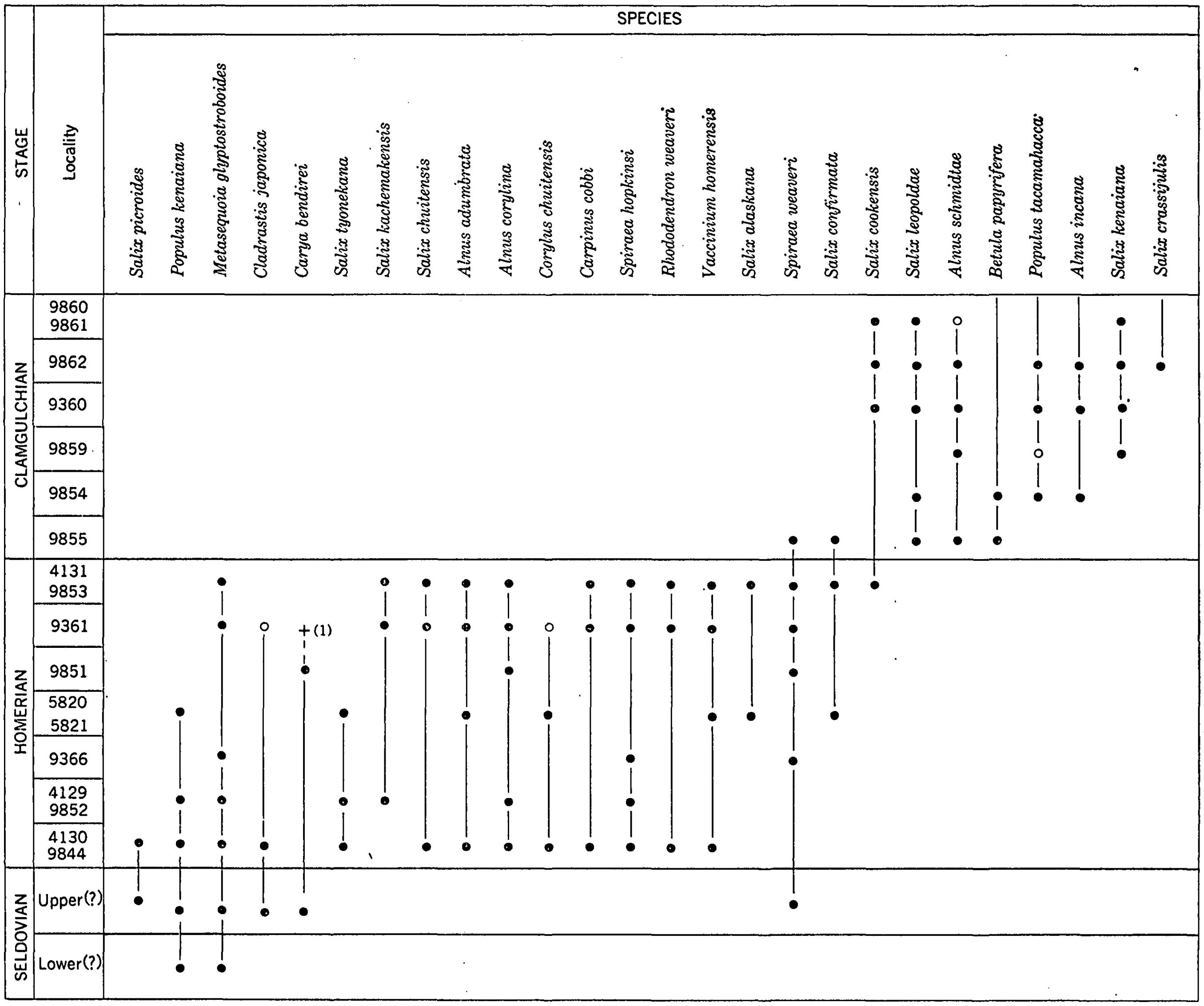
Summary of the Floral Sequence

Data obtained from a study of megafossils (table 5) and from a preliminary study of microfossils (table 6) indicate that three time-stratigraphic units—the Seldovian, Homerian, and Clamgulchian provincial stages—can be recognized in surface outcrops of the Kenai Formation. Megafossil plants are more clearly diagnostic of the three provincial stages at the present time, but microfossils are more useful in determining stage assignments for subsurface samples.

The stratigraphic ranges of individual plant species given in table 5 are abstracted from the checklists given earlier and illustrate graphically the bases for recognition of the three provincial stages. The relative stratigraphic positions of some of the Seldovian floras are somewhat debatable; for purposes of the table they are broken into two groups, thought to represent the lower and upper parts of the Seldovian Stage. The Homerian flora from locality 9844 on the Chuitna River is assumed to be at least as old if not older than the lowest flora collected in the Homerian type section. The Clamgulchian localities on Kachemak Bay are assumed for purposes of placement in table 5 to be at least as old as the lowest locality in the Clamgulchian type section.

Table 6 indicates the known stratigraphic ranges of various genera in the pollen floras of the Kenai Formation, and presents a generalized concept of the relative abundance of the genera. Several forms are found in all three stages, but the exotic broad-leaved element is *in Kenai and Tsadaka Formation, Cook Inlet region, Alaska.*

extension of range of species based on generic determination of pollen (+); number of grains given in parentheses]



obviously more abundant and diverse in the Seldovian Stage. *Juglans*, *Ilex*, *Nyssa*, and possibly *Liquidamber* appear to be restricted to the Seldovian pollen floras. Our somewhat limited sampling is probably responsible for the apparent restriction of *Corylus* to the Homerian and of Compositae to the Clamgulchian; the former is known from leaves in the Seldovian as well as the Homerian, and Compositae pollen should also be expected throughout the Clamgulchian. The first occurrence of Compositae pollen might be taken by some palynologists to mark the base of the Miocene Series, but our experience in Miocene floras in Oregon and the late Pliocene or early Pleistocene "Submarine Beach" at Nome indicates that pollen of Compositae is rare or lacking in many floras of undoubted Neogene age. It would seem that the presence of this group is not consistent enough to be a helpful index to sediments of post-Oligocene age.

Pollen-abundance diagrams were prepared for each of the pollen floras discussed in this report, but they are not reproduced here because they yielded little or no information that is not already apparent from generic lists of the various assemblages. A progressive general impoverishment of the Kenai pollen flora through time is apparent even from the limited sampling of the pollen reported here and is fully confirmed by the study of the megafossils. A general predominance of Betulaceae and Pinaceae is characteristic of all Kenai Formation samples examined thus far, except for two from the Seldovian type section near Capps Glacier which are dominated by *Ulmus-Zelkova* pollen. More significant

TABLE 6.—*Stratigraphic distribution of pollen types in Kenai and Tsadaka Formations.*

[+, present but not included in counts; o, less than 2 percent; •, more than 2 percent]

STAGE	Locality	*Abies*	*Picea*	*Pinus*	*Tsuga*	Taxodiaceae	*Salix*	*Alnus*	*Betula*-type	*Corylus*	*Carya*	*Juglans*	*Pterocarya*	*Ulmus*-type	*Liquidambar*	*Nyssa*	*Tilia*	*Ilex*	Ericales	*Diervilla*	Compositae
CLAMGULCHIAN	D1943			•	o	o	•	•	•						+				o		
	D1775			•	o			•	•				o						•		
	D1945		o	o	+	o		•	+											o	
	D1954		•	•	o		o	•	•					+			o				
	D1955		•	•		•	o	•	•										•	•	+
HOMERIAN	D1948	•	•	•	•	•	o	•	•										•		
	D1776			•		•		•	•		o			•					o		
	D1951	•	•	•	o	•		•	•	+			+						•		
	D1950	o	•	•	•			•	•				o	•					o		
	D1947	•	•	•	•			•	•											o	
	D1717	o	o	•	o			•	•		o			o					•		
SELDOVIAN	D1949		•	•	+	•	+	•	•		+	•	•	•					+		
	D1719			•				•	•				•	•	•	•			•		
	D1718		o	•	o			•	•		+		o	o		o					
	D1720		o	o				•			o		o	•	o	o	+				
	D1953			•	o			•	•		•	o	•	•		•		+	•		
	D1952	+	•	•	+	•		o	•		o	+		+				+	•		
	D1946	+	•	+	+	•	•	•	•		+	+	+	•	+	•				+	

are minor changes in the frequency of the exotic broad-leaved element; this element represents 5 and 19 percent of the count in two samples collected near Seldovia Point and from 1 to 92 percent of samples collected in the type section of the Seldovian Stage. In contrast, broad-leaved trees are represented by no more than 5 percent of the Homerian pollen tallies and by less than 1 percent of the Clamgulchian tallies. The parameter of the pollen floras expressed by the percentage of now-exotic forms appears to constitute a highly useful stratigraphic tool for the recognition of the three stages erected here.

Both the megafossil and the microfossil floras demonstrate that the broad-leaved forest trees now most common in warm-temperate floras were not dominant in the Cook Inlet region after the Seldovian Age. Representatives of typically warm-temperate families such as Juglandaceae, Fagaceae, Ulmaceae, and Aceraceae gradually disappeared, whereas representatives of typically cool-temperate families such as Betulaceae, Rosaceae, Ericaceae, and Caprifoliaceae proliferated and became steadily more abundant in floras that gradually approached the character of the modern boreal floras of southern Alaska. Although deteriorating climatic conditions undoubtedly played a major role in dictating the changing generic composition of successively younger Kenai floras, assumptions concerning past climatic conditions do not provide a secure basis for dating individual fossil floras. Instead, age assignments must be based upon accumulated knowledge of the stratigraphic ranges of the individual species represented in the megafossil floras and of the considerably longer local stratigraphic ranges of the individual genera constituting the microfossil floras. Heer (1869), in basing his Miocene age assignment of certain Kenai floras upon the supposed presence in them of plant species found in Miocene beds in Switzerland, was more nearly correct than his critics, who named these floras "the Arctic Miocene" and diagnosed them as Eocene throughout the next 80 years because they believed that an Eocene flora found in northern latitudes should resemble a Miocene flora found in middle latitudes!

FOSSIL-PLANT LOCALITIES

Description of some fossil-plant localities in Chickaloon Formation

USGS Paleobotany locality	Description of locality, collector and year (if known)
5892	Lat 61°40.3′ N., long 149°03.5′ W. North side of Alaska Railroad cut on north side of Matanuska River. About 1,500 ft above base of formation. Anchorage (C–6) quad. Martin, 1910; Hopkins and Wolfe, 1962.
9870	Lat 61°42.6′ N., long 149°05′ W. At new cut at old Baxter mine on east side of Moose Creek valley. Premier coal group. Anchorage (C–6) quad. Hopkins and Wolfe, 1962.
9871	Lat 61°45.2′ N., long 148°52.9′ W. Hanging wall of strip pit topographically high in Mrak mine. Stratigraphically below 9872. Anchorage (D–6) quad. Hopkins and Wolfe, 1962.
9872	Lat 61°44.9′ N., long 148°53.5′ W. Hanging wall of strip pit topographically lower than 9871 in Mrak mine. Stratigraphically above 9871. Anchorage (C–6) quad. Hopkins and Wolfe, 1962.

Description of some fossil-plant localities in Chickaloon Formation—Continued

USGS Paleobotany locality	Description of locality, collector and year (if known)
9873	Lat 61°44.8′ N., long 148°52.8′ W. Hanging wall of strip pit topographically lower than 9872 in Mrak mine. Stratigraphically above 9872. Anchorage (C–6) quad. Hopkins and Wolfe, 1962.
9874	Lat 61°38.3′ W., long 148°57.5′ W. West side of valley of Wolverine Creek. Anchorage (C–6) quad. Hopkins and Wolfe, 1962.
9877	Lat 61°48.0′ N., long 147°59.5′ W. North side of cut along old Glenn Highway. Anchorage (D–3) quad. Hopkins and Wolfe, 1962.
9881	Lat 61°44.4′ N., long 148°57.5′ to 148°58.4′ W. Collections from dumps of strip pits in Evan Jones mine. Between Premier (No. 5) and Jonesville (No. 3) coal groups. Anchorage (C–6) quad. Hopkins and Wolfe, 1962.

Description of megafossil-plant localities in Kenai and Tsadaka Formations

USGS Paleobotany locality	Description of locality, stage assignment, and collector and year (if known)
3505	Chinitna Bay, near entrance to bay on north side. From sandstone at top of exposure above conglomerate. Seldovian(?). Stanton and Martin, 1904.
4129	At entrance to Troublesome Gulch. Seldovia (C–5) quad. Homerian. Weaver, 1906.
4130	0.5 mile south of town of Old Tyonek on sea cliff. Tyonek (A–4) quad. Homerian. Weaver, 1906.
4131	Near entrance to Fritz Creek, Kachemak Bay. Seldovia (C–4) quad. Homerian. Weaver, 1906.
5820	Bluff Point, 7 miles west of Homer, "30 ft. below Bradley coal" according to the specimen label, but F. F. Barnes informs us that the Cooper coal bed is the only named coal bed present at Bluff Point. Seldovia (C–5) quad. Homerian. Stone and Stanton, 1904.
5821	Talus on beach at Bluff Point about 1.5 miles west of Cook Inlet Coal Field Company's mine. Seldovia (C–5) quad. Homerian. Stone and Stanton, 1904.
6061	2.5 miles southwest of Point Naskowhak. Seldovia (B–5) quad. Seldovian. Martin, 1911.
6063	From Cache Creek, 1.5 miles above Cache Creek Mining Company's camp. Talkeetna (B–2) quad. Seldovian. Capps, 1911.
6066	Mills Creek Basin, Chicago Gulch. Talkeetna (B–4) quad. Seldovian. Capps, 1911.
8380	Lat 61°41′ N., long 149°08′ W. Core material. Anchorage (C–6) quad. Seldovian. Waring and Davidson, 1932.
9359	Lat 61°42.1′ N., long 149°05.6′ W. West side of Tsadaka Canyon. Anchorage (C–6) quad. Seldovian. Barnes, Bender, and Brown, 1955; Hopkins and Wolfe, 1962.
9360	Lat 60°01.8′ N., long 151°42.1′ W. 0.75 mile south of mouth of Deep Creek. Kenai (A–5) quad. Clamgulchian. Bender and Brown, 1955.

Description of megafossil-plant localities in Kenai and Tsadaka Formations—Continued

USGS Paleobotany locality	*Description of locality, stage assignment, and collector and year (if known)*
9361	Lat 59°39.4′ N., long 151°26.3′ W. Sea cliff about 1 mile south of Millers Landing. Seldovia (C–4) quad. Homerian. Barnes, Bender, and Brown, 1955; Wolfe, 1962.
9364	Lat 61°39.8′ N., long 149°27.9′ W. On Coal Creek. Anchorage (C–7) quad. Seldovian. Barnes, Bender, and Brown, 1955.
9365	Same as USGS Cenozoic loc. 23343. Lat 61°38.4′ N., long 149°50.8′ W. In Houston strip pit. Anchorage (C–8) quad. Seldovian. Barnes and Brown, 1955; Hopkins and Wolfe, 1962.
9366	Lat 59°40.3′ N., long 151°42.4′ W. 0.25 mile northwest of mouth of Diamond Creek. Seldovia (C–5) quad. Homerian. Bender and Brown, 1955.
9760	0.25 mile west of southern tip of Redoubt Point. Kenai (B–6) quad. Seldovian. Gulf Oil Corp.
9761	Cape Douglas. Afognak quad. Seldovian. Gulf Oil Corp.
9763	Lat 60°11.5′ N., long 150°28.5′ W. Sea cliff north of Ninilchik. Clamgulchian. Gulf Oil Corp.
9844	Lat 61°07.1′ N., long 151°18.1′ W. South bank of Chuitna River. Tyonek (A–4) quad. Homerian. Barnes, 1961; Wolfe, 1962.
9845	Lat 61°18.9′ N., long 151°46.2′ W. Cliffs on south side of Capps Glacier. Tyonek (B–5) quad. Seldovian. Wolfe, 1962.
9846	Lat 61°16.7′ N., long 151°45.1′ W. West side of high hill. Tyonek (B–5) quad. Seldovian. Barnes, 1961; Wolfe, 1962.
9848	Lat 61°14.2′ N., long 151°14.7′ W. South bank of Beluga River. Tyonek (A–4) quad. Seldovian. Wolfe, 1962.
9849	Lat 61°15.1′ N., long 151°14.4′ W. North bank of Beluga River. Tyonek (B–4) quad. Seldovian. Wolfe, 1962.
9850	Lat 61°25.6′ N., long 151°31.2′ W. East bank of Coal Creek. Tyonek (B–5) quad. Seldovian. Wolfe, 1962.
9851	Lat 59°38.6′ N., long 151°35.1′ W. In sea cliffs west of Homer. Seldovia (C–5) quad. Homerian. Wolfe, 1962.
9852	Lat 59°43.2′ N., long 151°49.4′ W. 0.25 mile south of Mutnala Gulch in sea cliffs. Seldovia (C–5) quad. Homerian. Wolfe, 1962.
9853	Lat 59°40.9′ N., long 151°22.6′ W. Just west of mouth of Fritz Creek. Seldovia (C–4) quad. Homerian. Wolfe, 1962.
9854	Lat 59°45.1′ N., long 151°10.2′ W. 0.33 mile west of mouth of Eastland Creek. Seldovia (C–4) quad. Clamgulchian. Wolfe, 1962.
9855	Lat 59°44.0′ N., long 151°12.4′ W. 0.25 mile west of mouth of Cottonwood Creek. Seldovia (C–4) quad. Clamgulchian. Wolfe, 1962.
9856	Lat 59°23.7′ N., long 151°53.7′ W. North side of Coal Cove on Port Graham, probably the "Sinus Anglorum" (English Bay) locality of Heer. Seldovia (B–6) quad. Seldovian. Hopkins, Schmidt, and Wolfe, 1962.
9857	Lat 59°25.0′ N., long 151°53.1′ W. 0.6 mile south of Point Pogibshi. Seldovia (B–6) quad. Seldovian. Hopkins, Schmidt, and Wolfe, 1962.
9858	Lat 59°28.3′ N., long 151°40.6′ W. 0.7 mile east of Seldovia Point. Seldovia (B–5) quad. Seldovian. Hopkins, Schmidt, and Wolfe, 1962.
9859	Lat 59°49.2′ N. long 151°07.4′ W. East bank of Swift Creek. Seldovia (D–4) quad. Clamgulchian. Hopkins and Wolfe, 1962.
9860	Lat 60°15.2′ N., long 151°23.5′ W. Sea cliffs 0.9 mile north of Clam Gulch. Kenai (B–4) quad. Clamgulchian. Hopkins and Wolfe, 1962.
9861	Lat 60°15.7′ N., long 151°23.3′ W. Sea cliffs 1.5 miles north of Clam Gulch. Kenai (B–4) quad. Clamgulchian. Hopkins and Wolfe, 1962.
9862	Lat 60°12.5′ N., long 151°25.5′ W. Sea cliffs 2.4 miles south of Clam Gulch. Kenai (A–4) quad. Clamgulchian. Hopkins and Wolfe, 1962.
9863	Lat 61°19.1′ N., long 149°36.5′ W. South bank of Eagle River. Anchorage (B–7) quad. Seldovian. Hopkins and Wolfe, 1962.
9864	Same as USGS Cenozoic loc. 23368. Lat 61° 18.7′ N., long 149°34.8′ W. South bank of Eagle River. Anchorage (B–7) quad. Seldovian. Hopkins and Wolfe, 1962.
9865	Lat 61°39.4′ N., long 149°27.8′ W. North bank of Little Susitna River. Anchorage (C–7) quad. Seldovian. Hopkins and Wolfe, 1962.
9866	Lat 61°41.7′ N., long 149°14.7′ W. West bank of Little Susitna River. Anchorage (C–6) quad. Seldovian. Hopkins and Wolfe, 1962.
9867	Lat 62°29.4′ N., long 150°58.7′ W. South side of Cache Creek opposite mouth of Rambler Creek. Talkeetna (B–2) quad. Seldovian. Hopkins and Wolfe, 1962.
9868	Lat 62°29.9′ N., long 150°56.9′ W. South side of Cache Creek. Talkeetna (B–2) quad. Homerian. Hopkins and Wolfe, 1962.
9883	Near mouth of Happy Creek. Seldovia (D–5) quad. Clamgulchian. Benninghof, 1955.
9884	North of Harriet Point. Sec. 13, T. 5 N., R. 18 W. Kenai (C–6) quad. Seldovian. Shell Oil Co.
9885	North of Harriet Point. Sec. 25, T. 5 N., R. 18 W. Kenai (B–6) quad. Seldovian. Shell Oil Co.
9886	North of Harriet Point. Sec. 15, T. 4 N., R. 18 W. Kenai (B–6) quad. Seldovian. Shell Oil Co.

Description of megafossil-plant localities in Kenai and Tsadaka Formations—Continued

USGS Paleobotany locality	*Description of locality, stage assignment, and collector and year (if known)*
9887	Near Redoubt Point. Sec. 33, T. 3 N., R. 18 W. Kenai (B-6) quad. Seldovian. Shell Oil Co.
9937	Lat 61°18.4′ N., long 151°46.5′ W. Cliffs on south side of Capps Glacier. Tyonek (B-5) quad. Seldovian. British Petroleum Co., 1962.
9945	On Harriet Creek, 21.85 miles east and 30.15 miles north of southwest corner of Kenai quad. (Scale 1:250,000). Kenai (B-6) quad. Seldovian. Mobil Oil Co.

Description of microfossil-plant localities in Kenai Formation

USGS locality, Denver catalog	*Description of locality, stage assignment, and collector and year*
D1717	Lat 61°06.8′ N., long 151°20.4′ W. Tyonek (A-4) quad. Homerian. Barnes, 1961.
D1718	Lat 61°09.3′ N., long 151°30′W. Tyonek (A-5) quad. Seldovian. Barnes, 1961.
D1719	Lat 61°9.4′ N., long 151°30.4′ W. Tyonek (A-5) quad. Seldovian. Barnes, 1961.
D1720	Lat 61°10.2′ N., long 151°34.1′ W. Tyonek (A-5) quad. Seldovian. Barnes, 1961.
D1775	Sec. 34, T. 51 S., R. 14 W. Kenai (A-5) quad. Clamgulchian. Barnes, 1960.
D1776	Sec. 24, T. 6 S., R. 14 W. Seldovia (C-4) quad. Homerian. Barnes, 1960.
D1943	Same as loc. 9860. Kenai (B-4) quad. Clamgulchian. Hopkins and Wolfe, 1962.
D1944	Same as loc. 9858. Seldovia (B-5) quad. Seldovian. Hopkins, Schmidt, and Wolfe, 1962.
D1945	Carbonaceous claystone 30 ft stratigraphically above loc. 9859. Seldovia (D-4) quad. Clamgulchian. Hopkins and Wolfe, 1962.
D1946	Same as loc. 9845. Tyonek (B-5) quad. Seldovian. Wolfe, 1962.
D1947	Same as loc. 9366. Seldovia (C-5) quad. Homerian. Bender and Brown, 1955.
D1948	Coal bed 10 ft stratigraphically below loc. 9853. Seldovia (C-4) quad. Homerian. Wolfe, 1962.
D1949	Coal bed about 30 ft stratigraphically below loc. 9844. Tyonek (A-4) quad. Seldovian. Wolfe, 1962.
D1950	Coal bed 30 ft stratigraphically above loc. 9851. Seldovia (C-5) quad. Homerian. Wolfe, 1962.
D1951	Coal bed 130 ft stratigraphically above loc. 9851. Seldovian (C-5) quad. Homerian. Wolfe, 1962.
D1952	Coal bed about 125 ft stratigraphically lower than loc. 9846. Lat 61°15′ N., long 151°45′ W. Tyonek (B-5) quad. Seldovian. Wolfe, 1962.
D1953	Coal bed about 150 ft stratigraphically above loc. 9845. Tyonek (B-5) quad. Seldovian. Wolfe, 1962.
D1954	Same as loc. 9854. Seldovia (C-4) quad. Clamgulchian. Wolfe, 1962.
D1955	Same as loc. 9855. Seldovia (C-4) quad. Clamgulchian. Wolfe, 1962.
D1973	Same as loc. 9857. Seldovia (B-6) quad. Seldovian. Hopkins, Schmidt, and Wolfe, 1962.

Description of fossil-plant localities outside the Cook Inlet region mentioned in text

USGS Paleobotany locality	*Locality description, stratigraphic assignment, and collector and year (if known)*
3519	About 1 mile east of north from Alaska Packers Association cannery at Chignik and about 200 yd south of native village. Paleocene. Chignik quad. Stanton, 1904.
3522	From steeply inclined beds in valley of creek about 1 mile northeast of Pacific Packing and N. W. Company cannery, Anchorage Bay. Paleocene. Chignik quad. Stanton and Stone, 1904.
3523	Talus slopes on mountain about 1 mile southeast of Pacific Packing and N. W. Company cannery, Anchorage Bay. Chignik quad. Paleocene. Stanton and Stone, 1904.
3652	Head of Hamilton Bay, Kupreanof Island. Petersburg quad. Paleocene. Kindle, 1905.
4389	South side of Hamilton Bay, near head. Highest of three horizons. Petersburg quad. Paleocene. Atwood, 1907.
4391	South side of Hamilton Bay, near head. Intermediate of three horizons. Petersburg quad. Paleocene. Atwood, 1907.
4392	South side of Hamilton Bay, near head. Lowest of three horizons. Petersburg quad. Paleocene. Atwood, 1907.
5182	West side of Herendeen Bay, opposite Marble Point. Port Moller quad. Homerian. Atwood and Eakin, 1908.
7474	Hamilton Bay, Kupreanof Island. Petersburg quad. Paleocene. Wright, 1904.
7565	Near head of Hamilton Bay, in middle of broad head land and on south side of bay. A little south of 4.25 miles true east of Point Hamilton, opposite 8.25 fathom mark. Petersburg quad. Paleocene. Buddington, 1922.
8680	Crooked River (tributary of Seventymile River), about 1 mile from mouth. Eagle quad. Paleocene. Mertie, 1938.
8681	Fourth of July Creek, about 7 miles from mouth. Charley River quad. Paleocene. Mertie, 1938.
9924	Lat 63°52.6′ N., long 148°40′ W. From interval of about No. 1 bed, on east side of Coal Creek. Healy (D-4) quad. Seldovian. Wolfe, 1963.
9933	Lat 61°39.7′ N., long 142°10.1′ W. South side of Skolai Creek. McCarthy (C-4) quad. Upper(?) Seldovian or Homerian(?). Wolfe, 1963.
9935	Lat 61°39.2′ N., long 142°40.7′ W. Northeast side of West Fork Glacier. McCarthy (C-5) quad. Upper(?) Seldovian. Wolfe, 1963.
10002	Lat 56°32′ N., long 154°07′ W. Sitkinak Island. Trinity Islands quad. Oligocene. Earle Taylor.
10003	Lat 56°32′ N., long 154°07′ W. Sitkinak Island. Trinity Islands quad. Oligocene. G. W. Moore, 1962.

FOSSIL-MOLLUSK LOCALITIES

Description of localities in Kenai and Chickaloon Formations

USGS Cenozoic locality	*Locality description, stratigraphic assignment, and collector and year*
23343	Same as USGS Paleobotany loc. 9365. Anchorage (C–8) quad. Kenai Formation. Seldovian. Barnes and Brown, 1955; Hopkins and Wolfe, 1962.
23367	Lat 61°48.2′ N., long 148°26.5′ W. Along west side of Chickaloon River. Anchorage (D–4) quad. Chickaloon Formation. Paleocene. Hopkins and Wolfe, 1962.
23368	Same as USGS Paleobotany loc. 9864. Anchorage (B–7) quad. Kenai Formation. Seldovian. Hopkins and Wolfe, 1962.
23396	Lat 61°13.4′ N., long 151°11.3′ W. Along north side of Beluga River. Tyonek (A–4) quad. Kenai Formation. Homerian(?). Barnes, 1962.

REFERENCES

Barnes, F. F., 1962a, Geologic map of lower Matanuska Valley, Alaska: U.S. Geol. Survey Misc. Geol. Inv. Map I–359.

——— 1962b, Topographic and geologic map of the Knob Creek area of the Wishbone Hill district, Matanuska coal field, Alaska: U.S. Geol. Survey Coal Inv. Map C–51.

——— 1962c, Variation in rank of Tertiary coals in the Cook Inlet basin, Alaska, *in* Short papers in geology and hydrology: U.S. Geol. Survey Prof. Paper 450–C, p. C14–C16.

——— 1966, Geology and coal resources of the Beluga-Yentna region, Alaska. U.S. Geol. Survey Bull. 1202–C, 54 p.

Barnes, F. F., and Cobb, E. H., 1959, Geology and coal resources of the Homer district, Kenai coal field, Alaska: U.S. Geol. Survey Bull. 1058–F, p. 217–260.

Barnes, F. F., and Payne, T. G., 1956, The Wishbone Hill district, Matanuska coal field, Alaska: U.S. Geol. Survey Bull. 1016, 88 p.

Barnes, F. F., and Sokol, Daniel, 1959, Geology and coal resources of the Little Susitna district, Matanuska coal field, Alaska: U.S. Geol. Survey Bull. 1058–D, p. 121–138.

Brooks, A. H., 1906, The geography and geology of Alaska: U.S. Geol. Survey Prof. Paper 45, 327 p.

Brown, R. W., 1962, Paleocene flora of the Rocky Mountains and Great Plains: U.S. Geol. Survey Prof. Paper 375, 119 p., 69 pls.

Capps, S. R., 1913, The Yentna district, Alaska: U.S. Geol. Survey Bull. 534, 75 p.

——— 1927, Geology of the upper Matanuska Valley, Alaska: U.S. Geol. Survey Bull. 791, 92 p.

——— 1935, The southern Alaska Range: U.S. Geol. Survey Bull. 862, 101 p.

——— 1940, Geology of the Alaska Railroad region: U.S. Geol. Survey Bull. 907, 201 p.

Chaney, R. W., and Axelrod, D. I., 1959, Miocene floras of the Columbia Plateau, Pt. 2, Systematic considerations: Carnegie Inst. Washington Pub. 617, p. 135–237, 44 pls.

Dall, W. H., and Harris, G. D., 1892, Correlation papers: Neocene: U.S. Geol. Survey Bull. 84, p. 232–268.

Davison, K., 1963, Cook Inlet gas finds are important: World Oil, v. 157, no. 7, p. 92–98.

Gardner, J. S., and Ettingshausen, Constantin, 1879, A monograph of the British Eocene flora: London, Palaeontogr. Soc., 159 p.

Grantz, Arthur, and Jones, D. L., 1960, Stratigraphy and age of the Matanuska Formation, south-central Alaska, *in* Short papers in the geological sciences: U.S. Geol. Survey Prof. Paper 400–B, p. B347–B350.

Grantz, Arthur, and Wolfe, J. A., 1961, Age of the Arkose Ridge Formation, south-central Alaska: Am. Assoc. Petroleum Geologists Bull., v. 45, no. 10, p. 1762–1765.

Grantz, Arthur, Zeitz, Isidore, and Andreasen, G. E., 1963, An aeromagnetic reconnaissance of the Cook Inlet area, Alaska: U.S. Geol. Survey Prof. Paper 316–G, p. 117–134.

Hazzard, J. C., Moran, W. R., Lian, H. M., and Simonson, R. R., 1963, The search for oil in Alaska: an analysis of a successful exploration cycle, *in* Proceedings of the Second Symposium on the development of petroleum resources of Asia and the Far East: United Nations Econ. Comm. Asia and Far East, Mineral Resources Devel. ser. no. 18, v. 1, p. 372–380.

Heer, Oswald, 1868, Flora fossilis arctica: Zürich, J. Wurster and Co., v. 1, 192 p., 49 pls.

——— 1869, Flora fossilis alaskana: K. Svenska Vetenskapsakad. Handl., v. 8, no. 4, 41 p., 10 pls.

Hill, M. L., 1963, Here's how Alaska's search for oil is going at Cook Inlet: Oil and Gas Jour., v. 61, no. 26, p. 194–198.

——— 1963, Occurrences of petroleum in the Cook Inlet area, Alaska: World Petroleum Cong., 6th, Frankfurt, June 1963, Proc., sec. 1, paper 39, p. 509–517.

Hollick, Arthur, 1936, Tertiary floras of Alaska: U.S. Geol. Survey Prof. Paper 182, 185 p., 122 pls.

Karlstrom, T. N. V., 1964, Quaternary geology of the Kenai Lowland and glacial history of the Cook Inlet region, Alaska: U.S. Geol. Survey Prof. Paper 443, 69 p., 7 pls.

Kelly, T. E., 1963, Geology and hydrocarbons in Cook Inlet basin, Alaska: Am. Assoc. Petroleum Geologists, Mem. 2, p. 278–296.

Knowlton, F. H., 1894, A review of the fossil flora of Alaska, with descriptions of new species: U.S. Natl. Museum Proc., v. 17, p. 207–240.

——— 1904, Fossil plants from Kukak Bay: Harriman Alaska Exped., v. 4, p. 149–162.

Koch, B. E., 1959, Contribution to the stratigraphy of the nonmarine Tertiary deposits: Medd. om Grønland, v. 162, no. 1, p. 1–100.

——— 1963, Fossil plants from the lower Paleocene of the Agatdalen (Angmartussut) area, central Nugssuaq Peninsula, northwest Greenland: Medd. om Grønland, v. 172, no. 5, 120 p., 55 pls.

MacNeil, F. S., Wolfe, J. A., Miller, D. J., and Hopkins, D. M., 1961, Correlation of Tertiary formations of Alaska: Am. Assoc. Petroleum Geologists Bull., v. 45, no. 11, p. 1801–1809.

Martin, G. C., Johnson, B. L., and Grant, U. S., 1915, Geology and mineral resources of Kenai Peninsula, Alaska: U.S. Geol. Survey Bull. 587, 243 p.

Martin, G. C., and Katz, F. J., 1912, Geology and coal fields of the lower Matanuska Valley, Alaska: U.S. Geol. Survey Bull. 500, 98 p.

Moffitt, F. H., 1927, The Iniskin-Chinitna Peninsula and the Snug Harbor district, Alaska: U.S. Geol. Survey Bull. 789, 71 p.

Parkinson, L. J., 1962, One field, one giant . . . the story of Swanson River: Oil and Gas Jour., v. 60, no. 13, p. 180–183.

Payne, T. G., 1955, Mesozoic and Cenozoic tectonic elements of Alaska: U.S. Geol. Survey Misc. Geol. Inv. Map I–84.

Tuck, Ralph, 1934, The Curry district, Alaska: U.S. Geol. Survey Bull. 862–C, p. 99-140.

——— 1937, The Eska Creek coal deposits, Matanuska Valley, Alaska: U.S. Geol. Survey Bull. 880–D, p. 185–214.

Waring, G. A., 1934, Core drilling for coal in the Moose Creek area, Alaska: U.S. Geol. Survey Bull. 857–E, p. 155–173.

——— 1936, Geology of the Anthracite Ridge coal district, Alaska: U.S. Geol. Survey Bull. 861, 57 p.

Wolfe, J. A., 1962, A Miocene pollen sequence from the Cascade Range of northern Oregon, *in* Short papers in geology and hydrology: U.S. Geol. Survey Prof. Paper 450–C, p. C81–C84.

——— 1966, Tertiary plants from the Cook Inlet region, Alaska: U.S. Geol. Survey Prof. Paper 398–B., 31 p.

Wood, H. E. and others, 1941, Nomenclature and correlation of the North American continental Tertiary: Geol. Soc. America Bull., v. 52, no. 1, p. 1–48.