The Coal-Bearing Group in the Nenana Coal Field, Alaska

By CLYDE WAHRHAFTIG, JACK A. WOLFE, ESTELLA B. LEOPOLD, *and* MARVIN A. LANPHERE

CONTRIBUTIONS TO STRATIGRAPHY

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CONTENTS

ILLUSTRATIONS

TABLES

CONTRIBUTIONS TO STRATIGRAPHY

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Abstract

The coal-bearing group of rocks of the Nenana coal field in the central part of the Alaska Range is formally subdivided into five new formations, in ascending order: the Healy Creek, Sanctuary, Suntrana, Lignite Creek, and Grubstake Formations. Fossil leaves and pollen indicate that the coal-bearing group, which is wholly continental, ranges in age from the late Oligocene through the late Miocene. Volcanic glass from the Grubstake Formation has an apparent age of 8.1 million years, based on potassium-argon analyses.

INTRODUCTION

The Nenana coal field in the northern foothills of the Alaska Range is a group of synclinal basins containing coal-bearing rocks of Tertiary age. The coal field was probably discovered about 1898, but the first geologic observations were by A. H. Brooks and L. M. Prindle in 1902 and 1906 (Brooks, in Collier, 1903, p. 46; Prindle, 1907; Brooks, 1911, p. 95–103). Brooks and Prindle correlated the coal-bearing beds with the Kenai Formation. Capps (1912, p. 26–29), who outlined the coal basins about as we know them today, first called the coal-bearing rocks simply the "coal-bearing beds of early Tertiary (Eocene?) age," and this usage was followed by Martin (1919) in his detailed study of the central part of the coal field. By 1919, however, Capps (1919, p. 44–51) was referring to these rocks as the Tertiary coal-bearing formation, and this usage has been in general practice to the present day (Capps, 1924, p. 103; 1932, p. 272; 1940, p. 118; Wahrhaftig and others, 1951, where the rocks are called the coal-bearing formation (Tertiary); Wahrhaftig, 1958, p. 9; Péwé and others, 1966, where the rocks are referred to informally as the coal-bearing formation).

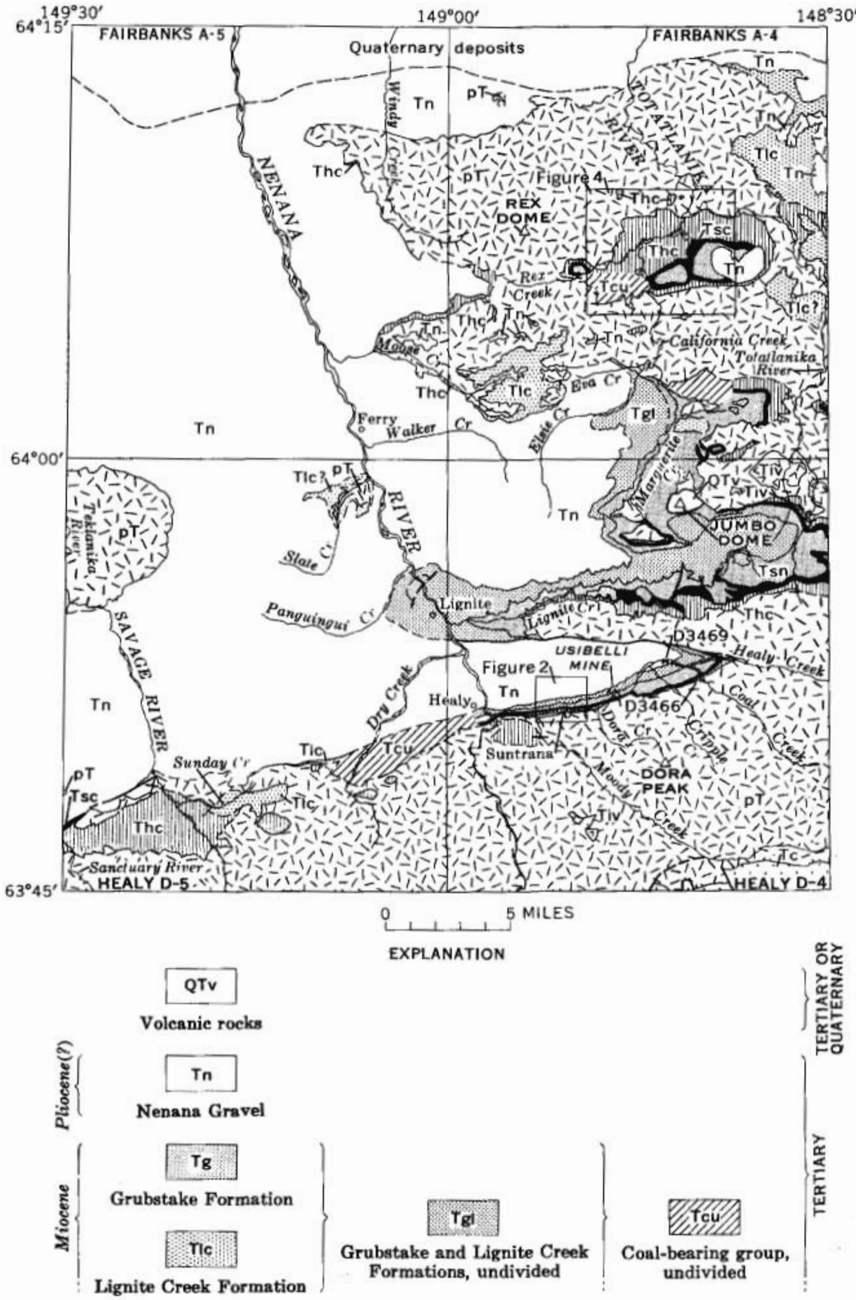

FIGURE 1.—Generalized geologic map of the Healy D–2, D–3, D–4, and D–5 quadrangles and the Fairbanks A–2, A–3, A–4, and A–5 quadrangles, showing distribution of Tertiary formations and localities mentioned in text.

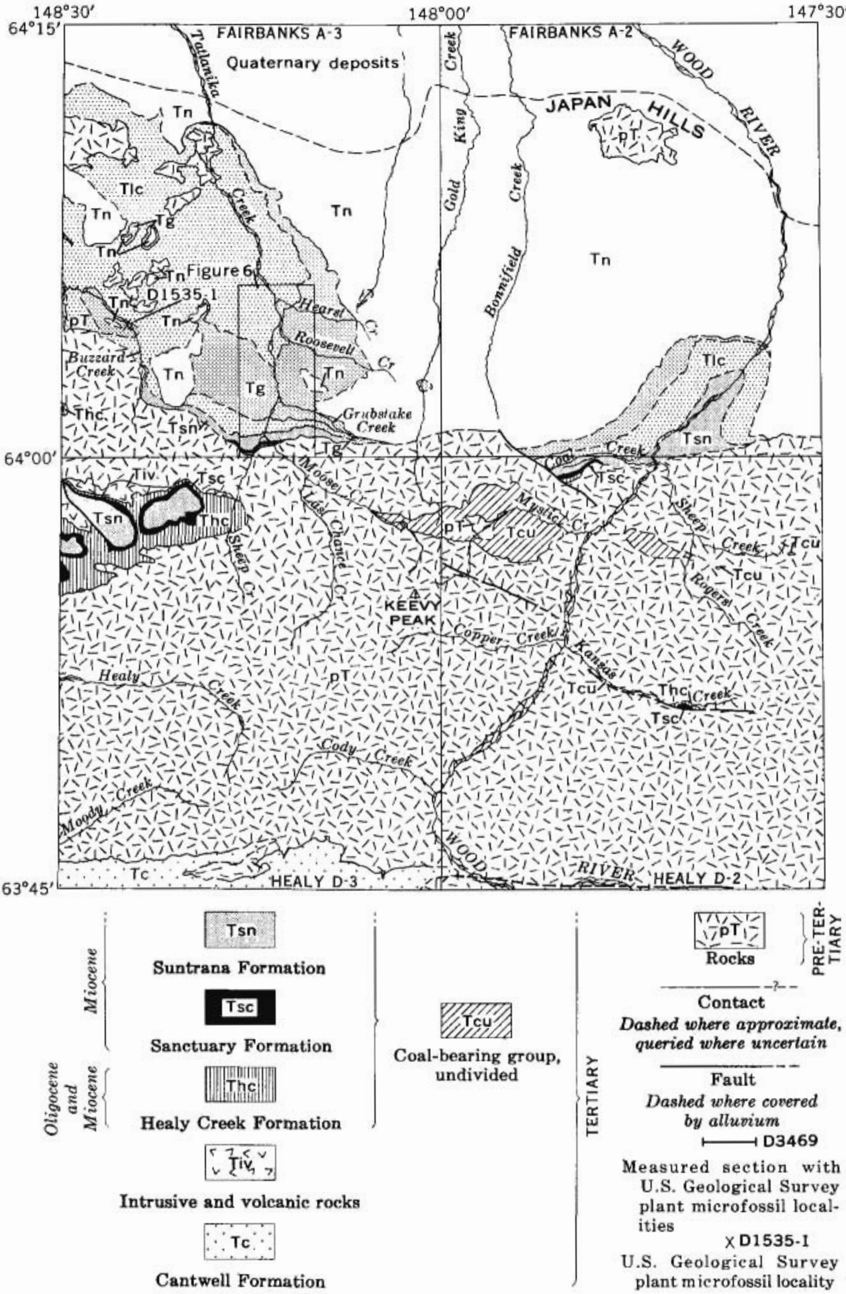

FIGURE 1.—Continued.

In this paper the coal-bearing formation is informally designated a group and is divided into five formations; four of the five formations are assigned to provincial floral stages recognized in the Cook Inlet region (Wolfe and others, 1966). This stratigraphic revision is the outgrowth of about 15 seasons of geologic mapping of the Nenana coal field and surrounding areas, between the years 1943 and 1958 (Wahrhaftig and others, 1951; Wahrhaftig, 1951; Wahrhaftig and Hickcox, 1955; Wahrhaftig and Birman, 1954; Wahrhaftig, 1958). The areal results of this mapping appear as geologic quadrangle maps of eight 15-minute quadrangles (Wahrhaftig, 1968a—1968h). The areal distribution of the Tertiary formations is shown in figure 1, which is generalized from the eight geologic quadrangle maps. The age assignments are based on studies of plant megafossils and palynological materials collected throughout the history of the study of the coal field, but chiefly by Wolfe and Leopold in July 1963. A large quantity of volcanic ash from a bed in the Grubstake Formation, collected at that time, was dated by Lanphere with the results reported herein. The sections on physical stratigraphy are by Wahrhaftig. The biostratigraphy and age assignments are by Wolfe and Leopold.

COAL-BEARING GROUP

The informal term coal-bearing formation is here redesignated the coal-bearing group and is divided into five formations. The group is represented by the section continuously exposed in the E½ sec. 23 and SW¼ sec. 24, T. 12 S., R. 7 W., Fairbanks base line and meridian, Healy D–4 quadrangle, along the north bank of Healy Creek from a basal contact on the Birch Creek Schist at the Usibelli tipple westward to the mouth of Suntrana Creek and up Suntrana Creek for 2,500 feet where, at the forks of the creek, the coal-bearing group is overlain apparently conformably by the Nenana Gravel (figs. 1, 2). Four of the five formations into which the group is here divided have their type sections in this exposure, and a reference section for the fifth exists here (fig. 3).

Other places within the Nenana coal field that have nearly complete exposures of the group include the exposures on Lignite Creek in secs. 25 and 35, T. 10 S., R. 7 W. (in Healy D–4 quadrangle), about 6 miles above its mouth; the banks of

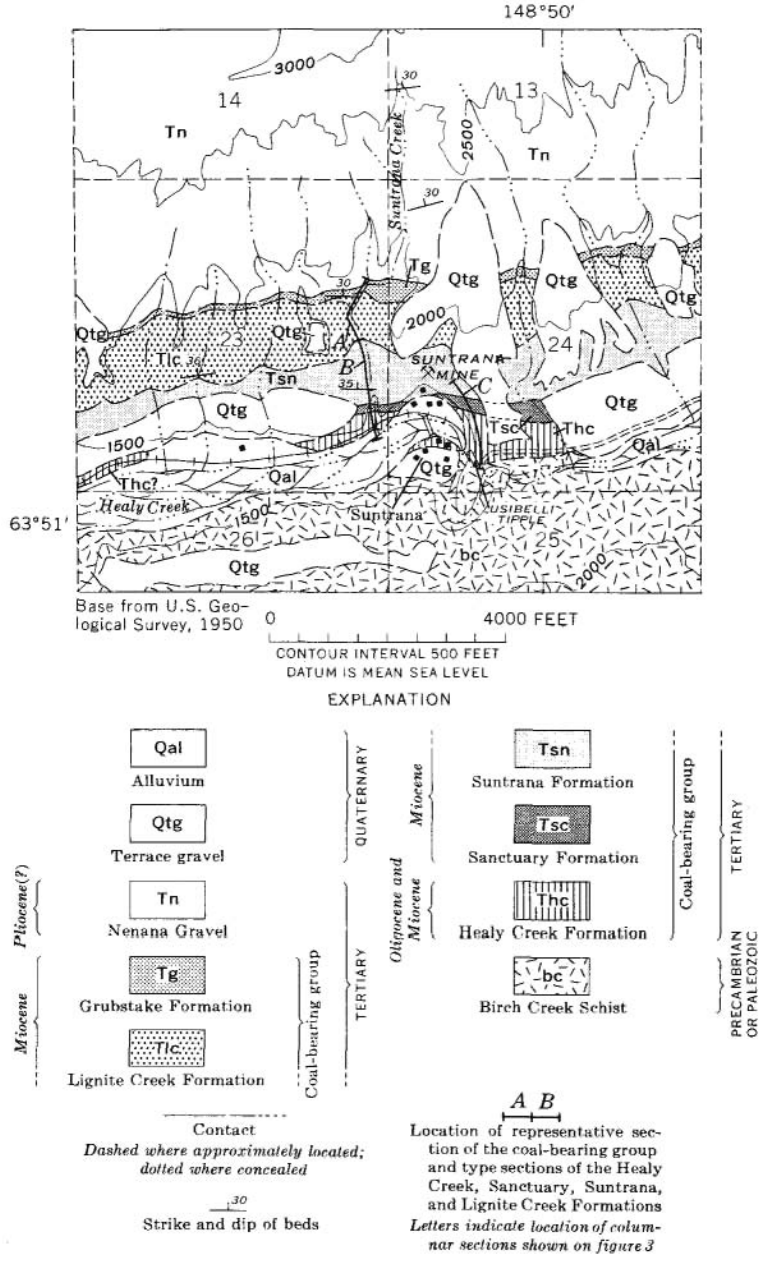

FIGURE 2.—Geologic map of secs. 23 and 24 and parts of secs. 13, 14, 25, and 26, T. 12 S., R. 7 W., Healy D-4 quadrangle, showing the Tertiary coal-bearing group and type localities for the Healy Creek, Sanctuary, Suntrana, and Lignite Creek Formations.

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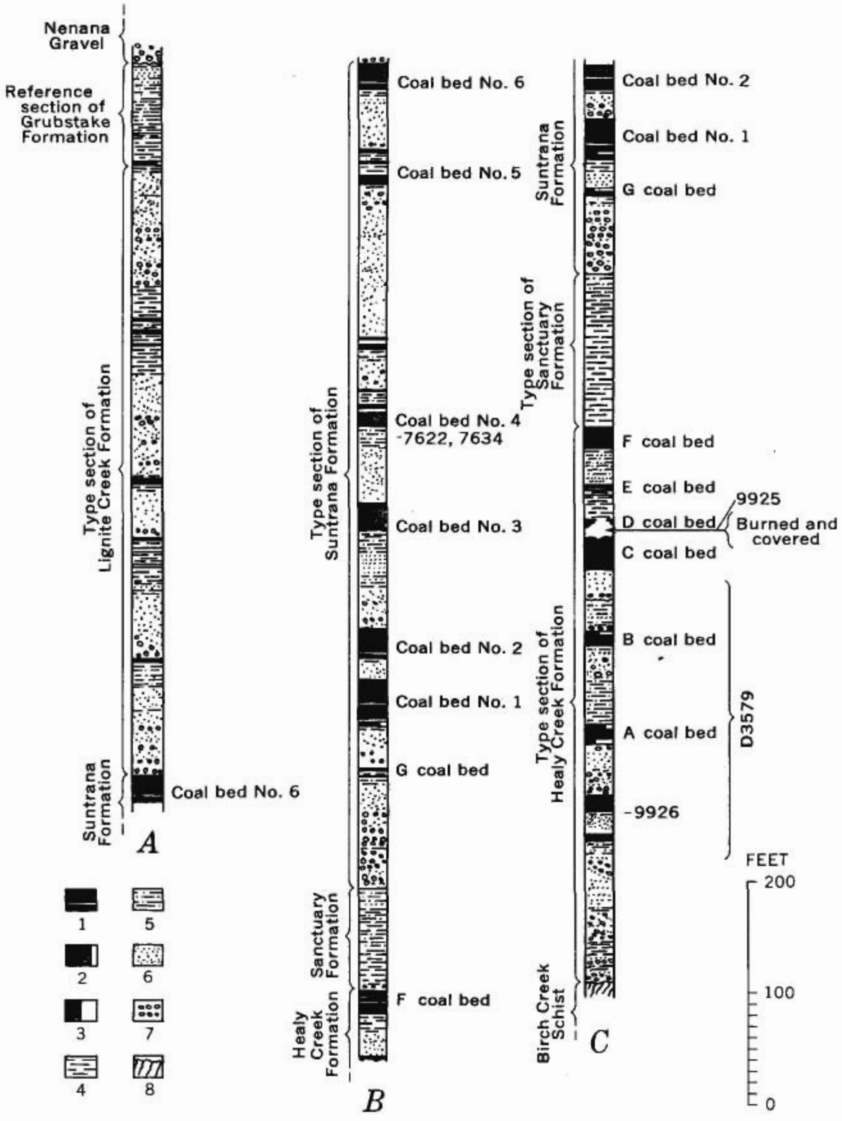

FIGURE 3.—Stratigraphic column of the type sections of the formations of the coal-bearing group at Suntrana, showing locations of plant megafossil localities and microfossil localities. Section *A*, measured along Suntrana Creek from coal bed No. 6 to the base of the Nenana Gravel; section *B*, measured along Suntrana Creek from near the railroad bridge to coal bed No. 6; section *C*, measured on the north bank of Healy Creek from the Usibelli tipple to top of the badland exposure east of the Suntrana mine. 1, coal (showing bone or clay parting); 2, bony coal; 3, bone; 4, claystone and shale; 5, siltstone; 6, sandstone, in part crossbedded; 7, pebbles and conglomerate; 8, schist (unconformity at top).

Tatlanika Creek and its headwaters, Moose Creek and Sheep Creek, from about 1,500 feet south of their junction northward to the mouth of Grubstake Creek (fig. 6); and the headwaters of Coal Creek, a tributary of the Wood River, in southwestern Fairbanks A–2 quadrangle and northwestern Healy D–2 quadrangle (fig. 1).

HEALY CREEK FORMATION

The lowest formation within the coal-bearing group is here named the Healy Creek Formation from exposures along Healy Creek in the Healy D–4 quadrangle. The Healy Creek Formation includes all strata of the coal-bearing group below the top of the F coal bed of the Suntrana coal mine. Its type section, in the SW¼ sec. 24, T. 12 S., R. 7 W., Fairbanks base line and meridian (figs. 2, and 3, section *C*), is the exposure on the northeast wall of the canyon of Healy Creek at Suntrana, from its basal contact with the unconformably underlying Birch Creek Schist a few feet south of the Usibelli tipple, northward for 1,000 feet to the top of the F coal bed, where it is overlain conformably by the brown-weathering shale of the Sanctuary Formation. The Healy Creek Formation includes all the lower member of the coal-bearing formation of Wahrhaftig, Hickcox, and Freedman (1951, p. 147–152) below the brown shale.

At the east end of the Healy Creek syncline, about 6½ miles east of the type section, the Healy Creek Formation includes beds that are probably much older than those of the type section. This is about the thickest well-exposed section of the Healy Creek in the Nenana coal field and is therefore designated a reference section. It includes beds on the south bank of Healy Creek between the basal unconformity at the east edge of sec. 12, T. 12 S., R. 6 W., and the top of the Moose coal bed, the stratigraphic equivalent of the F coal bed at Suntrana, about 2,000 feet west of the basal unconfomrity along the creek bank. (See Wahrhaftig and others, 1951, pl. 19, section M.)

The Healy Creek Formation is probably the most widely distributed of the formations that constitute the coal-bearing group, but its distribution is patchy (fig. 1). As the lower member of the coal-bearing formation, it was recognized from the Sushana River on the west (Wahrhaftig, 1951, p. 174–175) to the Jarvis Creek coal field on the east (Wahrhaftig and Hickcox, 1955, p. 359), a distance of 125 miles. Many if not most of the isolated patches of coal-bearing rocks, which are a few hundred yards to a mile or two across and are widely scattered throughout the Alaska Range and adjacent regions, should probably be correlated with the Healy Creek Formation.

The Healy Creek Formation was deposited on an irregular surface of considerable relief; in places this surface stood above the level of the base of the overlying formations, and in these places the Healy Creek Formation was never deposited. Because of this irregular basal surface, the thickness of the Healy Creek Formation varies markedly over short distances.

The maximum measured thickness in the Nenana coal field is 1,150 feet on the south side of the Lignite Creek coal basin near the western edge of Healy D–3 quadrangle (fig. 1). It is 800 feet thick at the east end of the Healy Creek coal basin and about 1,000 feet thick in the Mystic Creek coal basin. About 2,000 feet of beds in the Jarvis Creek coal field have been correlated on the basis of lithology with the Healy Creek Formation (Wahrhaftig and Hickcox, 1955, p. 357–359).

The Healy Creek Formation consists of interbedded poorly consolidated sandstone, conglomerate, claystone, and subbituminous coal. The most characteristic features of this formation are the lenticularity of its beds and the tendency for its lithologic components—pebbles, sand, clay, and coal—to be mixed together in the same bed rather than to be cleanly separated as they are in the overlying formations. Thus, many of the coals are thin bedded, lenticular, and bony, and thin claystone partings thicken abruptly and grade into coarse sandstone; sandstones, commonly have a clay binder; and claystones with pebbles and angular rock fragments are common, especially near the base of the formation.

The sandstone and conglomerate characteristically consist of materials from nearby basement rock. Where quartz-sericite schist is the basement, the characteristic sandstone is buff to cream and consists largely of grains of quartz and fine flakes of silvery sericite. The associated conglomerate generally consists wholly or largely of quartz pebbles, presumably derived from quartz veins in the schist. Where the basement is feldspathic schist and gneiss, the sandstone tends to be strongly arkosic and the associated conglomerate contains an abundance of pebbles of the schist and gneiss.

The Healy Creek Formation appears to have gradually buried a fairly rugged topography on the north side of the Alaska Range and its foothills by filling the valleys first and covering the hills later. Current directions, such as crossbedding, indicate a diversity of directions of streamflow during its accumulation. The prominent direction of streamflow was northward, which was probably the general direction of outflow from the area of the Nenana coal field to the sea at that time.

Biostratigraphy and Age

The flora, both megafossil and microfossil, of the Healy Creek Formation can be separated into two markedly distinct assemblages: the lower Healy Creek (or Rex Creek) flora and the upper Healy Creek flora.

The lower part of the Healy Creek Formation on Rex and California Creeks (fig. 4) contains a distinctive assemblage of fossil plants that has not been recognized elsewhere in Alaska. Two of the most characteristic species of this assemblage are new: *Alnus* sp. aff. *A. carpinoides* Lesq. and *Spiraea* sp. aff. *S. hopkinsi* Wolfe. This assemblage also contains *Engelhardia,* which is not known in Miocene rocks in Alaska, and *Sequoia affinis* Lesq., which is not known above the Oligocene; *S. affinis* probably is ancestral to the Miocene through Holocene species *S. sempervirens* Endl. Some of the Rex Creek species are known in the Tsadaka flora and its age equivalents; particularly noteworthy is the occurrence of *Alnus evidens* (Holl.) Wolfe because this species is thought to be ancestral to the early and middle Miocene *A. cappsi* (Holl.) Wolfe (Wolfe, 1966, p. B18).

The Tsadaka flora (and by inference the Tsadaka Formation) was placed in the lower(?) Seldovian, which was considered to be of latest Oligocene(?) and earliest Miocene age (Wolfe and others, 1966, p. A16–A17). At the time the Seldovian Stage was erected, it was thought that certain floras, although showing a close relationship to the floras of the type section of the Seldovian, were somewhat older, and these probably older floras were designated as lower(?) Seldovian floras (Wolfe and others, 1966, p. A15). At the time, no floras were known from the lowest part of the type section of the Seldovian Stage, and it was thought that lower(?) Seldovian floras might be represented in the type section. Additional collecting and study from

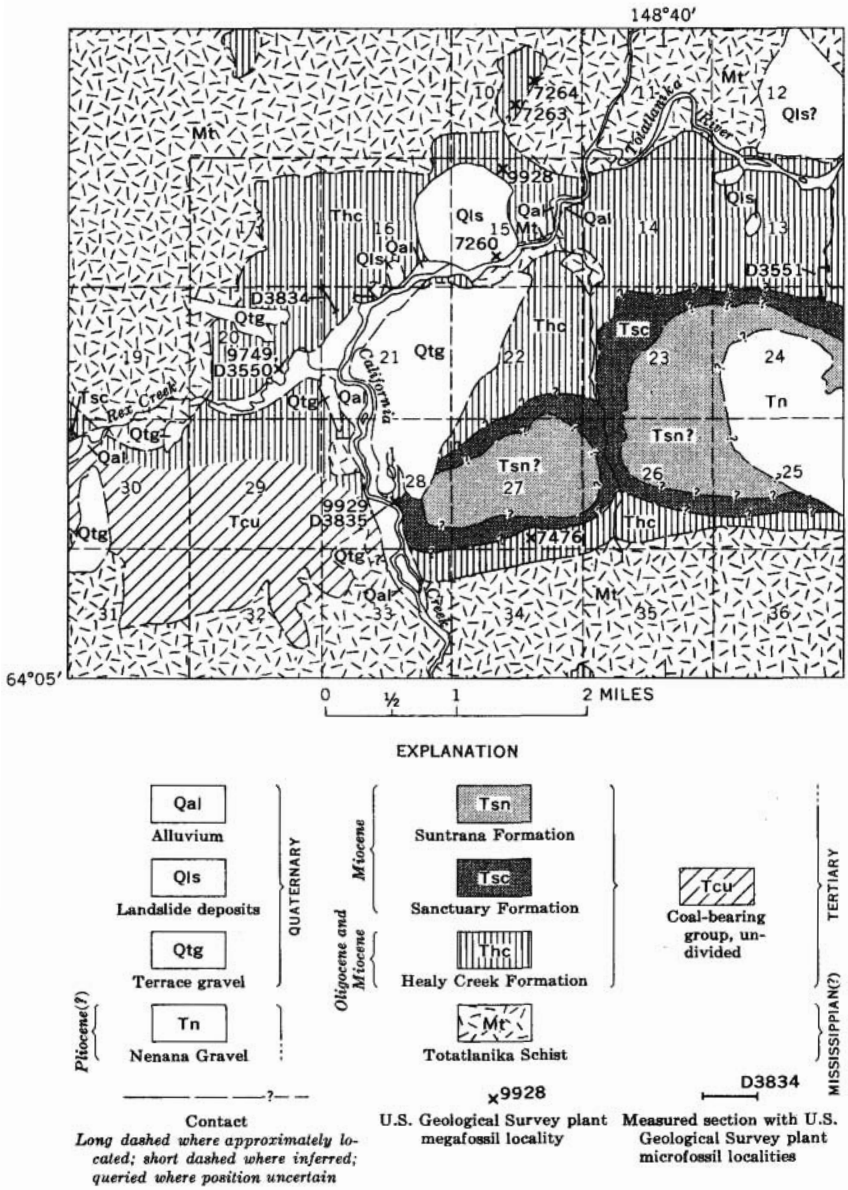

FIGURE 4.—Geologic map of part of T. 9 S., R. 6 W., Fairbanks A–4 quadrangle, showing plant fossil localities in the Rex Creek coal basin.

the type section has, however, indicated that the lowest floras from the type section of the Seldovian are those that were referred to as "upper(?) Seldovian." Therefore, the "lower(?) Seldovian. The Tsadaka flora and other "lower(?) Seldovian" cluded from the Seldovian, and the "upper(?) Seldovian" of former usage, of early and (or) middle Miocene age (Wolfe and others, 1966, p. A17), is now considered to be the only valid Seldovian. The Tsadaka flora and other "lower(?) Seldovian" floras are therefore considered to be of pre-Seldovian (pre-Miocene) age. Because the Rex Creek flora is close stratigraphically to true Seldovian floras, it is probably of late Oligocene age. The Tsadaka Formation and flora are probably older than the Rex Creek flora and are now considered to be of middle and late(?) Oligocene age.

The eight pollen and spore assemblages from the lower part of the Healy Creek Formation are perhaps even more distinctive than the megafossil assemblages. The lower part of section D3551 and the two samples at D3550 (fig. 4) are characterized by the most diverse pollen floras yet found in the coal-bearing group and by several forms not found elsewhere in the group. These forms include: *Aquilapollenites* n. spp. (heteropolar and isopolar), *Orbiculapollis, Saxifraga, Itea, Pachysandra/Sarcococca, Cuphea*-type, *Melia/Cedrela, Engelhardia/Alfaroa,* and *Proteacidites globisporus* Samoil. The species of *Aquilapollenites* are abundant in some samples and occur in most. *Engelhardia/Alfaroa* occurs in one-third of the samples, although it is not common in the tallies. All the samples contain a diversity of pollen that came from deciduous broad-leaved trees. Pollen of Pinaceae is present but is rare compared to that of Taxodiaceae. Of the 40 vascular plant genera identified, 60 percent are now exotic to Alaska; this is the highest percentage for any pollen assemblage from the coal-bearing group.

The flora from the upper part of the Healy Creek Formation (fig. 3, locs. 9925, 9926), is an assemblage clearly distinct from the older assemblage and is of Seldovian age. *Alnus healyensis, A. cappsi, Quercus furuhjelmi, Cocculus auriculata, and Cladrastis japonica* make their first appearances in the Alaska Range Tertiary rocks in the upper part of the Healy Creek Formation. A few species, for example *Ulmus appendiculata* Heer, *Betula* sp.

aff. *B. thor* Knowl., *and Carya* sp. aff. *C. simulata* (Knowl.) R. W. Br., appear to be ancestral to species that occur in early(?) and middle Miocene floras in conterminous United States. At least one of these species—*Betula* sp. aff. *B. thor*—occurs in floras of late Oligocene(?) and early Miocene age in Oregon. Thus, the Seldovian floras such as the upper Healy Creek flora are considered to be of early Miocene age.

The eight pollen assemblages from the upper part of the Healy Creek Formation contain several forms not found in the lower part: *Ephedra, Quercus, Nyssa,* and Compositae (only one grain of a short-spined type). In addition, the upper Healy Creek flora lacks the forms listed above that characterize the Rex Creek flora; the percentage of genera now exotic to Alaska is 58, which is slightly lower than that of the assemblage from the lower part of the Healy Creek. Pollen of *Viburnum,* which is also found in the Rex Creek flora, has not been found above the upper part of the Healy Creek Formation. The extinct genus *Gynkaletes* is apparently restricted to the upper Healy Creek flora. The pollen flora, in general, contains a diversity of the deciduous broad-leaved trees and is comparable to the pollen floras from the type and reference sections of the Seldovian Stage. The pollen thus substantiates that the upper part of the Healy Creek Formation is within the Seldovian Stage. Therefore, the Healy Creek Formation ranges in age from late(?) Oligocene to early Miocene, but in its type locality, is of early Miocene age only.

SANCTUARY FORMATION

The Sanctuary Formation is the brown-weathering shale that lies between the top of the F coal bed and the base of the coarse conglomerate beneath the No. 1 and G coal beds at the Suntrana mine, in SW¼ sec. 24, and SE¼ sec. 23, T. 12 S., R. 7 W., the type locality, in the Healy D–4 quadrangle (figs. 2, 3). The type section is designated as the outcrops east of the Suntrana tipple, shown on section *C* of figure 3. It is the "thick bed of yellowish-brown varved silt and clay" at the top of the lower member of the coal-bearing formation of Wahrhaftig, Hickcox, and Freedman (1951, p. 147). At the type locality the Sanctuary Formation is 90–130 feet thick and forms a prominent brown band of rounded landforms extending across the north wall of the badland amphitheatre in which the surface workings of the Suntrana mine are located. It is named for exposures of similar brown-weathering shale on the east bank of the Sanctuary River ¾ to 1 mile south of the north boundary of Mount McKinley National Park, which are believed to be the stratigraphic equivalent of the Sanctuary Formation at its type locality (Wahrhaftig, 1951, p. 176).

The Sanctuary Formation occupies an interval 350 feet thick between the Moose coal bed and the coal beds beneath the No. 1 bed at the east end of the Healy Creek coal basin (Wahrhaftig and others, 1951, pl. 19, section M). In the Lignite Creek coal basin it ranges in thickness from 5 to 250 feet. It is present in the Rex Creek coal basin (figs. 1, 4), at the head of Tatlanika Creek, on Coal Creek tributary to the Wood River, on Kansas Creek (fig. 1), and from the Sanctuary River southwestward to the divide between the Sushana and the Toklat Rivers (Wahrhaftig, 1951). It may be present in exposures on the east bank of the Delta River about 2½ miles west of Donnelly Dome in Mount Hayes D–4 quadrangle (Péwé and Holmes, 1964; Wahrhaftig and Hickcox, 1955, p. 359–360).

Over most of its area of exposure the Sanctuary Formation rests conformably on the Healy Creek Formation. However, to the north and northwest it overlaps the Healy Creek Formation to rest directly on schist and other basement rocks and is in turn cut out by overlap of the Suntrana Formation. The formation thickens southeastward from this line of overlap (shown in fig. 5), and its original southern limits are unknown.

The Sanctuary Formation is predominantly a gray shale that weathers to a characteristic chocolate brown or yellowish brown. In clean exposures, such as the narrow gully floors that score its outcrop at Suntrana, the shale is seen to be finely banded (possibly varved) with alternating pale-weathering and dark-weathering laminae a fraction of an inch to an inch thick. Exposures that exhibit bedding are rare, for the shale breaks down quickly on exposure to a mass of flat yellow-brown chips that have split along the bedding, and where it is continually saturated with water, it forms masses of brown to gray sticky mud and is the locus of persistent large landslides. Its yellow-brown color on weathered outcrops and the tendency to break into flat

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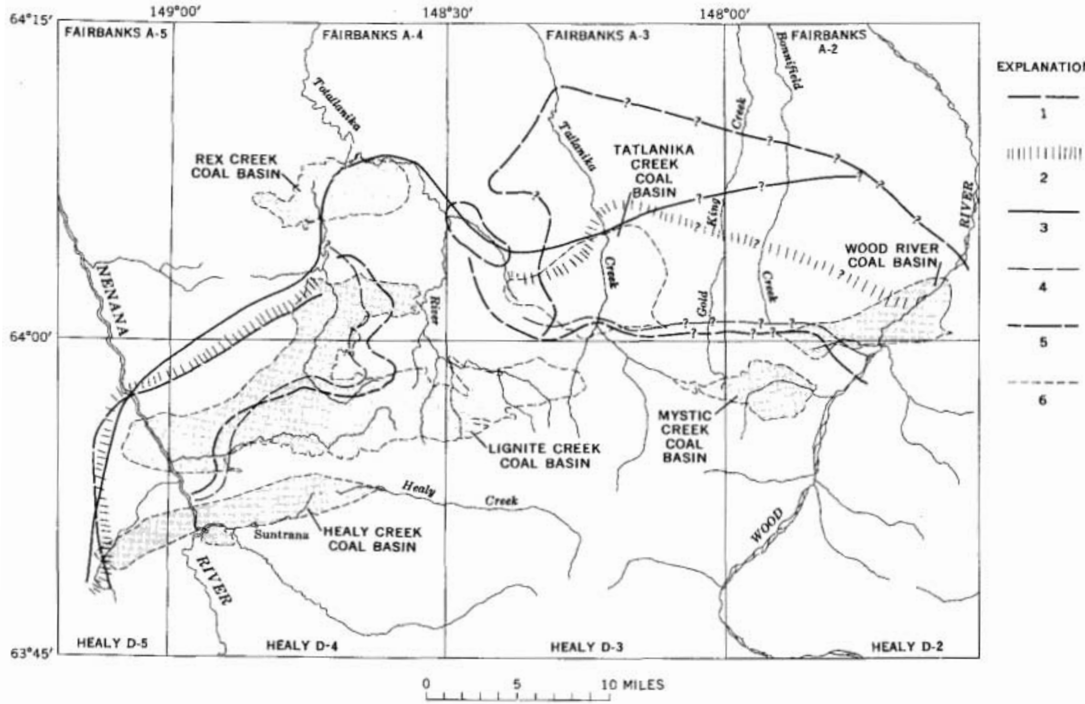

FIGURE 5.—Map of the Nenana coal field and environs, Central Alaska Range, showing the major coal basins of the coal field and northern limits of several of the formations. 1, northern limit of deposition of the Grubstake Formation; 2, approximate zone of interfingering of coal-bearing and noncoal-bearing facies of the Lignite Creek Formation; 3, northern limit of deposition of the Suntrana Formation; 4, northern limit of deposition of the Sanctuary Formation; 5, northern limit of deposition of the Healy Creek Formation; 6, boundary of coal basin.

yellow-brown chips make the Sanctuary Formation a useful stratigraphic marker in the Nenana coal field.

In the type section at the Suntrana mine the upper half of the formation is silty and contains numerous beds of fine sand a few inches to a few feet thick. Sand beds are common in the Sanctuary Formation elsewhere in the Nenana coal field. Coal and bone are also common near the top of the Sanctuary Formation in such places as upper Lignite Creek and Coal Creek on the Wood River.

The Sanctuary Formation probably accumulated in a large shallow lake, the north shore of which is the line of overlap of the Sanctuary Formation by the Suntrana Formation, shown in figure 5. The change from gradual burial of an old land surface, with deposition keeping pace with subsidence, which was the history of Healy Creek time, to flooding of a large area by a fresh-water lake, could only have been brought about by sudden increase in the rate of downwarping, depressing a large area below some local base level. The local basin of subsidence indicated by the southward and southeastward thickening of the Sanctuary Formation continued to subside during the period of accumulation of the overlying formations.

Biostratigraphy and Age

The megafossils from the Sanctuary Formation represent two species: *Metasequoia glytostroboides* Hu and Cheng and *Fagus antipofi* Heer. Thus far, the latter species has not been found in Alaska in rocks younger than Seldovian in age.

The microfossil flora, known from six samples from the Sanctuary Formation, is notable for the occurrence of numerous aquatic plants: dinoflagellate algae, algal cysts referred to *Tetraporina*, colonial bluegreen algae, *Nymphaea, Scirpus, Polygonum,* and *Myriophyllum.*

Pollen of deciduous broad-leaved trees is consistently represented in the Sanctuary pollen floras. Pollen of this element represents about 5 percent of the pollen tallied and is somewhat more common than in the upper part of the Healy Creek Formation. One sample has pollen of *Pinus* as a dominant, but in the other samples pollen of Taxodiaceae is more common than Pinaceae. Of the 33 identified vascular genera, 52 percent are now exotic to Alaska. This percentage in conjunction with the consistent representation of the deciduous broad-leaved tree element indicates that the Sanctuary Formation should be placed in the Seldovian Stage. Thus the Sanctuary is assigned to the early or middle Miocene or both.

SUNTRANA FORMATION

The Suntrana Formation is that part of the coal-bearing group between the top of the conformably underlying Sanctuary Formation and the top of the No. 6 coal bed which underlies, with apparent conformity, the Lignite Creek Formation at the Suntrana mine. It is equivalent to the middle member of the coal-bearing formation of Wahrhaftig, Hickcox, and Freedman (1951). It is named for its exposures on the walls of Suntrana Creek, the type locality, in SE¼ sec. 23, T. 12 S., R. 7 W., Healy D–4 quadrangle (fig. 2 and fig. 3, section *B*). All the numbered coal beds of the Suntrana mine are in the Suntrana Formation, and it contains the bulk of the coal reserves of the Nenana coal field, including nearly all the thick and persistent coal beds.

The Suntrana Formation is a many-times-repeated sequence with coarse pebbly sandstone grading upward from the base through medium- and fine-grained sandstone to clay and coal at the top. Generally there is only one thick coal bed at the top of each unit, but in some places two or three thin coal beds are interbedded with the claystone. In a typical sequence the sandstone at the base is 20–100 feet thick, the clay and silt unit is 2–15 feet thick, and the coal is 2–40 feet thick. On the average there are eight repetitions of this sequence in the formation, but in the northern part of the Lignite Creek coal basin there are as few as five or six, and in the sections at the head of Lignite Creek and at the east end of the Healy Creek coal basin there are as many as 10 or 12. The formation as a whole averages about 70 percent sandstone (including pebble beds) and 15 percent each coal and clay.

The sandstone is poorly consolidated, generally clean, well sorted, and crossbedded. It is chalk white to very light buff, although it may be stained by iron oxide to orange or red for a foot or two above each coal bed. In the field this type of sandstone was called salt-and-pepper sandstone because under a hand lens it is seen to consist predominantly of white grains with a scattering of black- to dark-gray grains of chert. This salt-and-pepper appearance is quite different from that of the more colorful sandstone of the overlying Lignite Creek Formation. Petrographic studies by M. C. Blake (written commun., 1959) showed that quartz makes up 70–75 percent of the sandstone; orthoclase, 5–10 percent; plagioclase, 1–5 percent; chert and rock fragments, 5–10 percent; and heavy minerals, chiefly of low-grade metamorphic suites, 6½ percent.

The pebbles, which average ¼ to 1 inch in diameter, consist of more than 65 percent quartz, chert, quartzite, argillite, and jasper—resistant rock types—and of less than 35 percent nonresistant rocks such as granitic rocks, gabbro, greenstone, graywacke, or volcanic rocks. Below the No. 5 coal bed the proportion of resistant rock types in the pebble population is about 80 percent.

The coal beds, which are generally 10–60 feet thick, can be traced laterally for long distances and appear to thicken regularly to a single maximum for each bed, located either in the eastern part of the Healy Creek coal basin or in the southern part of the Lignite Creek coal basin. The coal is black with a dark-brown streak, is comparatively low in ash, and characteristically breaks into small equidimensional blocks.

The Suntrana Formation appears to have accumulated in a subsiding basin whose axis lay at the south edge or to the south of the present coal field. Current directions indicated by the persistent crossbedding of the sandstone are predominantly southward in the Healy Creek and Lignite Creek coal basins and are westward in the Tatlanika Creek and Wood River coal basins. The source area of the clastic components probably lay in the southern Yukon-Tanana Upland, including the area of the Livengood Chert (Mertie, 1937, p. 105–111).

The lateral continuity of the coal beds and of the intervening sandstones indicates that at any one time conditions throughout the coal basin were fairly uniform, but that they alternated between periods when the entire plain was a coal-forming swamp and periods when vigorous streams from the north were depositing sheets of gravel and sand over the plain.

The Suntrana Formation is widely exposed in the Healy Creek and Lignite Creek coal basins and may also occur in the center of the Rex Creek coal basin. It is exposed at the head of Tatlanika Creek and in the large badland at the head of Coal Creek on the Wood River. It is apparently absent from the western part of the Nenana coal field (Wahrhaftig, 1951).

The Suntrana Formation pinches out northward along a line shown in figure 5. Southward from this line, the formation thickens at a rate of 50–100 feet per mile to maximum measured thicknesses of 1,000 feet on Coal Creek on the Wood River and of 1,290 feet on Coal Creek on Healy Creek. The individual coal beds and sandstone units of the Suntrana Formation also thicken regularly southward, but some of these reach their maximum thickness in the Lignite Creek coal basin.

Biostratigraphy and Age

The megafossil flora of the Suntrana Formation is not well known, primarily because the lack of induration of the shales makes collecting entire leaves difficult. Species of *Salix* and *Populus* are typically the most abundant leaves at each locality. Leaves of broad-leaved tree genera now exotic to Alaska are, however, present at most localities. The Suntrana leaf floras differ from those of the upper part of the Healy Creek Formation by the presence of "*Ficus*" *overbecki* Holl. (this should be transferred to *Populus*) and *Ulmus californica* Lesq. The latter species is probably descended from *U. appendiculata* Heer, which occurs in the upper part of the Healy Creek. *U. californica* is known in the conterminous United States from floras of early (?) Miocene and younger age. *Alangium aequifolium* (Geopp.) Kryst., however, is known in Japan in floras of middle Miocene and older age. The Suntrana flora also contains *Alnus cappsi* and *A. fairi*, which are not known to range into the late Miocene in either Alaska or the conterminous United States. *A. cappsi* is particularly significant because it is thought to be ancestral to the late Miocene *A. corylina* Knowl. and Cocker. The presence in the Suntrana flora (fig. 3, loc. 7622) of *Quercus* (*Leucobalanus*) also indicates a pre-Homerian age; *Quercus* is not known to occur in Alaska in beds younger than the Seldovian.

The pollen floras (known from 26 samples) contain an abundance of four-pored *Alnus* and *Betula* grains; in one sample these compose 75 percent of the pollen tallied. The deciduous broad-leaved tree element is considerably reduced in consistency of occurrence and generally represents about 3 percent of the pollen tallied. The percentage of now exotic genera, however, is the same as for the Sanctuary Formation (52 percent). Both *Fagus* and *Acer* have their highest local occurrence in the Suntrana.

The pollen and megafossil floras thus indicate that the Suntrana Formation should be placed in the Seldovian Stage. Because of the overlap in ranges of some of the megafossil species, the Suntrana Formation is probably of middle Miocene age.

LIGNITE CREEK FORMATION

The Lignite Creek Formation is the sequence of interbedded buff sandstone, greenish-gray claystone, and thin coal beds that lie between the top of the No. 6 coal bed of the Suntrana mine and the base of the prominent greenish-gray shale at the top of the coal-bearing formation. It includes sandstone beds in the northern part of the Nenana coal field thought to be contemporaneous with this sequence. The type section is in sec. 23, T. 12 S., R. 7 W., Healy D–4 quadrangle, along Suntrana Creek from the top of the No. 6 coal bed northward for about 1,000 feet to the top of the sandstone outcrop between the first forks of the creek and totals about 540 feet in thickness (figs. 2, 3). It makes up approximately the lower five-sixths of the upper member of the coal-bearing formation of Wahrhaftig, Hickcox, and Freedman (1951).

The Lignite Creek Formation has two facies: a coal-bearing facies, exposed in Healy Creek and Lignite Creek coal basins and in the southern part of the Tatlanika Creek and Wood River coal basins; and a noncoal-bearing facies in the northern and western parts of the coal field. Their common boundary is shown approximately in figure 5. The noncoal-bearing facies was mapped by Capps (1940, pl. 3) as the Nenana Gravel.

The coal-bearing facies is about 500 feet thick in the northwestern part of the Lignite Creek coal basin and thickens southeastward to about 750 feet thick at the east end of the Healy Creek coal basin. It is about 620 feet thick in the Tatlanika Creek ccal basin and about 800 feet thick in the Wood River coal basin. Like the Suntrana Formation, it is made up of a repeated sequence of pebbly sandstone, claystone, and coal. In contrast to the Suntrana Formation, the top of each sequence in the Lignite Creek Formation has several thin coal beds interbedded with claystone. Five sequences are present at the type locality. The coal-bearing facies averages about 5 percent coal, 30 percent siltstone and claystone (with interbedded fine-grained sandstone), and 65 percent sandstone, pebble beds, and conglomerate.

Sandstone units in the coal-bearing facies are as much as 160 feet thick. Some are laterally persistent, but others grade laterally into claystone or lens out altogether. The sandstone is generally poorly consolidated, clean, crossbedded, well sorted, and permeable. It is buff and under the hand lens is seen to contain an abundance of variously colored grains. This contrast with the salt-and-pepper sandstone of the Suntrana Formation is one of the most readily recognizable distinctions between the two formations. Petrographic study by M. C. Blake (written commun., 1959) showed the sandstone to consist of 65–70 percent quartz, 10–15 percent plagioclase, 5–10 percent orthoclase, 10 percent chert and rock fragments, and 10 percent heavy minerals. Etched pigeonite grains, an abundance of fresh ferromagnesian minerals, and predominance of plagioclase over orthoclase distinguish the sandstone of the Lignite Creek Formation petrographically from that of the Suntrana Formation.

Pebble layers and conglomerate beds make up 20–50 percent of the lower parts of some of the sandstone units, and conglomerate beds are as much as 20 feet thick. Average pebble size is 1–2 inches and the maximum size at a given locality is 6–8 inches. Rocks that are relatively unresistant to weathering—such as granite, diorite, gabbro, greenstone, basalt, andesite, rhyolite, schist, conglomerate, and graywacke—make up 35–60 percent of the pebble population, including most of the cobbles and boulders; resistant rock types—quartz, chert, quartzite, argillite, and jasper—make up the remainder. Individual counts of 75–150 pebbles were repeated many times in each measured section, and the abrupt change in pebble population at the top of the No. 6 bed was the principal means for distinguishing the Lignite Creek from the Suntrana Formation.

Coal beds in the Lignite Creek Formation are thin and discontinuous and are difficult to correlate from outcrop to outcrop. The coal breaks up on weathering into masses of long narrow flakes parallel to the bedding. Broken edges of these flakes show tightly compressed annual growth rings, and the flakes are believed to be highly compressed branches and twigs of the coal-forming forest. This character of the coal contrasts strongly with the blocky fracture of the coals of the Suntrana Formation.

Only in the top few feet of the No. 5 and No. 6 coal beds is flaky weathering coal like that of the Lignite Creek Formation found.

The noncoal-bearing facies interfingers with the coal-bearing facies along the banks of Tatlanika Creek for a few miles north of Hearst Creek. Along the east and north sides of the Tatlanika Creek basin both facies are overlain by the Grubstake Formation, but the Grubstake Formation pinches out along a line extending roughly from the mouth of Buzzard Creek to the Canyon of Tatlanika Creek (fig. 5), and the Lignite Creek Formation and Nenana Gravel are in contact northwest and west of this line. The two formations are poorly consolidated and have few exposures, and their contact in this area (fig. 1) is drawn largely on a change in color from buff in the Lignite Creek Formation to dark brown or dark gray in the Nenana Gravel and on a corresponding change in pebble population. In the upland between Tatlanika Creek and the Totatlanika River, the noncoal-bearing facies is about 250 feet thick, increasing to 1,000–1,300 feet along the north edge of the foothills. Between Moose Creek and Eva Creek in southwest Fairbanks A–4 quadrangle (fig. 1), it is 70–180 feet thick, and near Slate Creek it is about 300 feet thick. In all these areas bedding in the Lignite Creek Formation and Nenana Gravel is almost parallel. In the area between Sunday Creek and Dry Creek in the southwest part of Healy D–5 quadrangle (fig. 1), angular unconformities appear to separate the Nenana Gravel from the Lignite Creek Formation and the Lignite Creek from the Healy Creek Formation.

Crossbedding in the sandstone of the Lignite Creek Formation indicates current directions to the west and southwest in the noncoal-bearing facies and in the coal-bearing facies of the Tatlanika Creek coal basin. Elsewhere current directions are persistently to the south. A northward increase in grain size and pinching out of coal and clay indicate a source of clastic components to the north.

Biostratigraphy and Age

The flora of the Lignite Creek Formation is known only from six microfossil samples. In these samples, *Pinus*, *Alnus*, or *Betula* are the dominants. The deciduous broad-leaved tree element is considerably reduced, both in regard to abundance (less than 2 percent of the pollen tallied) and diversity of types. In addition, the percentage of genera now exotic to Alaska is 44, which is considerably less than in the underlying formations. The Lignite Creek, however, contains the highest occurrence of *Nyssa,* which has its highest occurrence in the Cook Inlet basin in the Seldovian. The Lignite Creek Formation is probably of late Seldovian and hence middle Miocene age.

GRUBSTAKE FORMATION

The Grubstake Formation includes interbedded dark claystone, dark sandstone, and fine conglomerate between the uppermost buff sandstone beds of the Lignite Creek Formation and the coarse conglomerate of the Nenana Gravel. The type locality, in Fairbanks A–3 quadrangle, consists of the exposures along the east bank of Tatlanika Creek from the mouth of Grubstake Creek to a point about 1 mile south where it is underlain by the buff sandstone of the Lignite Creek Formation (fig. 6). It is between 600 and 1,000 feet thick at this locality, rests with apparent conformity on the Lignite Creek Formation, and is overlain by the Nenana Gravel. The flat-lying beds of the Nenana Gravel apparently rest unconformably across the upturned edges of the coal-bearing group at the heads of Grubstake and Buzzard Creeks, but elsewhere in the Tatlanika Creek basin the beds are parallel to the bedding of the underlying formations.

The 90 feet of greenish-gray shale at the top of the section of the coal-bearing group on Suntrana Creek, in the W½ sec. 23, T. 12 S., R. 7 W., Healy D–4 quadrangle, is designated as a reference section (fig. 3).

The Grubstake Formation appears to underlie three separate areas in the Nenana coal field. The largest and thickest body extends from the western part of the Tatlanika Creek coal basin to the Wood River and appears to underlie much of the plateau of Nenana Gravel around Bonnifield and Gold King Creeks (fig. 1). Maximum thicknesses of this body are about 1,500 feet north of Coal Creek and 1,000 feet in the basin of Grubstake Creek, and the formation appears to thicken abruptly (in places by as much as 500 feet per mile) from its line of pinchout (shown in fig. 5). The second body lies on lower Buzzard Creek in the southwest part of Fairbanks A–3 quadrangle and reaches a maximum thickness of 500 feet. The third body is the unit of greenish-gray shale on top of the Lignite Creek Formation in

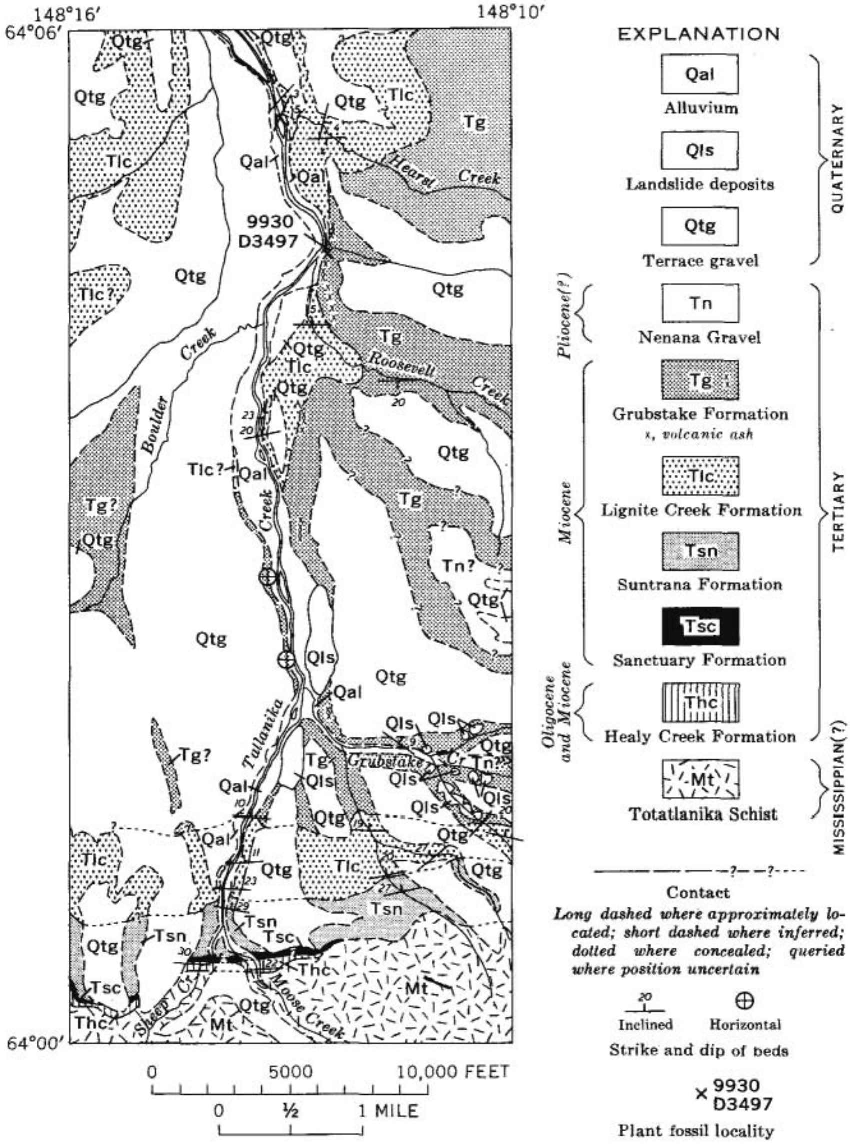

FIGURE 6.—Geologic map of part of the valley of Tatlanika Creek, Fairbanks A–3 quadrangle, showing the type locality for the Grubstake Formation, the section on upper Tatlanika Creek, and the site of USGS paleobotanical locality 9930.

the Lignite Creek and Healy Creek coal basins; it thickens southward from a line of pinchout where the Lignite Creek-Nenana Gravel contact crosses Elsie Creek in southwestern Fairbanks A-4 quadrangle (fig. 1) to about 250 feet at the east end of the Healy Creek coal basin.

In the Buzzard Creek and Tatlanika Creek-Wood River bodies, the claystone of the Grubstake Formation is dark gray, poorly consolidated, silty, and massive. Locally, it is thin bedded or varved and greenish gray. It contains numerous coaly partings and thin beds of coal and bone. The coal is usually about an inch thick; the thickest bed is 1 foot. Interbedded with this claystone are beds of dark-gray, poorly consolidated sandstone 3–40 feet thick, with abundant grains of black chert, dark rock fragments, and dark minerals. This sandstone weathers brownish red and is stained orange on joints and cracks. Conglomerate layers with pebbles 1/4 to 1/2 inch in diameter (maximum 1 1/2 inches) are also present. Pebbles are milky quartz and dull-black chert, both apparently reworked from the conglomerate of the Cantwell Formation 17–35 miles to the south.

Two thick beds of fine white vitric ash are exposed in the lower part of the Grubstake Formation at USGS paleobotany locality 9930 on the east bank of Tatlanika Creek between the mouths of Roosevelt and Hearst Creeks (fig. 6). The lower ash is about 24 feet thick in the exposure, with small-scale crossbedding, and the upper ash is about 13 feet thick. White outcrops seen in the bluffs from a helicopter for about 2 miles south of the fossil locality are thought to be of the ash. No white outcrops were spotted in a helicopter traverse of Grubstake Creek, nor was any ash seen in a ground traverse of the large gully exposure in the Grubstake Formation at the head of Coal Creek, but the base of the formation is not exposed in the gully.

The ash consists of more than 99 percent glass in lunelike shards and contains less than 1 percent crystals of chlorite, muscovite, quartz, plagioclase, and sanidine. The refractive index of the glass is given in table 1. Eruption of the lower ash apparently buried a forest growing at the site, and erect coalified trunks, rooted in place, rise 15–20 feet into the ash. USGS paleobotany locality 9930 is the buried litter of this forest.

TABLE 1.—*Indices of refraction of volcanic glass from the Grubstake Formation*

[Measurements by G. D. Eberlein (written commun., Nov. 1967)]

Sample	Locality	Index of refraction (n_D 25°C)
63Awg 32	USGS paleobotany loc. 9930, east bank of Tatlanika Creek, Fairbanks A-3 quadrangle. (See fig. 6.)	1.499±0.001
	Hard layer with fine white markings perpendicular to bedding, 30 ft above base of Grubstake Formation, forks of Suntrana Creek, Healy D-4 quadrangle. (See figs. 2, 3.)	1.499±0.001

It was not possible to obtain pure separates of the minerals because of their rarity and small size. The biotite separate (—150+200 mesh fraction) contains about 90 percent biotite and 10 percent chlorite. The muscovite separate (—150+270 mesh fraction) only contains about 50 percent muscovite; plagioclase, quartz, sanidine, and glass make up the remaining 50 percent. Potassium-argon analyses of the biotite and muscovite concentrates gave ages of 57.3 and 54.4 million years, respectively. A determination on the glass itself gave an age of 8.1 million years. This should be regarded as a minimum age for the ash. The analytical data for these determinations are given in table 2. A discussion of the implications of these dates follows the fossil data.

TABLE 2.—*Potassium-argon ages and analytical data*

[Field No. 63Awg 32. Potassium analyses by H. C. Whitehead and L. B. Schlocker; argon analyses by M. A. Lanphere. Decay constants for K^{40}: $\lambda_e=0.585\times10^{-10}$ year^{-1}; $\lambda_B=4.72\times10^{-10}$ year^{-1}. Atomic abundance of $K^{40}=1.19\times10^{-4}$]

Material	K_2O analyses (percent)	Average K_2O (percent)	Ar^{40} (10^{-10} rad moles/g)	Ar^{40} rad / Ar^{40} total	Apparent age (millions of years)
Biotite	2.82, 2.85	2.84	2.439	0.33	57.3±2.3
Muscovite	3.52, 3.60	3.56	2.902	.36	54.4±2.2
Glass	3.98, 3.98	3.98	.6936	.30	8.1± .4

The Grubstake Formation in the Healy Creek and Lignite Creek coal basins is greenish-gray thin-bedded shale and claystone. At its base is a thin bony coal bed. The upper part of the shale has several sand and silt beds and commonly grades into dark sandstone at the top. At about one-fourth to one-third of its thickness above the base is a zone of thin chalky weathering layers with closely spaced lines of parting perpendicular to the bedding. Microscopic examination of these layers showed they contained abundant glass shards with the same refractive index as the ash on Tatlanika Creek. (See table 1.) The presence of this ash in both areas establishes the correlation of the shale on Healy and Lignite Creeks with the type Grubstake Formation.

The Grubstake Formation appears to have accumulated mainly in a lacustrine environment in two relatively small basins of rapid subsidence—a larger basin including the exposures on Tatlanika Creek, Wood River, Healy Creek, and Lignite Creek, and a much smaller basin on Buzzard Creek. Its abrupt thinning and its absence from structural highs such as the dome north of Buzzard Creek (fig. 1) suggest that it accumulated during a period of tectonism. Crossbedding and pebble lithology suggest a southerly source. It probably represents the period of transition from south-flowing drainage during accumulation of the Suntrana and Lignite Creek Formations to north-flowing drainage during deposition of the Nenana Gravel. Although lithologically it is somewhat more akin to the Nenana Gravel than to the underlying formations, it has been mapped in the past as part of the coal-bearing formation. In areas of poor exposure where mapping depends heavily on topographic expression, the only contact to be marked topographically is the Grubstake-Nenana contact at the sharp conclave angle at the base of the steep bluffs of the coarse permeable Nenana Gravel.

Biostratigraphy and Age

The megafossil flora of the Grubstake Formation is known only from the tuff bed on Tatlanika Creek, which is in the basal part of the formation. At this locality, the forest has been preserved in place, and around individual stumps organs of a particular species—presumably from the tree of which only a stump remains—are abundant. The dominants of this vegetation were *Betula papyrifera* Michx. and *Pinus monticola* Dougl.; other genera of Pinaceae and *Salix* are also common.

The occurrence of the extant *Betula papyrifera* indicates that the Grubstake can be no older than late Miocene (Homerian), because a probably ancestral species, *B. thor*, is present in the Seldovian. Elsewhere in western North America, *B. papyrifera* is unknown in rocks older than late Miocene. The species of Pinaceae of the Grubstake flora are all apparently extant species that are known to range into the Miocene, and they are thus of little value in placing an upper age limit on the Grubstake Formation. One fragmentary leaflet, however, appears to represent the typical Homerian species *Spiraea hopkinsi*. The available megafossil evidence thus indicates that the basal part of the Grubstake Formation is of late Miocene age. Lacking any data on the upper age limit of the Grubstake, the late Miocene age assignment for the entire unit should be considered provisional.

The microfossil floras of the Grubstake (known from 11 samples) are problematic in that some of the pollen may have been redeposited from the older formations of the coal-bearing group. As in the megafossil flora, Pinaceae and Betulaceae dominate the microfossil floras. Only one sample contains pollen of several broad-leaved exotic genera; this sample has the only occurrence in the Grubstake of *Liquidambar, Juglans, Itea*-type, and *Aquilapollenites* and also contains genera that are rare in other Grubstake samples such as *Carya, Pterocarya, Ulmus,* and *Ostrya/Carpinus*. We think it is highly probable that this sample contains significant amounts of redeposited pollen and should, therefore, be considered an unreliable indicator of the Grubstake flora and vegetation. Similarly, another sample contains *Quercus, Carya, Pterocarya, Ulmus*-type, and *Tilia*. In the remaining nine samples, the only broad-leaved exotic genera are *Ostrya/Carpinus, Diervilla, Carya, Pterocarya,* and *Tilia,* and no more than two or three of these occur in any one sample. The Grubstake samples are, therefore, comparable to the samples from the type section of the Homerian Stage in which the frequency of genera of broad-leaved exotics is low (Wolfe and others, 1966), and Betulaceae and Pinaceae are dominant.

SIGNIFICANCE OF THE RADIOMETRIC DATES

The apparent age of 8.1 million years on the glass from the Grubstake Formation is not incompatible with a late Miocene age for the flora from the ash. The Miocene-Pliocene boundary is currently placed at about 10 million years (Evernden and others, 1964, p. 147, 164, 167). The argon retention characteristics of glass are known to be poor, and leakage of argon sufficient to lower the apparent age of the glass by 2 million years is not unreasonable.

The dates of 57.3 million years for the biotite and 54.4 million years for the muscovite concentrate are in good agreement with each other but are inconsistent with the late Miocene age of the flora. The biotite and muscovite dates suggest an early Tertiary age for these minerals (Evernden and others, 1964). The ash is remarkably pure and contains no recognizable epiclastic contaminants. The ash fall appears to have stripped the trees and left the trunks standing as now coalified fossils. Shards and crystals of the ash have been found at the same stratigraphic position in the Grubstake Formation as much as 25 miles away.

There seems to be little likelihood that the ash could be redeposited from an earlier eruption, as this would have required transport of the ash across several miles of poorly consolidated Tertiary rocks and probable contamination during transport. In addition, no ash of the appropriate stratigraphic position is known from the vicinity of the Nenana coal field. Thus, it seems likely that the biotite and muscovite are contaminants from the vent from which the ash was erupted.

Dalrymple (1964) has shown that xenoliths in a basalt flow were not completely degassed of their accumulated radiogenic argon. In a basalt flow xenoliths probably would be heated to above 1,000°C and held at a temperature of several hundred degrees at least several days. In an eruption of the sort that deposited the ash of the Grubstake Formation, individual crystals and glass shards would cool rapidly. The character of the buried vegetation—uncharred and merely coalified—shows that the ash was cool when it was deposited. This reasoning combined with the concordant ages of the two xenocrystic minerals suggests that they have lost little if any radiogenic argon during incorporation in the ash. The minerals probably were derived from crystalline rocks of the Alaska Range whose ages are poorly known at present.

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