K-Ar and fission-track dating of ash partings in coal beds from the Kenai Peninsula, Alaska: A revised age for the Homerian Stage–Clamgulchian Stage boundary

DON M. TRIPLEHORN *Solid-Earth Sciences Program, University of Alaska, Fairbanks, Alaska 99701*
DONALD L. TURNER *Geophysical Institute and Solid-Earth Sciences Program, University of Alaska, Fairbanks, Alaska 99701*
CHARLES W. NAESER *U.S. Geological Survey, Denver, Colorado 80225*

ABSTRACT

K-Ar and fission-track mineral ages determined from ash partings in upper Tertiary coal beds from the Kenai Peninsula, Alaska, establish an age of approximately 8 m.y. (late Miocene) for the Homerian Stage–Clamgulchian Stage boundary at the type section for the Homerian Stage and a late Miocene age for the early part of the Clamgulchian Stage. Our data do not support the concept that there is an "Arcto-Tertiary geoflora" which is different in age from similar floras at lower latitudes.

This study demonstrates, for the first time, that volcanic ash partings contained wholly within coals are valuable for radiometric dating and stratigraphic correlation.

INTRODUCTION

In this paper we present ten K-Ar and fission-track ages obtained from six volcanic ash partings in coal of the Kenai Group on the Kenai Peninsula, south-central Alaska.

These ages are significant for three reasons. First, they date parts of the type and reference sections for two paleobotanical stages, the Homerian and Clamgulchian, defined by Wolfe and others (1966). Second, generally concordant K-Ar and fission-track ages have been determined on different minerals in the same sample, which thus rules out the possibility of mixed volcanic and detrital mineral sources. Third, ash partings actually contained within coals were used successfully for stratigraphic correlation of terrestial coal-bearing sequences for the first time.

LOCATION AND DESCRIPTION OF SAMPLES

Figure 1 shows the sample localities on the Kenai Peninsula; all samples were collected at or near the base of sea cliffs. Stratigraphic control in the field was obtained by relating our samples to the measured sections of Barnes and Cobb (1959). Stratigraphic relationships of our samples to pollen and megafloral localities of Wolfe and others (1966) and to their provincial paleobotanical stages have also been determined (J. A. Wolfe, 1974, personal commun.).

Outcrops sampled along the western side of the Kenai Peninsula (Figs. 1 and 3; App. 1) are from the Sterling Formation as defined in the subsurface by Calderwood and Fackler (1972, p. 751). Outcrops from the northwest shore of Kachemak Bay (Fig. 1 and 2; App. 1) probably include both the Beluga and Sterling Formations of these authors, but no formational boundaries have yet been designated for surface exposures.

The six samples (described in App. 1) were selected from 27 different volcanic ash partings on the basis of datable mineral content, relative freedom from alteration, and stratigraphic distribution.

The dated ash partings are enclosed within coal beds and range from 2.5 to 15 cm (1 to 6 in.) thick. All have sharp upper and lower contacts and lack layering. They range from light gray to dark reddish-brown and consist of predominantly sand-sized to predominantly clay-sized material. X-ray diffraction study of <2-μm size fractions showed montmorillonite to be the only crystalline clay-sized material. Glass, in the form of shards and pumice, is the dominant constituent of silty-appearing samples, but is scarce or absent in samples composed of sand-sized or clay-sized material. Sand-sized material consists of volcanic mineral grains, mainly plagioclase, quartz, and hornblende.

CRITERIA FOR IDENTIFICATION OF PRIMARY VOLCANIC ASH

To yield a meaningful age for the enclosing coal bed, an ash parting must not be reworked or contain admixed detritus of nonvolcanic origin. The following criteria were used to identify primary

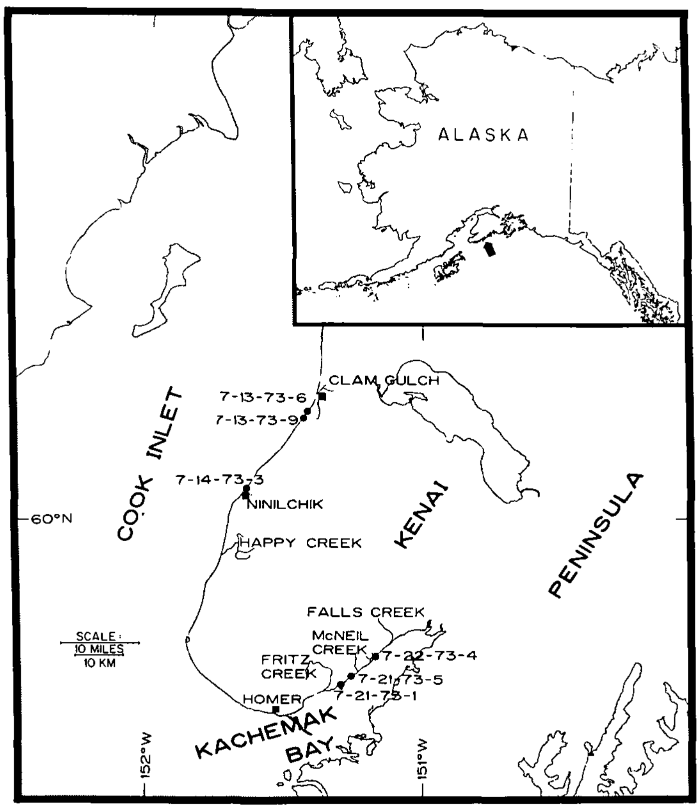

Figure 1. Sample localities on Kenai Peninsula (indicated in inset by arrow).

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volcanic ashes: (1) beds are composed entirely of volcanic glass and (or) crystals; detrital quartz, rock fragments, and other obviously nonvolcanic grains are absent, (2) glass occurs as shards and (or) pumice or as coatings on mineral grains and may be altered by postdepositional processes, (3) crystals are euhedral (plagioclase, hornblende, beta quartz, apatite, zircon, and magnetite), (4) plagioclase is zoned, (5) layers are unstratified (may be graded), and (6) contacts with enclosing coal are sharp and planar.

Although these criteria may permit identifications of primary volcanic ash beds, they do not completely preclude the possibility of admixed detrital material. Further evidence consistent with a primary volcanic origin comes from generally concordant, stratigraphically consistent radiometric ages determined on minerals from multiple samples.

RADIOMETRIC DATING

Plagioclase K-Ar and zircon fission-track ages (Table 1) are in excellent agreement from two ash partings (samples 7-14-73-3 and 7-22-73-4). Hornblende and plagioclase K-Ar ages from sample 7-13-73-6 are apparently slightly discordant at 7.2 ± 0.72 and 8.6 ± 0.52 m.y., respectively. Plagioclase K-Ar and zircon fission-track ages from sample 7-21-73-1 are also apparently discordant at 11.0 ± 0.66 and 8.6 ± 1.0 m.y., respectively. However, all ages are in agreement with the stratigraphic positions of individual samples, with the possible exception of sample 7-13-73-9, which has structural complications, as discussed below.

The limited data available do not permit an evaluation of whether the apparently small age discordances in samples 7-13-73-6 and 7-21-73-1 are geologically meaningful or not. It should be realized that the 2σ values quoted are only estimates of analytical uncertainty and that therefore the uncertainty in a single age determination may sometimes be greater than the estimated value.

We believe that (1) the excellent internal agreement of ages from samples 7-14-73-3 and 7-22-73-4, (2) the agreement of ages with stratigraphic position, and (3) the fact that the apparent age discordances found are relatively small argue for the primary volcanic origin of the dated minerals.

Attempts to obtain fission-track ages for apatites were unsuccessful because numerous crystal defects interfered with track counting. In spite of this problem, four apatite samples yielded apparent age estimates ranging from 6.5 to 10 m.y. Although these age estimates cannot be considered reliable, they do suggest that the dated apatites are generally compatible in age with other dated minerals —that is, that no markedly younger or older apatites are present.

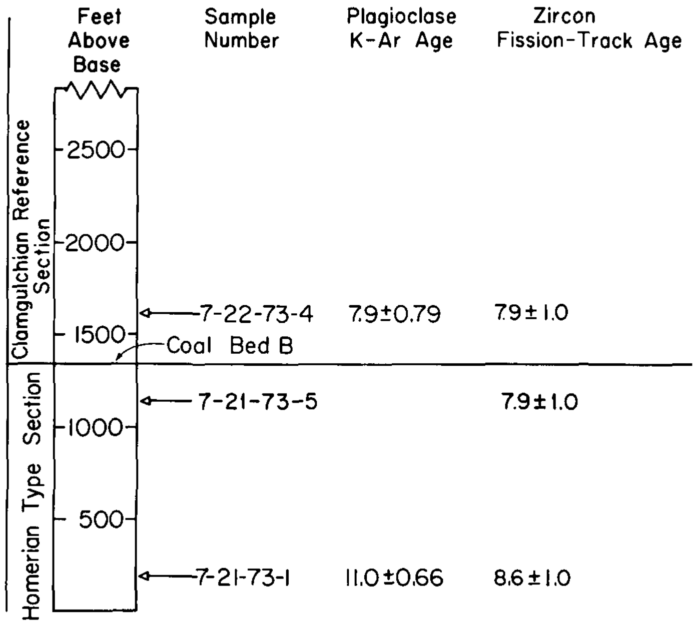

Figure 2. Estimated stratigraphic positions of dated samples. Homerian type section–Clamgulchian reference section, northwest shore of Kachemak Bay. Base of Homerian section taken as crest of anticline exposed in sea cliff about 2.1 km (1.3 mi) east of Fritz Creek (J. A. Wolfe, 1975, personal commun.). Ages in millions of years.

DISCUSSION

Homerian Type Section and Homerian-Clamgulchian Boundary

The approximate stratigraphic positions of radiometrically dated ash partings on the Kachemak Bay section are shown on Figure 2. Wolfe and others (1966, p. A18) designated this section as the type section for the Homerian Stage and as a reference section for the

TABLE 1. ANALYTICAL DATA FOR K-Ar AND FISSION-TRACK AGE DETERMINATIONS

Field no.	Mineral dated	K_2O (wt %)	$^{40}Ar_{rad}$ (wt %)	Avg $^{40}Ar_{rad}/^{40}K$ ($\times 10^{-4}$)	Spontaneous tracks: Density ($\times 10^6/cm^2$)	Spontaneous tracks: Total counted	Induced tracks: Density ($\times 10^6/cm^2$)	Induced tracks: Total counted	Thermal neutron dose ($\times 10^{15}/cm^2$)	Age (m.y. ± 2 σ)
					Kachemak Bay section					
7-22-73-4	Plagioclase	0.167, 0.160, 0.159, 0.169	34.9	4.616						7.9 ± 0.79
	Zircon				1.32	329	11.69	1,461	1.15	7.9 ± 1.0
7-21-73-5	Zircon				1.28	343	11.32	1,520	1.15	7.9 ± 1.0
7-21-73-1	Plagioclase	0.195, 0.196	37.3	6.455						11.0 ± 0.66
	Zircon				1.56	389	12.85	1,606	1.16	8.6 ± 1.0
					Southeast Cook Inlet section					
7-13-73-6	Plagioclase	0.163, 0.164	29.1	5.023						8.6 ± 0.52
	Hornblende	0.176, 0.184	44.9	4.205						7.2 ± 0.72
7-13-73-9	Plagioclase	0.192, 0.198	50.2	4.016						6.8 ± 0.73
7-14-73-3	Plagioclase	0.202, 0.186, 0.185, 0.191	49.1	5.093						8.7 ± 0.96
	Zircon				1.32	318	11.31	1,361	1.16	8.3 ± 1.0

Note: rad. = radiogenic; $\lambda_\epsilon = 0.585 \times 10^{-10}$ yr^{-1}, $\lambda_\beta = 4.72 \times 10^{-10}$ yr^{-1}, $^{40}K/K_{total} = 1.19 \times 10^{-4}$ mol/mol; $\lambda_f = 6.85 \times 10^{-17}$ yr^{-1}. $^{40}K/^{40}Ar$ dating was done by Turner at the Geochronology Laboratory of the Geophysical Institute, University of Alaska, Fairbanks. Zircon fission track dating was done by Naeser at the Denver Laboratory of the U.S. Geological Survey. Our analytical techniques have been described previously (Turner and others, 1973).

Clamgulchian Stage, but did not define the exact position of the Homerian-Clamgulchian boundary, indicating only that it is within a 460-m (1,500-ft) interval near the lower middle part of the section. During subsequent unpublished field studies, Wolfe placed the boundary at the top of coal bed B (Fig. 2), also called the Curtis seam, in section 143 of Barnes and Cobb (1959) near the mouth of McNeil Canyon (J. A. Wolfe, 1975, personal commun.). Our lowest sample (7-21-73-1) is, therefore, Homerian and the highest sample (7-22-73-4) is lower Clamgulchian; the middle sample (7-21-73-5) is upper Homerian, located about 60 m (200 ft) below the boundary.

The boundary occurs about 90 m (300 ft) below an ash yielding a plagioclase K-Ar age of 7.9 ± 0.79 m.y. corroborated by a zircon fission-track age of 7.9 ± 1.0 m.y. The boundary is about 60 m (200 ft) above an ash that yielded a zircon fission-track age of 7.9 ± 1.0 m.y. The Homerian-Clamgulchian boundary is therefore dated as approximately 8 m.y. B.P. in this particular section. We wish to emphasize that we have only dated this boundary in one locality, albeit the type section. Further radiometric dating in other areas may or may not show the boundary to be time-transgressive. Caution should be exercised in the extension of the 8-m.y. boundary age to other areas until additional radiometric data are available for evaluating its synchroneity over a wide geographic region.

Wahrhaftig and others (1969) reported a K-Ar minimum age of 8.1 m.y. for glass shards from a vitric tuff associated with a Homerian flora in the Grubstake Formation in the Healy area in central Alaska. Although volcanic glass shards are generally considered to be unreliable for K-Ar dating (Dalrymple and Lanphere, 1969), the agreement between this age determination and our Homerian age is noteworthy.

Clamgulchian Type Section

Estimated stratigraphic positions of samples and radiometric dates from the Clamgulchian type section are shown on Figure 3. The samples represent a small stratigraphic interval from the lower part of the section, and all five ages fall within a span of less than 2 m.y.

Because of the small stratigraphic interval involved, we have taken the 7.9-m.y. mean of the five radiometric ages as the best estimate of the age of the lower part of the section. This mean age is essentially the same as the estimated 8-m.y. age of the Homerian-Clamgulchian boundary in the Kachemak Bay section, although three of the five ages from the Clamgulchian section are older than 8 m.y. The plagioclase K-Ar age of 6.8 ± 0.73 m.y. for sample 7-13-73-9 seems out of sequence when compared to the other data.

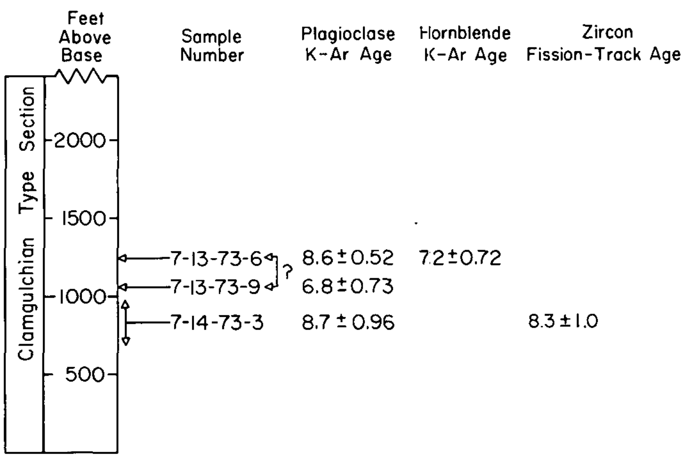

Figure 3. Estimated stratigraphic positions of dated samples. Clamgulchian type section, southeast shore of Cook Inlet. Base of section taken at Happy Creek. Ages in millions of years.

This effect may be due to local structural complexities, as evidenced by the lack of correlation between Barnes and Cobb's (1959) sections 8 and 9 in this area. It is possible that the real stratigraphic positions of samples 7-13-73-9 and 7-13-73-6 are reversed, as indicated on Figure 3.

The relatively old dates for most of the samples from this section are compatible with the fact that their associated floras place them within the lower part of the Clamgulchian Stage (J. A. Wolfe, 1975, personal commun.).

Hopkins and others (1971) reported a whole-rock K-Ar age of 5.7 ± 0.32 (2σ) m.y. from a basalt flow overlying a Clamgulchian flora in the northern Seward Peninsula in northwest Alaska. This age is the only other published radiometric age estimate for the Clamgulchian Stage. It documents the existence of a Clamgulchian flora at a much later time than that represented by the dated part of the type section.

CONCLUSIONS AND SPECULATIONS

Tertiary Stratigraphy

Many small Tertiary coal basins occur in Alaska. To what extent these may have originally existed as larger contemporaneous basins of terrestrial sedimentation is difficult to assess. Later tectonism has broken them up; major portions have been buried or eroded, and only isolated exposed remnants remain. Radiometric dating of volcanic ash partings in coal beds from these basins can provide an important basis, perhaps the only basis, for regional correlation and reconstruction of the nonmarine Tertiary history of Alaska.

The ages reported here provide a time framework for two paleobotanical stages that have been used in the terrestial stratigraphy of Alaska, the Canadian Arctic, and eastern Siberia. These stages were established for provincial usage, but have become widely used because no other upper Tertiary paleobotanical stages have been established for these areas or elsewhere.

The 8-m.y. age estimate for the Homerian-Clamgulchian boundary at the type section for the Homerian Stage at Kachemak Bay makes direct radiometric correlation possible between the dated boundary here and other radiometrically dated time-stratigraphic units around the world. This can be done by utilizing the correlation charts of Berggren and Van Couvering (1974). In their extensive synthesis of the world Neogene literature, these authors summarized the evidence for assigning a 5-m.y. age to the Miocene-Pliocene boundary. This boundary age has gained international acceptance, as evidenced by its extensive use in the reports of the Deep-Sea Drilling Project (for example, Vincent, 1975).

Following this usage, our age estimate of 8 m.y. for the Homerian-Clamgulchian boundary places it in the upper Miocene. The dated part of the Clamgulchian type section (7.9 m.y.) is thus upper Miocene also, although the Clamgulchian Stage has previously been considered to be Pliocene in West Coast provincial usage (Wolfe and others, 1966; Wolfe, 1972). The Miocene-Pliocene boundary must therefore be stratigraphically above the dated lower part of the Clamgulchian type section.

Durham (1974), in his compilation of Tertiary chronologies, gave a tentative estimate of 7.5 m.y. for the Homerian-Clamgulchian boundary age, which is remarkably close to our estimated 8 m.y. age. Durham's 2.5-m.y. estimate for the upper boundary of the Clamgulchian Stage must await two further developments before it can be evaluated. First, a biochronologic provincial time-stratigraphic unit must be defined above the Clamgulchian Stage, where none has thus far been proposed. Attempts can then be made to date the upper boundary of the Clamgulchian Stage radiometrically.

Paleobotanical Stages and the "Arcto-Tertiary Geoflora"

Heer (1869) first assigned a Miocene age to the rocks of the Kenai Formation based on leaf impressions (these rocks were raised to group status by Calderwood and Fackler, 1972). During the later part of the 19th century, however, Heer's "Arctic Miocene" (all Tertiary plant-bearing beds from high northern latitudes) was accepted by almost all paleobotanists as Eocene. Although independent evidence was largely lacking or contradictory (see Wolfe, 1969a, p. 69–80), an Eocene age for such northern floras was accepted as "fact." The floras of the Kenai, in particular, served as supposed documentation for a concept that became known as the "Arcto-Tertiary geoflora."

This concept provides a simple explanation for disjunctions of temperate flora between different middle-latitude areas (for example, China and the eastern United States). It holds that during the Paleocene and Eocene, high northern latitudes were occupied by temperate vegetation that in response to a cooling climate, migrated southward "with only minor changes" (Chaney, 1959, p. 12). This temperate vegetation supposedly arrived at middle latitudes by middle Tertiary time.

The fundamental "principle" underlying this concept is homotaxis; that is, similar or identical species appearing in two or more assemblages of markedly different ages. This "principle" has been rejected by paleontological disciplines other than paleobotany, particularly with regard to taxa that are parts of inferred phylogenies. Thus, contrary to that "principle," if a species has a known or inferred ancestor and descendant in one region, then an occurrence of that species in a second region must fall within its age range in the first region.

Following this latter approach, Wolfe and others (1966) assigned most floral assemblages from the Kenai to the Neogene. The Homerian assemblages, which contain *Alnus corylina* Knowlt. & Cocker., were correlated by Wolfe (1969b) with assemblages in Oregon (Stinking Water) and Nevada (Aldrich Station) containing this species. *Alnus corylina* is thought to be descended from the pre-Homerian *A. cappsi* (Holl.) Wolfe and to have given rise to the Clamgulchian to Holocene *A. incana* (L.) Moench. Ignoring such data, Chaney (1967) reiterated his support of the concept of an Arcto-Tertiary geoflora and considered the Homerian assemblages to be no younger than middle Oligocene.

Our radiometric ages, when compared to those known for floral assemblages in the conterminous United States, argue strongly against homotaxis as applied in the Arcto-Tertiary geoflora concept. Our Homerian age of 11 m.y. (for sample 7-21-73-1) compares favorably with the K-Ar ages of Evernden and James (1964) on the Stinking Water (12.1 m.y.) and Aldrich Station (10.7 to 11.2 m.y.) assemblages. The occurrences of *Alnus corylina* in Alaska are thus approximately contemporaneous with occurrences in Oregon and Nevada. Today, in fact, the descendant *A. incana* ranges from California (lat 36°N) to Alaska (lat 67°N). A given plant species may, therefore, be of considerable value in time correlation over many degrees of latitude. Just as significantly, our ages clearly contradict the Eocene-Oligocene age assignments postulated for certain flora assemblages in the context of an "Arcto-Tertiary geoflora."

Potential Use and Abundance of Volcanic Ash Partings in Coals

Environments of coal deposition provide ideal settings for preservation of ash falls. Once deposited in a coal swamp, an ash fall has a good chance of remaining undisturbed because the shallow quiet water, low stream gradients, lack of relief, and flow-baffling effects of abundant vegetation minimize processes that could cause reworking or mixing in of water-transported sediment. Parts of many such swamps were apparently so distant from major streams that they received little or no stream-borne detritus. Thus it is likely that ash falls into such areas would remain free of nonvolcanic minerals from fluvial sources. The rapid fall of ash compared with the very slow accumulation of organic material enhances the formation of discrete ash layers.

Because volcanic ash is relatively susceptible to diagenetic modification, the best chances of finding ash beds that are datable and can still be recognized as such in the field are in younger, lower-rank coals, such as those on the Kenai Peninsula. Volcanic ash partings in older, higher-rank coals are likely to be more thoroughly altered with redistribution and loss of some elements and may not be readily recognized as volcanic in origin. For example, the Carboniferous tonsteins (kaolinite-rich partings in coal) of western Europe and Great Britain have had various interpretations but are now commonly accepted as of volcanic origin (Spears, 1970; Spears and Rice, 1973). Some are reported to contain zircon and apatite (Spears and Rice, 1973; Seiders, 1965; Williamson, 1961; Price and Duff, 1969) that may prove to be datable by the fission-track method.

Because feldspar and other K-bearing minerals from volcanic ash partings in coals are commonly altered to clay, the K-Ar method may have only limited application to older coal-bearing strata. However, volcanic ash partings are sometimes impregnated by carbonate minerals, probably because they are permeable conduits for fluids during compaction. If carbonate cementation occurred early enough, this cement might "embalm" unstable materials and preserve them from later alteration. Such preservation in concretions has been reported frequently (Muller, 1967). If this cementation process were to preserve K-bearing minerals in ash partings, K-Ar dating could be applied to some older coals. We suggest searching for cemented ash partings as a prospecting technique for datable ash in older, higher-rank coals.

ACKNOWLEDGMENTS

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APPENDIX I. SAMPLE LOCALITIES AND DESCRIPTIONS

7-22-73-4. Between Cottonwood Creek and Falls Creek, NE¼ sec. 17, T. 5 S., R. 11 W., Seldovia (C-4) quadrangle. Sample from a white-weathering, porcelain-like layer 5 to 15 cm (2 to 6 in.) thick near the base of a coal 0.45 m (1.5 ft) thick at a small waterfall about 2.4 m (8 ft) above mean high-tide level. This is the lower coal in section 155 of Barnes and Cobb (1959), about 80 m (60 ft) below bed E, and within the lower 90 m (300 ft) of the Clamgulchian Stage reference section (Wolfe and others, 1966; J. A. Wolfe, 1975, personal commun.). The sand-sized fraction consists of about 66% plagioclase (commonly euhedral), 33% pumice, and about 1% dark minerals; the pumice is partly altered to montmorillonite.

7-21-73-1. About 17 km (10 mi) northeast of Homer, along the northwest shore of Kachemak Bay, NE½ sec. 35, T. 5 S., R. 12 W., Seldovia (C-4) quadrangle. This is the lower coal in section 137 of Barnes and Cobb (1959); it is below locality 9853 of Wolfe and others (1966) and this is low in the type section of the Homerian Stage. Sample from a 5-cm (2-in.) parting of light green clay that is soft and plastic when wet and dries with a "popcorn" surface. In thin section the clay (montmorillonite) has low birefringence and contains about 20% crystals of 0.25- to 0.12-mm maximum dimension, consisting mainly of plagioclase, minor quartz and hornblende, and rare apatite and zircon.

7-21-73-5. NW¼ sec. 35, T. 5 S., R. 12 W., Seldovia (C-4) quadrangle. Occurs near the top of coal bed A of section 140 of Barnes and Cobb (1959) and thus 60 m (200 ft) below the top of the Homerian Stage type section (Wolfe, 1974, personal commun.). Sample from a rusty-weathering, sandy clay, 10 cm (4 in.) thick. Coarse fraction is dominantly plagioclase, some euhedral grains, as much as 0.25 mm in length but mostly about 0.1 mm; minor magnetite, rare zircon and apatite, all primarily euhedral.

7-13-73-6. About 5 km (3 mi) south of Clam Gulch, at the mouth of Falls Creek, SW¼ sec. 6, T. 1 N., R. 12 W., Kenai (A-4) quadrangle. Section 8 of Barnes and Cobb (1959). Near locality 9862 of Wolfe and others (1966) in the lower middle part of the Clamgulchian Stage type section; within a few hundred feet, stratigraphically, of sample 7-13-73-9 and probably above it. Sampled layer appears as a soft, dark brown clayey sand parting, 5 to 7.5 cm (2 to 3 in.) thick, 0.45 m (1.5 ft) below the top of a coal 1.35 m (4.5 ft) thick. A crystal tuff containing crystals as much as 0.5 mm in diameter. Composed of 10% clay (montmorillonite plus iron oxide), 85% plagioclase, 3% pumice, and 2% hornblende.

7-13-73-9. About 6.4 km (4 mi) south of Clam Gulch, SW¼ sec. 12, T. 1 N., R. 13 W., Kenai (A-4) quadrangle. Near section 10 of Barnes and Cobb (1959). About 2.5 km (1.5 mi) south of and apparently several hundred feet stratigraphically lower than sample 9862 of Wolfe and others (1966). About 45 m (150 ft) stratigraphically below sample 7-13-73-6. Occurs as a 10-cm (4-in.) sandy parting between two 15-cm (6-in.) coal layers. A vitric crystal tuff composed of 30% euhedral and subhedral plagioclase in a clay matrix resulting from the alteration of pumice. Contains about 2% to 3% dark minerals, almost entirely euhedral hornblende and magnetite.

7-14-73-3. About 1.6 km (1 mi) north of Ninilchik, near the section line between secs. 26 and 27, T. 1 S., R. 14 W., Kenai (A-5) quadrangle. This is the lower coal in section 29 of Barnes and Cobb (1959), near pollen locality D1775 of Wolfe and others (1966). Although the exact stratigraphic position is uncertain, Wolfe (1974, personal commun.) suggested that it is below samples 7-13-73-6 and 7-13-73-9. Barnes and Cobb (1959, Pl. 19) showed at least 210 m (700 ft) of additional section below this sample position. These constraints place it in the lower middle part of the Clamgulchian type section. Sampled layer is a 2.5- to 7.6-cm-thick (1- to 3-in.) light-gray parting in the upper 15 cm (6 in.) of a prominent 1.2-m (4-ft) coal and consists of silt-sized material with abundant traces of plant rootlets. Composed dominantly of pumice with about 10% plagioclase (some euhedral crystals) and less than 1% dark minerals. The heavy-mineral fraction is mostly hornblende with minor apatite, zircon, and magnetite.

REFERENCES CITED

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.

Berggren, W. A., and Van Couvering, J. A., 1974, The Late Neogene: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 16, no. 1-2, 216 p.

Calderwood, K. W., and Fackler, W. C., 1972, Proposed stratigraphic nomenclature for Kenai Group, Cook Inlet, Alaska: Am. Assoc. Petroleum Geologists Bull., v. 56, no. 4, p. 739–754.

Chaney, R. W., 1959, Miocene floras of the Columbia Plateau, I. Composition and interpretation: Carnegie Inst. Washington Pub. 617, 1–134.

——1967, Miocene forests of the Pacific Basin: Their ancestors and their descendents, *in* Jubilee publication commending Professor Sasa's 60th birthday: Sapporo, Japan, Hokkaido Univ., p. 209–239.

Dalrymple, G., and Lanphere, M. A., 1969, Potassium argon dating: San Francisco, W. H. Freeman and Company, 258 p.

Durham, J. W., 1974, Tertiary Period: *in* Encyclopedia Britannica: Chicago, Encyclopedia Britannica, Inc., p. 151–161.

Evernden, J. F., and James, G. J., 1964, Potassium-argon dates and the Tertiary floras of North America: Am. Jour. Sci., v. 262, p. 945–974.

Heer, Oswald, 1869, Fossile flora von Alaska: Kgl. Svenska Vetenskapsakad. Handl., v. 8, no. 4, 41 p., 10 pls.

Hopkins, D. M., Matthews, J. V., Wolfe, J. A., and Silberman, M. L., 1971, A Pliocene flora and insect fauna from the Bering Strait region: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 9, p. 211–231.

Muller, G., 1967, Diagenesis in argillaceous sediments, *in* Larsen, G., and Chilingar, G. V., eds., Diagenesis in sediments: New York, Elsevier Pub. Co., p. 127–178.

Price, N. B., and Duff, P. McL., 1969, Mineralogy and chemistry of tonsteins from Carboniferous sequences in Great Britain: Sedimentology, v. 13, p. 45–69.

Seiders, V. M., 1965, Volcanic origin of flint clay in the Fire Clay coal bed, Breathitt Formation, eastern Kentucky: U.S. Geol. Survey Prof. Paper 525-D, p. D52–D54.

Spears, D. A., 1970, A kaolinite mudstone (tonstein) in the British coal measures: Jour. Sed. Petrology, v. 40, p. 386–394.

Spears, D. A., and Rice, C. M., 1973, An upper Carboniferous tonstein of volcanic origin: Sedimentology, v. 20, p. 281–294.

Turner, D. L., Forbes, R. B., and Naeser, C. W., 1973, Radiometric ages of Kodiak Seamount and Giacomini Guyot, Gulf of Alaska: Implications for circumpacific tectonics: Science, v. 182, p. 579–581.

Vincent, E., 1975, Neogene planktonic Foraminifera from the central north Pacific, Leg 32, Deep Sea Drilling Project, *in* Larson, R. L., Moberly, R., and others, Initial reports of the Deep Sea Drilling Project, Vol. 32: Washington, D.C., U.S. Govt. Printing Office, p. 765–801.

Wahrhaftig, C., Wolfe, J. A., Leopold, E. B., and Lanphere, M. A., 1969, The coal-bearing group in the Nenana coal field, Alaska: U.S. Geol. Survey Bull. 1274-D, p. D1–D30.

Williamson, I. A., 1961, Tonstein: A possible additional aid to coal field correlation: Mining Mag., v. 104, p. 9–14.

Wolfe, J. A., 1969a, Paleogene floras from the Gulf of Alaska region: U.S. Geol. Survey Open-File Rept. OF 69-323, 114 p.

——1969b, Neogene floristic and vegetational history of the Pacific Northwest: Madrono, v. 20, p. 83–110.

——1972, An interpretation of Alaskan Tertiary floras: *in* Graham, A., ed., Floristics and paleofloristics of Asia and eastern North America: New York, Elsevier, p. 201–233.

Wolfe, J. A., Hopkins, D. M., and Leopold, E. B., 1966, Tertiary stratigraphy and paleobotany of the Cook Inlet region, Alaska: U.S. Geol. Survey Prof. Paper 298-A, p. A1–A29.

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