Geology, Geochemistry, and Uranium Favorability of Tertiary Rocks in South-Central Alaska

A. Geology, Geochemistry, and Uranium Favorability of the Tertiary Kenai Group in the Susitna Lowlands at the Northern End of Cook Inlet Basin, Alaska

B. Geology, Geochemistry, and Uranium Favorability of Tertiary Continental Sedimentary Rocks in the Northwestern Part of the Cook Inlet Area, Alaska

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By Kendell A. Dickinson

URANIUM FAVORABILITY OF TERTIARY ROCKS, SOUTH-CENTRAL ALASKA

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Geology, Geochemistry, and Uranium Favorability of the Tertiary Kenai Group in the Susitna Lowlands at the Northern End of Cook Inlet Basin, Alaska

By Kendell A. Dickinson

ABSTRACT

The Susitna Lowlands at the northern end of the Cook Inlet Basin in south-central Alaska are underlain by more than 940 m of continental clastic rocks that are approximately correlative with the Tertiary Kenai Group farther to the south in the basin. The Susitna Lowlands section, which consists mostly of nonmarine conglomerate, sandstone, and shale and smaller amounts of bedded coal, is divided into the Tyonek(?) and Sterling(?) Formations. Parts of this section were measured and sampled during reconnaissance studies in 1977 and 1978 to determine favorability for uranium deposits. Samples were analyzed for uranium, thorium, and 19 other elements, and minerals were identified by X-ray diffraction. Statistical studies of the chemical and mineralogical data suggest that uranium is associated with copper, titanium, scandium, and aluminum, that chlorite and illite are detrital clay minerals, and that smectite and kaolinite are diagenetic.

Although the Kenai Group in the Susitna Lowlands exhibits most if not all of the favorable characteristics for epigenetic sedimentary uranium deposits, no significant large deposits are known. Uranium is epigenetically enriched (72 ppm eU_3O_8) in a kaolinitic mudstone layer associated with a thin coal bed in the Sterling(?) Formation at Camp Creek. The Sterling(?) is more highly oxidized than the underlying Tyonek(?) Formation and probably as a whole contains more epigenetic uranium. The positive correlation between uranium and copper suggests that copper may also have been epigenetically enriched.

A correlation coefficient matrix and an R-mode factor analysis using a five-factor model were determinined for the chemical and mineralogical data base of 29 samples. The factors are interpreted to represent fine-grained clayey sediments, rare earth elements, feldspathic coarse-grained sediments, iron-manganese, and altered fine-grained sediments.

INTRODUCTION

The Susitna Lowlands area (fig. 1) is a northern extension of the Cook Inlet Basin in south-central Alaska (Wahrhaftig, 1965). It contains a sequence of Tertiary continental sedimentary rocks of the Kenai Group that includes the Miocene Tyonek(?) and the Pliocene Sterling(?) Formations (Reed and Nelson, 1980). These rocks approximately correlate with the Kenai Group in the main part of the Cook Inlet Basin to the south where the Kenai Group, in ascending order, consists of the Oligocene Hemlock Conglomerate, the Oligocene and Miocene Tyonek Formation, the Miocene Beluga Formation, and the Miocene and Pliocene Sterling Formation (Magoon and others, 1976).

Early interest in Tertiary sedimentary rocks of Cook Inlet was motivated by the demand for coal. Coal resources of the northwestern part of the Cook Inlet area were described by Barnes (1966). Oil was discovered in 1957 (Parkinson, 1962), and much of the later interest in the area was stimulated by the search for petroleum (Calderwood and Fackler, 1966, 1972; Crick, 1971; Kirschner and Lyon, 1973). During the late 1970's interest developed in the uranium potential of the Kenai Group because the unit contains the necessary elements of a uranium resource area. Croff and others (1977) considered the area of this report favorable for sandstone-hosted uranium deposits. The area contains potentially favorable uranium sources in the form of felsic igneous rocks within and near the study area and in the Alaska and Aleutian Ranges to the northwest. In addition, the potential host rocks contain igneous constituents that could have supplied uranium to the circulating ground water. Thick Tertiary sequences of porous sandstone and conglomerate form favorable uranium host rocks. These possible host rocks contain abundant organic material that could have produced the chemically reducing environment necessary for deposition of the uranium (Dickinson and Campbell, 1978).

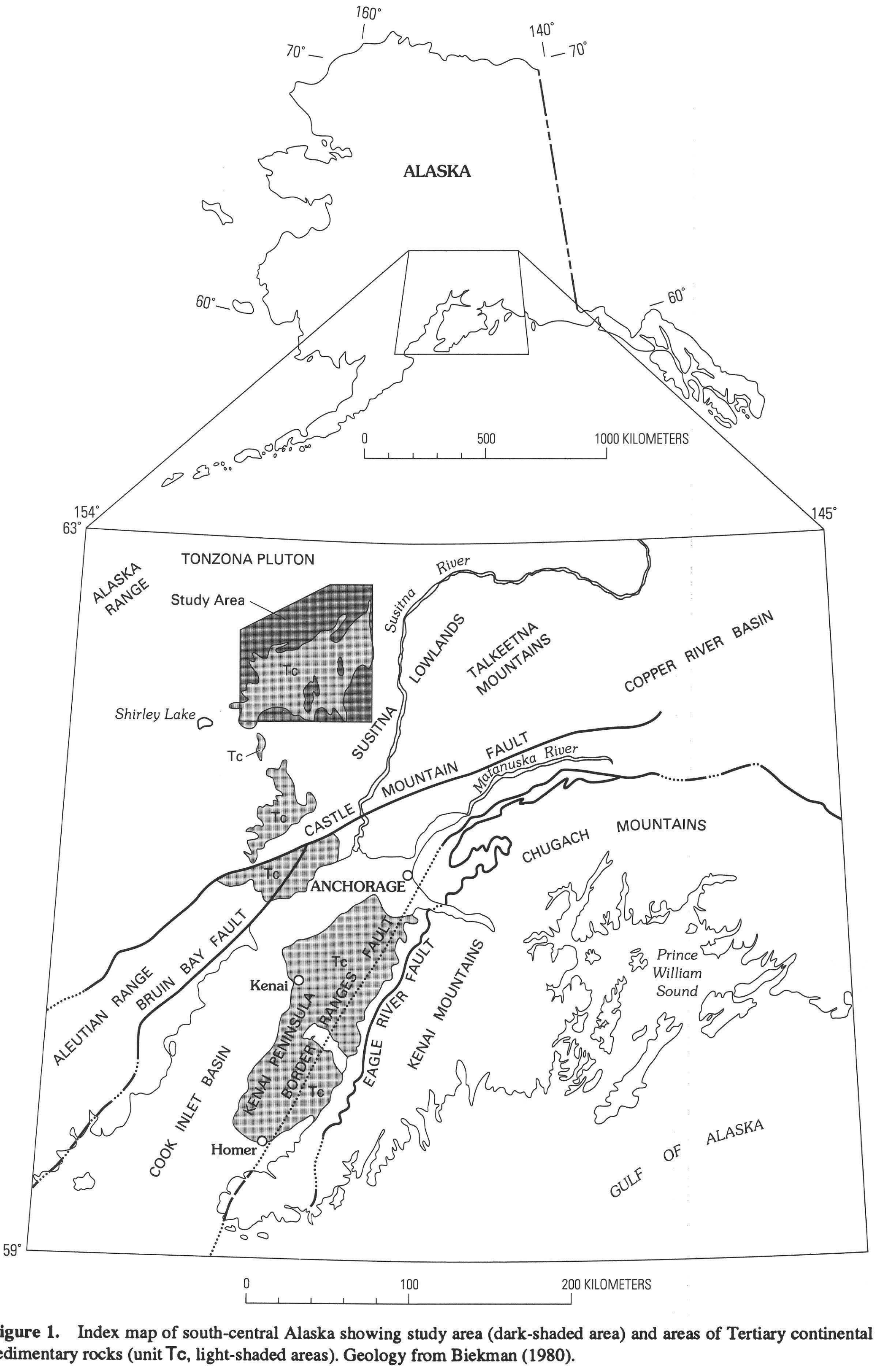

Figure 1. Index map of south-central Alaska showing study area (dark-shaded area) and areas of Tertiary continental sedimentary rocks (unit Tc, light-shaded areas). Geology from Biekman (1980).

The study area includes an area of scattered outcrops on the west side of the Susitna River valley north of the Castle Mountain fault (fig. 1, 2). The study area extends from Hewitt Lake on the south to the vicinity of Kahiltna Lake on the north. It includes outcrops west of the Yentna River, at Fairview Mountain, and in the Peters Hills and Cache Creek areas. These outcrops were selected because of their accessibility from a base camp at Talkeetna, Alaska, during the period available for fieldwork. Samples of the Tertiary sedimentary rocks as described herein were collected during a reconnaissance survey by helicopter August 16–23, 1977 and on a one-day return trip to one of the sites on July 30, 1978.

Eighteen sections were measured, and 29 samples were collected (fig. 2). The present report is based on chemical and mineralogical analyses of the samples (appendix 1) and on the described sections (appendix 2). These data provide new insight into diagenesis and sedimentation of the Tertiary units, as well as their favorability for uranium deposits.

Acknowledgments.—Gary Skipp prepared the oriented clay mineral mounts for X-ray diffraction studies and operated the X-ray diffraction machine. Samples were chemically analyzed in laboratories of the U.S. Geological Survey at Lakewood, Colorado. D.M. McKown supervised the radiochemical analysis, J.E. Taggart supervised the X-ray spectroscopy analysis, and D.E. Detra and L.R. Layman supervised the optical spectroscopy analysis.

GEOLOGY

The Cook Inlet Basin in the coastal area of south-central Alaska is mostly to the southeast of the present study area (Wahrhaftig, 1985). The basin separates the Aleutian and Alaska Ranges on the northwest from the Kenai and Chugach Ranges on the southeast (fig. 1). The Talkeetna Mountains and the Copper River Basin are to the northeast of Cook Inlet Basin. The Cook Inlet Basin is about 100 by 300 km; its axis is oriented about N. 25° E. It contains a sequence of nonmarine Tertiary sedimentary rocks as thick as 8,500 m comprising the Oligocene to Pliocene Kenai Group and the underlying Paleocene and Eocene West Foreland Formation (fig. 3). These Tertiary rocks overlie Jurassic and Cretaceous rocks (Kremer and Stadnicky, 1985) and underlie Quaternary alluvium and glacial deposits.

The Cook Inlet Basin is generally bounded on the east by the Border Ranges fault (Knik fault of Magoon and others, 1976), which strikes about N. 30° E. (fig. 1). The Bruin Bay fault, which generally forms the western margin of the basin, extends northward about N. 45° E. and intersects the Castle Mountain fault in the northern part of the basin. The Castle Mountain fault trends about N. 60° E. and generally forms the northwestern boundary of the basin (fig. 1). Undivided equivalents of the Kenai Group and the West Foreland Formation extend north of the Castle Mountain fault into the Susitna Lowlands. Other minor faults and lineaments have been mapped on the Kenai Peninsula. Several gentle anticlines and synclines, whose axes parallel the long axis of the basin, were mapped by Magoon and others (1976) in the eastern half of the Cook Inlet Basin (fig. 1). Water of Cook Inlet covers most of the northwest half of the basin.

The study area, to the north of the Cook Inlet Basin, contains scattered outcrops of the Miocene Tyonek(?) and Pliocene Sterling(?) Formations. Much of the study area is covered by Quaternary sedimentary deposits and glacial ice. The Tyonek(?) is unconformably underlain by thick sequences of Jurassic and Cretaceous metamorphic and sedimentary rocks including lithic graywacke, phyllite, and shale and locally interbedded lenses of quartz and chert conglomerate. This sequence contains thin beds of fossiliferous limestone and radiolarian chert with Jurassic and Cretaceous fossils in some areas and a few beds of red ferruginous sandstone in other areas. The rocks have been altered by thermal metamorphism near plutons and by low-grade metamorphism in other areas (Reed and Nelson, 1980).

Parts of two early Tertiary plutons are present in the study area: the southeastern part of the Kahiltna pluton and the southern part of the Ruth pluton (fig. 2). The Kahiltna pluton consists of fine- to coarse-grained biotite and biotite-muscovite granite and granodiorite. The southern part of the Ruth pluton consists of coarse-grained biotite granite and granodiorite that is locally weathered to grus and contains rare muscovite and hornblende. Two small granitic intrusive bodies also are present in the study area (fig. 2) (Reed and Nelson, 1977).

TERTIARY SEDIMENTARY ROCKS

The Tertiary sedimentary rocks of the Cook Inlet Basin were first referred to as the Kenai Group by Dall and Harris (1892), who assigned the group to the Miocene. Barnes and Cobb (1959) and Parkinson (1962) referred to the same rocks as the Kenai Formation. The Kenai Group was later divided into five formations (Calderwood and Fackler 1966, 1972; Crick, 1971; Magoon and others, 1976), in ascending order, the West Foreland Formation, Hemlock Conglomerate, Tyonek Formation, Beluga Formation, and Sterling Formation. Subsequently, Magoon and others (1976) removed the West Foreland Formation from the Kenai Group (fig. 3).

In the Susitna Lowlands area, north of the Castle Mountain fault (fig. 1), the Kenai Group, which has a minimum thickness of 940 m, was divided into a lower, Miocene unit designated the Tyonek(?) Formation and an upper, Pliocene unit designated the Sterling(?) Formation (fig. 4) (Reed and Nelson, 1980). The Tyonek Formation was also mapped along the southern margin of the study area by Magoon and others (1976). The West Foreland Formation, Hemlock Conglomerate, and Beluga Formation have not been recognized in the study area. The Alaska Range to the northwest and the

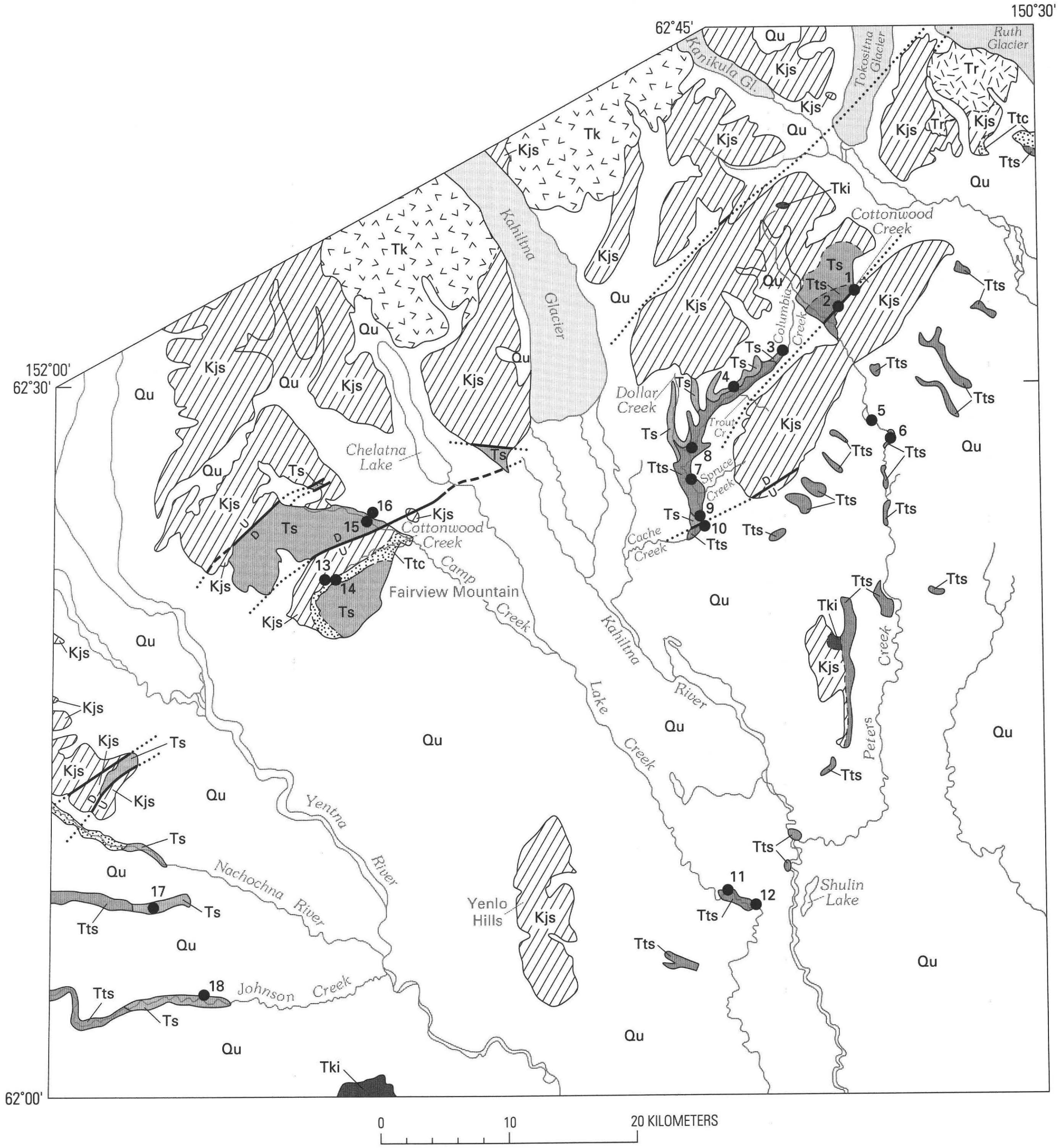

Figure 2 (above and facing column). Geology of the Susitna Lowlands area, Cook Inlet Basin, south-central Alaska. Locations of measured sections are also shown. Map area is shown in figure 1. Geology modified from Reed and Nelson (1977, 1980).

Talkeetna Mountains to the northeast were important sediment sources for the Kenai Group in the Susitna Lowlands.

The Tyonek(?) Formation, which has a minimum thickness of 170 m, is divided into sandstone and conglomerate members (fig. 2). The sandstone member conformably overlies or is interbedded with the conglomerate member. The conglomerate member of the Tyonek(?) consists of 40 percent or more conglomerate, 20 percent sandstone, and less than 40 percent siltstone, claystone, and coal (Reed and Nelson 1977). The conglomerate, which is poorly indurated and forms massive beds, is light brown, light gray, or bluish gray. Clasts are well rounded and their maximum size is about 10

EXPLANATION

(Glacier)	Glacier
Qu	**Glacial, alluvial, and mass-wasting deposits, undivided (Quaternary)**
Ts	**Sterling(?) Formation (Pliocene)**—Orange, light-tan or light-gray, massive-bedded conglomerate; poorly to moderately well indurated with clayey and locally ferruginous matrix; coal fragments and locally discontinuous coal beds a few centimeters thick
Tts	**Tyonek(?) Formation, sandstone member (Miocene)**—Approximately 80 percent sandstone, 20 percent siltstone and claystone, and less than 1 percent coal, conglomerate, and volcanic ash. Sandstone is light gray to light brown, poorly sorted, and crossbedded. Coal is mostly in beds as thick as 2 m
Ttc	**Tyonek(?) Formation, conglomerate member (Miocene)**—Approximately 40 percent conglomerate, 20 percent sandstone, and less than 40 percent siltstone, claystone, and coal. Conglomerate is light brown, light gray, or bluish gray and poorly indurated; sandstone is light gray or brown, coarse, pebbly, and poorly sorted; siltstone, claystone, and coal form sets of fining-upward strata. Coal is in beds as thick as 17 m
Tk	**Muscovite and biotite granite and granodiorite of Kahiltna pluton (early Tertiary)**
Tr	**Biotite granite and granodiorite of Ruth pluton (early Tertiary)**
Tki	**Intrusive rocks, undivided (early Tertiary and (or) Late Cretaceous)**—Medium-grained biotite granite and other rocks
Kjs	**Marine sedimentary rocks, undivided (Jurassic and Early Cretaceous)**
——	**Contact**—Dashed where approximate or inferred
U/D	**Fault**—Dashed where approximate or inferred, dotted where concealed. U (up) and D (down) indicate relative movement
●18	**Location of measured section**—Measured sections are shown in appendix 2

Age		Cook Inlet (Magoon and others, 1976)		Susitna Lowlands (Reed and Nelson, 1977)
Quaternary		Alluvium and glacial deposits		Alluvium and glacial deposits
Pliocene	Kenai Group	Sterling Formation	Kenai Group	Sterling(?) Formation
Miocene	Kenai Group	Sterling Formation; Beluga Formation; Tyonek Formation	Kenai Group	Tyonek(?) Formation
Oligocene	Kenai Group	Tyonek Formation; Hemlock Conglomerate		
Eocene		West Foreland Formation		
Paleocene		West Foreland Formation; Arkose Ridge Formation		
Mesozoic and older rocks				

Figure 3. Stratigraphy of Tertiary sedimentary rocks in Cook Inlet Basin and Susitna Lowlands areas, south-central Alaska.

cm. Sandstone, siltstone, claystone, and coal comprise interbedded fining-upward sequences. The sandstone is arkosic, coarse grained, poorly indurated, and conglomeratic. In this report only sections 13 and 14 (appendix 2) are from the conglomeratic member of the Tyonek(?). Both of these sections consist of a mudstone-coal interval with conglomerate above and below. The coal-mudstone intervals probably correlate between these two sections, which are less than a kilometer apart (fig. 2).

The sandstone member of the Tyonek(?) consists of approximately 80 percent sandstone, 20 percent siltstone, and less than 1 percent conglomerate, coal, and volcanic ash (Reed and Nelson, 1977). The sandstone is tan or light gray, coarse to medium grained, and poorly indurated and contains 75–85 percent chert and quartz grains, 10–20 percent feldspar, and about 5 percent mafic grains including biotite, hornblende, clinozoisite, and chlorite. Sandstone beds are as thick as 60 m. The siltstone is light to medium gray and is in sequences as thick as 15 m. Coal beds are as thick as 3 m and contain partly devitrified volcanic ash in beds as thick as 30 cm. The ash beds have been partly altered to clay minerals, probably kaolinite or smectite.

Eight of the sections shown in appendix 2 (sections 2, 5–8, 10–12) are from the sandstone member of the Tyonek(?) Formation. These sections show about 28 percent conglomerate, 39 percent sandstone, and 30 percent claystone, as well as about 3 percent coal. The conglomerate is light gray or brown, has a coarse-grained sandstone matrix, and is massive. The sandstone is light gray or brown, generally coarse grained, crossbedded, conglomeratic, and arkosic. The mudstone is medium brown to dark gray and interbedded with coal.

The Sterling(?) Formation, which is as thick as 770 m on Fairview Mountain and may be thicker in the lowlands, unconformably overlies the Tyonek(?) Formation (Reed and Nelson, 1977). It is lithologically similar to the Tyonek(?) in most respects and, according to Reed and Nelson (1977), may be partly derived from it. Conglomerate clasts in the Sterling(?) are lithologically similar to those in the Tyonek(?), but they are present in different proportions and have a larger maximum grain size (as much as 30 cm in diameter). Conglomeratic sequences in the Sterling(?) are streaked with iron oxide at intervals, suggesting that the unit was more thoroughly oxidized than the more drab Tyonek(?). The Sterling(?) contains less carbonaceous material, which would have been a barrier to oxidation, than the underlying Tyonek(?). Little bedded coal is present in the Sterling(?) Formation in the Susitna Lowlands.

Eight sections of the Sterling(?) Formation were described for this study (appendix 2, sections 1, 3, 4, 9, 15–18). They consist of 62 percent conglomerate, 13 percent sandstone, and 25 percent claystone and mudstone. Coal in the Sterling(?) is present only as thin (10 cm or less)

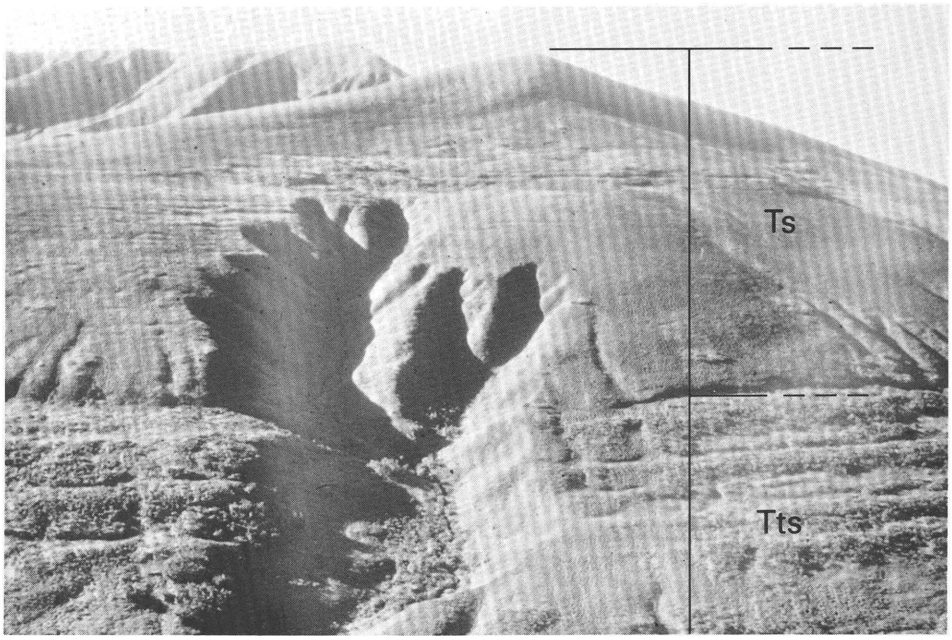

Figure 4. Several hundred meters of rocks of the Tertiary Kenai Group r on Fairview Mountain, Susitna Lowlands, south-central Alaska. Rock units: **Ts**, Sterling (?) Formation; **Tts**, sandstone member of Tyonek (?) Formation.

discontinuous beds or as clasts. One thin coal bed at Camp Creek (section 15) is overlain by a bed of kaolinitic mudstone about 30 cm thick. One of the samples from this bed (sample 28, appendix 1) contained 72 ppm uranium.

METHODS

The samples were analyzed for 21 elements and 6 minerals. Sample localities are shown in figure 2 and in measured sections in appendix 2. A data set was prepared containing 29 samples.

Uranium and thorium contents were determined using the delayed-neutron method (Millard, 1976). Elemental values were determined using the six-step semiquantitative spectroscopy method (Myers and others, 1961). Mineralogical determinations were made by X-ray diffraction of whole-rock cell mounts. For a few samples, oriented mounts of the <2-micron clay fractions were X-rayed after air-drying, glycolation, and heating to 550°C. The whole-rock X-ray diffraction data were obtained under conditions as uniform as possible for all of the runs. The same preparation procedures, instrument, and instrument settings were used for all samples. All the runs were made continuously, and a standard sample was X-rayed before and after each daily run. All analyses were made using sample splits.

The relative abundances of quartz, feldspar, chlorite, illite, smectite, and amphibole were determined by measuring the areas of the X-ray diffraction peaks (in square inches) as recorded on the whole-rock diffractograms. Illite, as determined, includes the clay mineral illite and mica undifferentiated. The peaks measured for each mineral are listed in table 1. The areas of individual X-ray diffraction peaks provide estimates of the relative abundances of the minerals. The X-ray diffraction data do not, however, represent the absolute abundances of the minerals.

Table 1. X-ray diffractogram peaks (Cu, Kα radiation) measured for the rock samples in the study.

Mineral	X-ray diffraction peak (degrees 2θ)	Crystallographic index
Feldspar	26.9-27.9	002
Quartz	20.8	100
Illite	8.8	001
Smectite	10.2	002
Chlorite	12.5	002
Kaolinite	12.5	001

A factor analysis and matrix of correlation coefficients for the data set in appendix 1 were calculated using a commercial program (Hintze, 1992). These analyses suggest many relationships that otherwise might be missed when perusing the data. The number of samples analyzed is too low, however, to represent comprehensively the total thickness of the combined Tyonek(?) and Sterling(?) Formations. The statistical analyses only represent the distribution and relationships of elements and minerals in the sample set.

For the few qualified values in appendix 1, the following substitutions were made. For values listed as N (not detected), half of the lower detection limit was used; for values listed as L (detected, but not determined), three-fourths of the lower detection limit was used; for values prefixed by <, three-fourths of the less than value was used; for values listed as G (greater than 10 percent), 12.5 percent was used. Beryllium, boron, and lead were excluded from the statistical calculations because of the large number of qualified values for these elements. Kaolinite and smectite were not included because most of the samples contained none. Sample number 28 was excluded because it was enriched in uranium.

STATISTICAL ANALYSIS

Mineralogical and chemical data for the Kenai Group in the Susitna Lowlands are given in appendix 1. Arithmetic means and standard deviations are given for the minerals and elements for each of the two stratigraphic units. A correlation coefficient matrix (table 2) and a five-factor model of an R-mode factor analysis (table 3) (Harmon, 1960) are presented for the data in appendix 1. The degree of correlation for all pairs of variables is shown by the correlation coefficients. The purpose of the factor analysis is to group related variables to reduce the amount of variation that must be interpreted and to investigate the underlying causes. The factors are calculated from the correlation matrix. The factor analysis includes the varimax rotation, which is rotation of the factors around the orthogonal axes. Varimax rotation enhances differences in factor loadings (Hintze, 1992). Factor loadings are the correlations between each variable and the factors. The sum of the squares of the factor loadings for each variable is equal to the communality, the proportion of each variable explained by the analysis. For more complete descriptions of factor analysis and its geological application see Davis (1986) and Koch and Link, (1971).

A five-factor model was chosen because it is the simplest model that offers a reasonable explanation of the observed data and because it gives high communalities for the variables of primary interest, which include uranium and thorium.

The geologic processes that underlie statistical factors are interpreted to be source area, sorting and alteration during transport and deposition, and postdepositional alteration (diagenesis). Differences in mineralogical and chemical makeup of the source areas result in differences in the composition of the sediment produced. During transport, the sediment is sorted into finer clay and coarser sand. The sand and clay fractions have somewhat different mineralogical and chemical makeup. Chemical and mineralogical alteration may also occur during sediment transport. Diagenesis results in changes in mineralogical and chemical makeup after lithification. The calculated factors represent combinations of the above processes that in some cases make interpretation speculative.

Factor one.—Factor one consists of potassium, chlorite, chromium, illite, magnesium, and zirconium (table 3). In part, this factor represents the claystone and mudstone containing the fine-grained clay minerals chlorite and illite. There is a strong correlation between chlorite and illite in the rocks of the Kenai Group, not only in this area, but also in the Tyonek-Capps Glacier area (Dickinson and others, this volume) and on the Kenai Peninsula (Dickinson and Skipp, 1992). Magnesium and potassium are expected in this factor because magnesium is a constituent of chlorite and potassium is a constituent of illite. The occurrence of chromiuim and zirconium in this factor is less easy to explain. Magnesium and chromium both suggest a relation to a mafic source area.

Factor two.—Factor two consists of Cu, Sc, Ga, V, Ba, Al, Ni, U, and Ti (table 3). The relationships between these elements are complex and not entirely clear. The factor contains uranium, which is epigenetically enriched in three of the samples (fig. 5*A*) and otherwise is related to thorium (r=+0.36) and other elements. The relation between uranium and copper (r=+0.8, table 2, fig. 5*B*) suggests that some parallel enrichment of the copper in the epigenetic environment may also have occurred, as discussed later. Vanadium is related to uranium (r=+0.53, table 2, fig 5*C*). Vanadium is typically related to carbonaceous material in sedimentary rock, and the relation between uranium and carbonaceous material in enriched samples may explain this correlation. Uranium ore on the Colorado Plateau also typically contains large amounts of vanadium (Fischer, 1968). Nickel and copper together with chromium, which has a high secondary loading in this factor, are linked by their common occurrence in sulfide minerals. Factor two also includes gallium and aluminum, which are commonly present together in fine-grained sediments and sedimentary rocks (hydrolysates) because of similar ionic potential (Mason, 1966, p. 163–164). Scandium, which is also in this factor, is generally present in greater amounts in fine-grained sedimentary rocks than in sandstone. Titanium, which is in this factor despite the low value of its loading (–0.59, table 3), is commonly enriched in placer deposits, and its occurrence here is not explained. In general, this factor is interpreted to represent altered fine-grained sedimentary rocks.

Factor three.—Factor three consists of plagioclase, sodium, strontium, and calcium (table 3). Plagioclase is present mainly as detrital grains in sandstone and coarser clastic rocks. Strontium, calcium, and sodium are all present in plagioclase. Strontium substitutes for calcium in plagioclase because of similar ionic charge and radius. A correlation between strontium and calcium is expected in granitic but not in basaltic rocks.

Factor four.—Factor four consists only of iron and manganese (table 3). These two elements behave similarly in oxidation-reduction environments and frequently are present together in oxide or hydroxide minerals. They are present together in the Sterling and Beluga Formations on the Kenai

Table 2. Correlation coefficient matrix for data set.
[Data set is given in appendix 1]

	Uranium	Thorium	Iron	Magnesium	Calcium	Titanium
Uranium	1.00					
Thorium	0.36	1.00				
Iron	–0.31	–0.22	1.00			
Magnesium	–0.16	0.32	–0.01	1.00		
Calcium	0.27	0.40	0.08	–0.03	1.00	
Titanium	0.58	0.51	–0.23	0.45	0.34	1.00
Manganese	–0.34	–0.19	0.80	–0.10	0.16	–0.39
Barium	0.24	0.16	0.02	0.47	–0.26	0.54
Chromium	0.06	0.43	0.08	0.68	–0.25	0.44
Copper	0.80	0.32	–0.12	0.04	0.04	0.60
Nickel	0.19	0.18	0.20	0.32	–0.26	0.38
Scandium	0.50	0.40	–0.07	0.57	–0.15	0.63
Strontium	0.33	0.33	–0.39	0.35	0.46	0.65
Vanadium	0.53	0.37	–0.24	0.49	–0.10	0.60
Yttrium	0.56	0.61	–0.35	0.19	0.26	0.31
Zirconium	0.07	0.15	–0.10	0.52	0.05	0.31
Aluminum	0.44	0.49	–0.28	0.45	–0.18	0.50
Sodium	–0.10	–0.05	0.10	0.18	0.21	0.16
Potassium	–0.10	0.38	0.02	0.66	–0.40	0.25
Gallium	0.43	0.31	–0.14	0.36	–0.22	0.50
Ytterbium	0.40	0.69	–0.26	0.45	0.11	0.52
Quartz	–0.54	–0.43	–0.22	–0.01	–0.27	–0.29
Plagioclase	0	0.09	–0.10	0.31	0.41	0.35
Chlorite	–0.22	0.34	–0.13	0.47	–0.36	0.06
Illite	–0.26	0.10	0.06	0.45	–0.37	0
	Manganese	**Barium**	**Chromium**	**Copper**	**Nickel**	**Scandium**
Manganese	1.00					
Barium	–0.19	1.00				
Chromium	–0.09	0.70	1.00			
Copper	–0.17	0.49	0.29	1.00		
Nickel	0.01	0.69	0.73	0.35	1.00	
Scandium	–0.25	0.73	0.79	0.69	0.62	1.00
Strontium	–0.26	0.12	0.07	0.39	–0.08	0.30
Vanadium	–0.35	0.66	0.62	0.68	0.51	0.87
Yttrium	–0.23	–0.07	0.20	0.38	0.14	0.39
Zirconium	–0.34	0.41	0.44	0.07	0.27	0.43
Aluminum	–0.31	0.57	0.64	0.59	0.51	0.71
Sodium	0.11	0.33	0.14	0.07	0.13	0.16
Potassium	–0.17	0.63	0.81	0.17	0.48	0.64
Gallium	–0.20	0.70	0.62	0.67	0.44	0.70
Ytterbium	–0.41	0.41	0.64	0.36	0.47	0.68
Quartz	–0.36	–0.09	–0.19	–0.56	–0.19	–0.40
Plagioclase	–0.05	0.17	–0.01	0.04	–0.04	0.11
Chlorite	–0.30	0.21	0.57	–0.08	0.11	0.29
Illite	–0.06	0.35	0.53	–0.01	0.26	0.35

Peninsula (Dickinson and Skipp, 1992) but not in rocks of the Kenai Group in the Tyonek–Capps Glacier area (Dickinson and others, this volume). Manganese is leached before iron in soils and follows iron in precipitation in sediments.

Factor five.—Quartz is at the positive pole in factor five, and ytterbium, thorium, and yttrium are at the negative pole (table 3). The distribution of quartz is complex because it is present as grains of all sizes, including clay sizes, and possibly also as an alteration product, although none was identified. Ytterbium and yttrium are rare earth elements and, as such, can be expected to be present together because of similar geochemical characteristics.

Table 2. Correlation coefficient matrix for data set—Continued.

	Strontium	Vanadium	Yttrium	Zirconium	Aluminum	Sodium
Strontium	1.00					
Vanadium	0.36	1.00				
Yttrium	0.22	0.36	1.00			
Zirconium	0.25	0.37	0.11	1.00		
Aluminum	0.24	0.70	0.43	0.23	1.00	
Sodium	0.39	0.08	–0.15	0.41	0.12	1.00
Potassium	0.01	0.51	0.11	0.52	0.55	0.26
Gallium	0.29	0.68	0.25	0.18	0.80	0.14
Ytterbium	0.27	0.60	0.64	0.51	0.54	0.13
Quartz	–0.19	–0.34	–0.55	0.27	–0.34	0
Plagioclase	0.50	0.18	–0.08	0.29	0.10	0.59
Chlorite	–0.02	0.20	0.14	0.32	0.25	–0.06
Illite	–0.21	0.25	0.07	0.26	0.27	0.23

	Potassium	Gallium	Ytterbium	Quartz	Plagioclase	Chlorite
Potassium	1.00					
Gallium	0.51	1.00				
Ytterbium	0.62	0.37	1.00			
Quartz	–0.06	–0.45	–0.25	1.00		
Plagioclase	0.10	0.01	0.06	–0.07	1.00	
Chlorite	0.78	0.29	0.48	0.11	–0.20	1.00
Illite	0.69	0.31	0.31	–0.02	0.19	0.55

Table 3. Varimax factor analysis for five factors.
[Primary factor loadings are are underlined]

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Communality
Uranium	–0.42	<u>–0.64</u>	–0.01	–0.25	–0.47	0.87
Thorium	0.28	–0.18	–0.10	–0.09	<u>–0.81</u>	0.79
Iron	0.06	0.06	0.02	<u>0.90</u>	0.16	0.84
Magnesium	<u>0.71</u>	–0.21	–0.37	–0.02	–0.14	0.70
Calcium	–0.36	0.23	<u>–0.59</u>	0.14	–0.57	0.87
Titanium	0.04	<u>–0.59</u>	–0.47	–0.24	–0.35	0.75
Manganese	–0.12	0.17	0.01	<u>0.94</u>	0.04	0.92
Barium	0.39	<u>–0.78</u>	–0.21	0	0.24	0.86
Chromium	<u>0.74</u>	–0.56	–0.02	0.10	–0.12	0.89
Copper	0.21	<u>–0.85</u>	–0.06	–0.05	–0.27	0.85
Nickel	0.36	<u>–0.66</u>	0.04	0.22	0.06	0.62
Scandium	0.40	<u>–0.82</u>	–0.12	–0.06	–0.22	0.89
Strontium	–0.13	–0.21	<u>–0.69</u>	–0.31	–0.32	0.74
Vanadium	0.25	<u>–0.79</u>	–0.15	–0.20	–0.20	0.79
Yttrium	0.06	–0.21	0.12	–0.17	<u>–0.84</u>	0.79
Zirconium	<u>0.52</u>	–0.15	–0.46	–0.28	0.04	0.59
Aluminum	0.31	<u>–0.73</u>	–0.01	–0.17	–0.25	0.72
Sodium	0.17	–0.10	<u>–0.74</u>	0.16	0.20	0.66
Potassium	<u>0.89</u>	–0.36	–0.04	0	–0.03	0.92
Gallium	0.23	<u>–0.81</u>	0	–0.05	–0.10	0.73
Ytterbium	0.52	–0.37	–0.11	–0.24	<u>–0.57</u>	0.80
Quartz	0.18	0.45	–0.03	–0.48	<u>0.62</u>	0.85
Plag.	0.03	–0.01	<u>–0.85</u>	0	0.01	0.73
Chlorite	<u>0.82</u>	0.03	0.22	–0.22	–0.15	0.79
Illite	<u>0.74</u>	–0.12	0.01	0.10	0.08	0.58

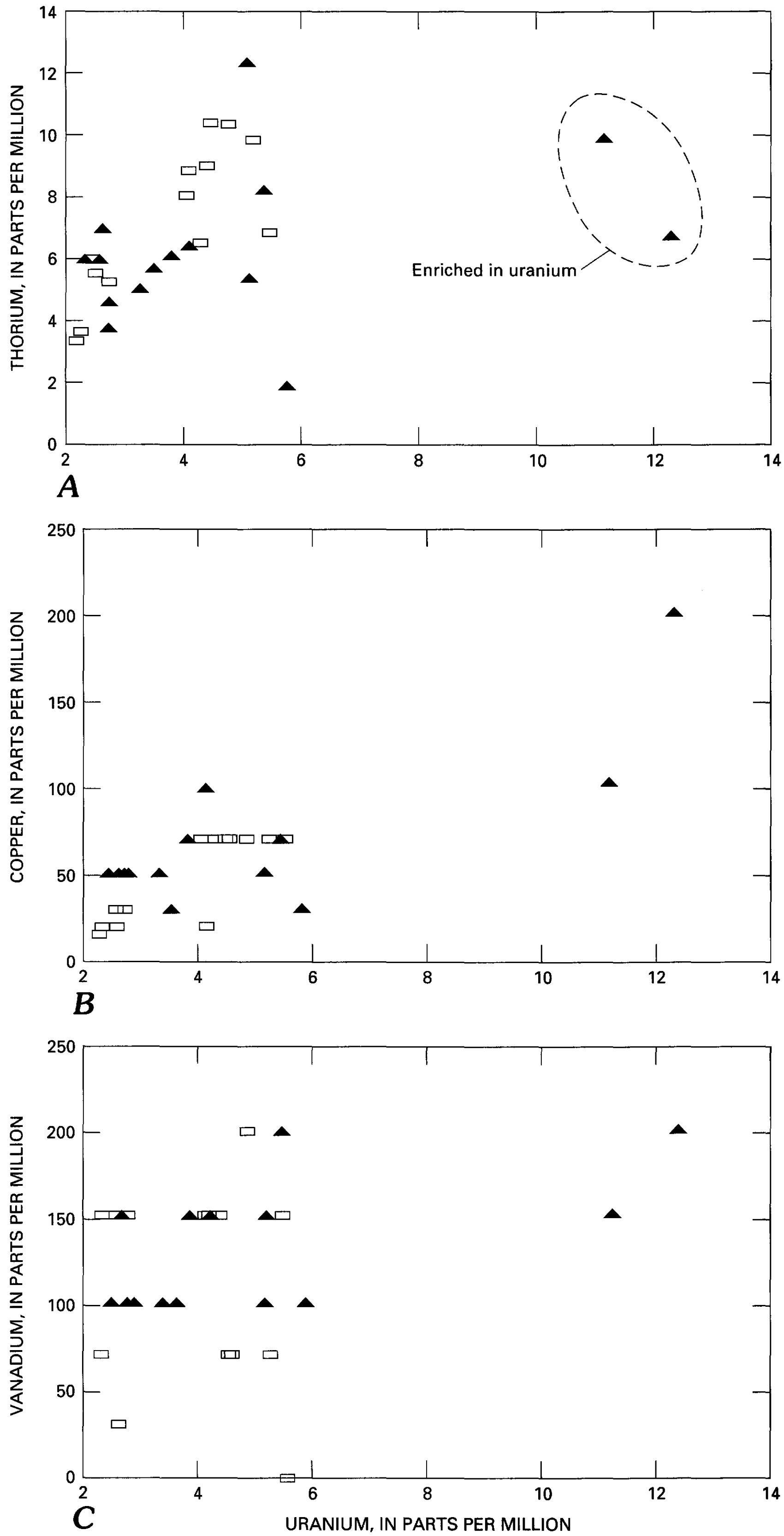

Figure 5. Scatterplots of uranium versus (*A*) thorium, (*B*) copper, and (*C*) vanadium for samples of the Tertiary Kenai Group. Sample data are given in appendix 1. Open squares indicate Tyonek (?) Formation; solid triangles indicate Sterling (?) Formation. Sample number 28, which is a uranium outlier, is not included.

CLAY MINERALS

Of the clay minerals present in rocks of the Kenai Group (table 4), chlorite and illite are interpreted as detrital, and kaolinite and smectite are thought to be mostly diagenetic. Chlorite and illite are abundant in samples that show no evidence of diagenesis. In addition, chlorite and illite are closely associated in samples of the Kenai Group from the Susitna Lowlands (*r*=+0.77), from the Capps Glacier area (*r*=+0.67) (Dickinson and others, this volume), and from the Kenai Peninsula area (*r*=+0.9) (Dickinson and Skipp, 1992). This association would be improbable if either the illite or the chlorite was of diagenetic origin.

Most of the smectite probably formed from volcanic material originally contained in the sediments, but some of it may have been altered prior to sediment deposition and is, therefore, detrital (Dickinson and others, this volume). The kaolinite has not been extensively studied but apparently is associated with coal beds or other occurrences of abundant carbonaceous material. The kaolinite probably formed diagenetically from volcanic material in the acidic conditions that developed in the peat-forming environment. The vitreous volcanic component of these sediments is not detectable by X-ray diffraction, and the smectite or kaolinite, which is detectable by X-ray diffraction, may be a reasonable indicator of original volcanic material in the sediments.

URANIUM FAVORABILITY

In the data set for this study, three samples from the Sterling(?) Formation contained more than 10 ppm U (appendix 1). Uranium at these concentrations in sedimentary rocks probably results from epigenetic enrichment. This origin is especially likely for a kaolinitic mudstone sample from the Sterling (?) Formation in the Camp Creek area that contains 72 ppm U_3O_8 (sample 28, fig. 6, appendix 1). The sample was collected within a few centimeters above a thin coal bed that could have produced the reducing environment necessary to precipitate uranium from ground water. Epigenetic enrichment of copper, which, similar to uranium, is mobilized by oxidizing solutions and precipitated in reducing environments, may also have occurred. The copper values in the data set are not high, averaging 48 ppm for the Sterling(?) Formation and 65 ppm for the Tyonek(?) Formation (appendix 1), compared to an average of 30 ppm for igneous rocks of the upper continental crust (Wedepohl, 1971). There is, however, a fairly strong correlation between uranium and copper in the data set presented here (*r*=+0.8, table 2, fig. 5*A*). The correlation coefficient for uranium and copper is +0.48 for the data set from the Tyonek-Capps Glacier area (Dickinson and others, this volume) and +0.31 for the data set from Kenai Peninsula area (Dickinson and Skipp, 1992).

Table 4. Clay content of selected samples.
[Sample numbers refer to appendixes 1 and 2. X indicates present in detectable amount; leaders (--) indicates not detected]

Field number	Smectite	Illite	Chlorite	Kaolinite
TYONEK(?) FORMATION				
1	X	X	X	--
2	--	X	X	--
4	--	X	X	--
5	X	X	X	--
10	--	X	X	X
11	--	--	--	X
STERLING(?) FORMATION				
15	X	X	X	--
28	--	--	--	X
29	--	--	--	X

Uranium is also positively correlated with Ti, Sc, V, Al, Y, Yb, and Ga (table 2). In the Capps Glacier area (fig. 1) uranium is associated with Th, Ga, K, Yb, Y, and V (Dickinson and others, this volume), and in the Kenai Peninsula area farther to the south the only strong elemental associations with uranium are thorium and chromium (Dickinson and Skipp, 1992). These associations are believed to be mostly detrital in nature in both areas. The strong association between uranium and thorium in the Tyonek-Capps Glacier and Kenai Peninsula areas indicates that uranium has not been mobilized in these rocks. The uranium-thorium association in the Susitna Lowlands is weaker (*r*=0.36, table 2). Figure 5*A* shows that the correlation between uranium and thorium holds true for most of the samples in the Susitna Lowlands but not for those with the higher uranium values. If the two outliers shown in figure 5 are omitted, the correlation is stronger (*r*=+0.6). The accuracy of thorium measurements by the delayed neutron method decreases in samples having high uranium contents, making the relationships difficult to quantify in samples enriched in uranium.

Judging from its color, the Sterling(?) Formation is more oxidized than the underlying Tyonek(?) Formation. The Sterling(?) lacks carbonaceous material and contains very little bedded coal that would retard oxidation. The Tyonek(?), on the other hand, contains abundant bedded coal and other carbonaceous material that could act as a barrier to widespread oxidation. Uranium was apparently mobilized by oxidizing ground water in the Sterling(?) and deposited in locally reducing environments. In the Susitna Lowlands area, the Sterling(?) Formation therefore has a higher potential for epigenetically enriched uranium deposits than does the Tyonek(?).

In addition to the uranium occurrences in the Sterling (?) Formation, other uranium occurrences are present in and near the study area. These include uraniferous resistate minerals in stream placers in the Cache Creek and upper Peters Creek areas, high uranium values in heavy-mineral samples from the Kahiltna and Ruth plutons (fig. 2), hydrothermal

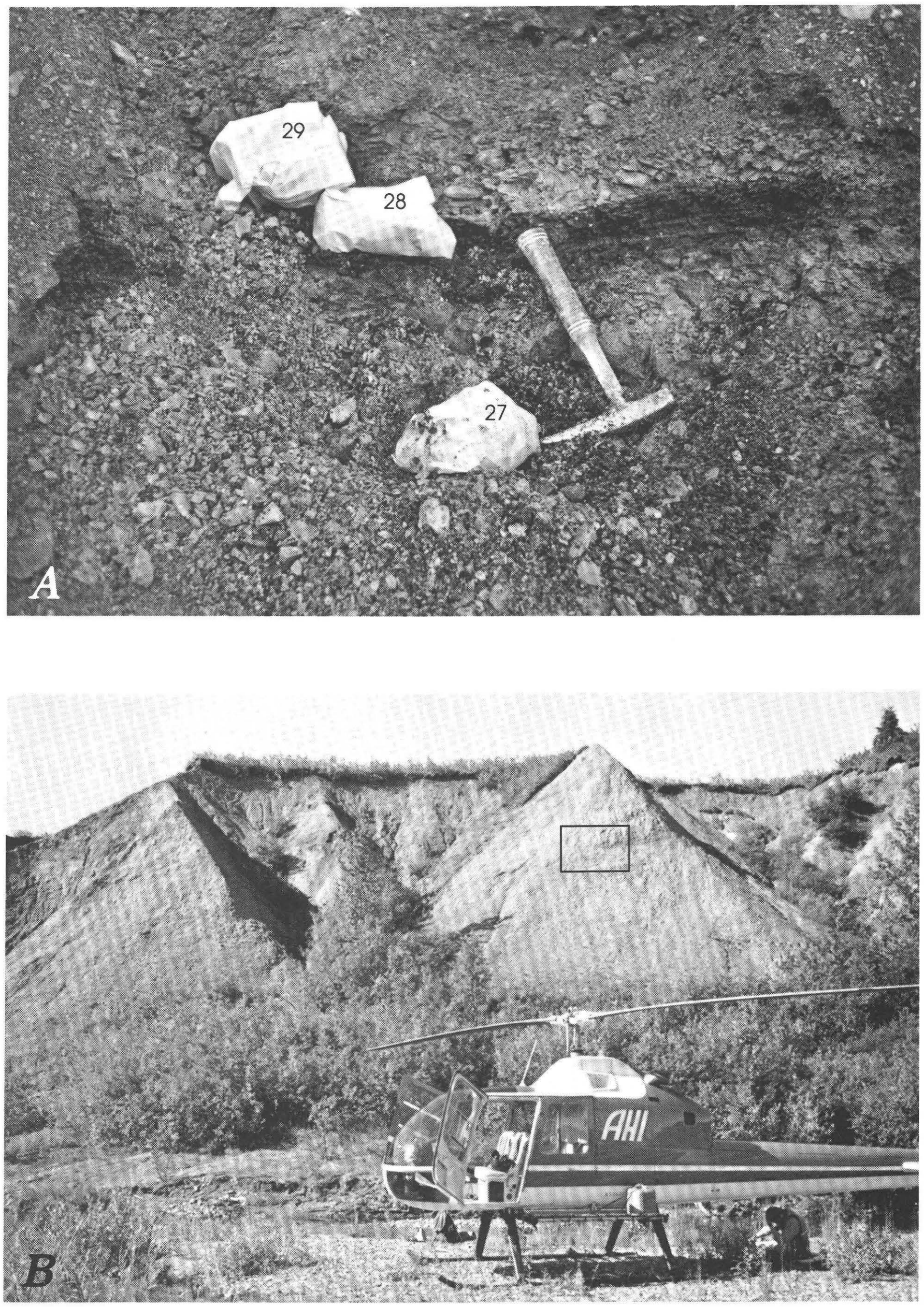

Figure 6. Sterling(?) Formation at Camp Creek (section 15, appendix 2). *A*, Close-up view; sample 27 is gray clayey sandstone, sample 28 uraniferous kaolinitic mudstone, and sample 29 barren kaolinitic mudstone. Sample bags show collections locations. Hammer is shown for scale. *B*, General view showing approximate area of *A* (indicated by outline).

vein deposits in the Tonzona pluton, and mineralization along fractures or joints near Shirley Lake (fig. 1). Robinson and others (1955) reported eU values as high as 0.009 percent equivalent U_3O_8 in concentrates from Quaternary stream gravels along Cache Creek and upper Peters Creek in the study area. Uranium and thorium were contained in grains of zircon, monazite, and uranothorianite that were found in the concentrates. Reed and others (1978) suggested that some of these minerals were derived from erosion of the Kenai Group. Curtin and others (1979) reported a uranium value of 2,200 ppm for a selected nonmagnetic heavy-mineral concentrate of a stream-sediment sample on the Kahiltna pluton. Other samples from the pluton contained much less uranium. A significant uranium occurrence is present at the

Mespelt prospect, which is associated with the Late Cretaceous or early Tertiary Tonzona pluton about 35 km northwest of the northern margin of the study area (fig. 1). This prospect is a hydrothermal vein deposit, and zeunerite and metazeunerite (copper-uranium arsenates) are present (Maloney and Thomas, 1966). A minor supergene uranium occurrence is present in and around joints and fractures in a basaltic and andesitic tuff near Shirley Lake (Freeman, 1963), about 25 km west of the southwest corner of the study area (fig. 1).

Friedman and Hinderman (1978) described two uranium occurrences in the Talkeetna 2° quadrangle, one at Tonzona pluton and one in the Cache Creek area. Both occurrences are described preceding. Friedman and Hinderman listed only the Tonzona pluton as an area favorable for commercial-size uranium deposits in the Talkeetna quadrangle but did not evaluate the Tertiary sedimentary rocks considered herein for that area.

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APPENDIX 1—CHEMICAL AND MINERALOGICAL DATA FOR SAMPLES OF THE TYONEK(?) AND STERLING(?) FORMATIONS OF THE TERTIARY KENAI GROUP

Samples are shown by number in the measured sections of appendix 2. Elements are in parts per million (ppm) or percent, as indicated at top of column. Values for quartz, plagioclase, chlorite, illite, smectite, and amphibole are peak area in square inches; the crystallographic indices of the peaks measured are given in table 1. Mean is the arithmetic mean; St. Dev. is standard deviation. For values listed as N (not detected), half of the lower detection limit was used; for values listed as L (detected, but not determined), three-fourths of the lower detection limit was used; for values prefixed with <, three-fourths of the less than value was used; for values listed as G (greater than 10 percent), 12.5 percent was used.

A. Description of samples

Sample number	Measured section	Rock type
		TYONEK(?) FORMATION
1	7	Claystone, gray-brown, dense, micaceous
2	8	Sandstone, gray-brown, dense, micaceous
3	6	Claystone, light-brown, dense, micaceous
4	2	Claystone, medium-gray to brown, dense
5	13	Claystone, light-gray, sandy, micaceous, noncalcareous
6	11	Siltstone, medium-gray, noncalcareous
7	10	Mudstone, gray, mottled; reddish-brown siderite
8	5	Sandstone, brown, hard, noncalcareous
9	5	Sandstone, gray, soft, medium- to coarse-grained
10	14	Mudstone, medium- to light-gray, dense; iron oxide
11	14	Sandstone, gray-brown, medium-grained, soft, silty
12	12	Mudstone, gray-brown, dense, micaceous, metallic luster
13	12	Sandstone, brown, very fine grained, soft, silty
		STERLING(?) FORMATION
14	9	Mudstone, medium- to dark-gray
15	17	Claystone, medium-gray, hard; lithic fragments
16	18	Claystone, gray, smooth, varved
17	3	Sandstone, light-brown, fine-grained, silty
18	15	Claystone, medium-gray, carbonaceous, noncalcareous
19	16	Sandstone, brown, soft, coarse-grained, conglomerate
20	1	Siltstone, light-brown, clayey, sandy, mottled
21	4	Claystone, light-gray, dense, micaceous
22	15	Sandstone, red-brown, fine- to medium-grained, clayey
23	15	Sandstone, dark-red-brown, fine- to medium-grained
24	15	Sandstone, red-brown, coarse- to medium-grained, soft
25	15	Sandstone, brown, poorly sorted, clayey, pebbled
26	15	Sandstone, red-brown, fine- to coarse-grained, pebbled
27	15	Mudstone, gray to brown, hard, micaceous
28	15	Mudstone, medium-gray, hard, kaolinitic, uraniferous
29	15	Mudstone, tan, dense, kaolinitic, chalky appearance

B. Chemical and mineralogical data

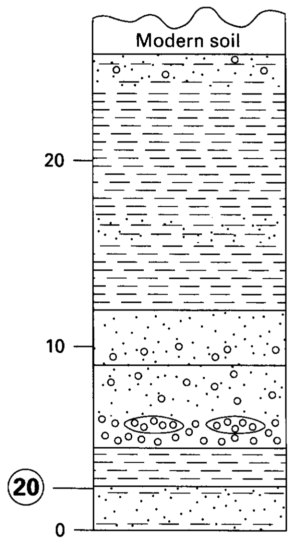
Sample number	U (ppm)	Th (ppm)	Fe (percent)	Mg (percent)	Ca (percent)	Ti (percent)	Mn (ppm)	Ba (ppm)	Cr (ppm)	Cu (ppm)	Ni (ppm)	Sc (ppm)	Sr (ppm)	V (ppm)
							TYONEK(?) FORMATION							
1	5.5	6.9	3.0	1.5	0.30	0.30	300	1,500	150	70	100	30	150	150
2	4.2	8.9	1.5	0.30	0.50	0.15	200	700	70	20	20	10	150	70
3	5.2	9.8	5.0	1.5	0.50	0.50	300	1,500	150	70	100	30	150	150
4	4.3	6.5	3.0	1.5	0.20	0.30	300	1,500	150	70	70	30	150	200
5	4.8	10	2.0	1.5	0.30	0.30	150	1,000	150	70	50	30	150	150
6	4.1	8.1	3.0	1.5	0.30	0.30	300	1,000	100	70	70	20	150	150
7	2.7	5.3	10	0.30	0.70	0.07	3,000	300	30	30	20	5.0	70	30
8	2.6	5.5	3.0	0.70	0.10	0.20	700	700	70	30	70	7.0	70	70
9	2.2	3.3	1.5	0.70	0.30	0.20	300	700	30	15	20	7.0	150	70
10	4.5	10.5	2.0	1.5	0.30	0.30	100	1,000	150	70	50	20	150	150
11	2.3	3.7	0.70	0.20	0.15	0.10	70	700	30	20	15	7.0	70	70
12	4.5	9.0	3.0	1.5	0.50	0.30	700	1,000	70	70	10	20	150	150
13	2.5	6.0	2.0	1.5	0.70	0.30	300	700	50	20	L	15	300	150
Mean	3.80	7.21	3.05	1.09	0.37	0.26	517	946	92.3	48.1	46.3	17.8	143	120
St. dev.	1.13	2.33	2.25	0.53	0.18	0.11	740	357	49.3	24.0	32.1	9.58	56.2	48.7
							STERLING(?) FORMATION							
14	5.4	8.2	3.0	1.5	0.30	0.30	700	1,500	150	70	150	30	150	200
15	2.8	4.6	2.0	1.5	0.70	0.30	700	700	70	50	30	15	300	100
16	4.2	6.5	5.0	1.5	0.30	0.30	1,500	1,500	150	100	100	30	150	150
17	5.8	1.9	3.0	1.0	0.30	0.30	300	700	70	50	70	15	150	100
18	2.7	7.0	3.0	0.70	0.30	0.30	30	300	30	100	30	20	150	150
19	11	9.8	0.50	0.30	1.0	0.30	300	1,000	70	30	50	15	100	100
20	5.1	12	3.0	1.5	1.50	0.50	700	1,000	100	50	50	15	300	100
21	3.8	6.1	5.0	1.5	0.30	0.30	700	700	150	70	70	30	200	150
22	3.5	5.7	5.0	0.70	0.50	0.30	700	1,000	100	30	70	15	100	100
23	2.6	6.0	5.0	0.70	0.50	0.20	1,500	1,000	100	50	70	15	100	150
24	2.4	6.0	5.0	0.70	0.50	0.20	700	1,000	100	50	70	15	100	100
25	2.8	3.8	5.0	1.0	0.50	0.20	700	1,000	50	50	10	15	100	100
26	3.3	5.0	7.0	1.0	0.50	0.20	700	1,000	70	50	70	15	100	100
27	5.2	5.4	5.0	1.0	0.70	0.30	500	1,000	100	50	70	20	100	150
28	72	<16	0.50	0.20	0.70	0.30	30	500	50	50	50	30	100	70
29	12	<6.7	2.0	0.20	0.50	0.50	50	1,500	70	200	70	30	300	200
Mean	9.06	6.94	3.69	0.94	0.57	0.30	613	963	89.4	65.6	64.4	20.3	156	126
St. dev.	16.5	3.30	1.78	0.46	0.31	0.09	421	330	35.4	39.7	30.4	6.72	74.7	37.4

Sample Number	Y (ppm)	Zr (ppm)	Al (percent)	Na (percent)	K (percent)	Ga (ppm)	Yb (ppm)	Quartz (in.^{2})	Plag. (in.^{2})	Chlorite (in.^{2})	Illite (in.^{2})	Smectite (in.^{2})	Kaolinite (in.^{2})
TYONEK(?) FORMATION													
1	30	150	7.0	0.70	3.0	20	3.0	0.29	0.04	0.12	0.08	0	0
2	30	150	7.0	1.5	3.0	15	3.0	0.33	0.06	0.14	0.07	0	0
3	30	100	10	1.0	3.0	20	3.0	0.25	0.03	0.10	0.06	0	0
4	30	150	10	0.70	3.0	30	3.0	0.28	0.02	0.12	0.07	0	0
5	30	150	G	0.70	3.0	20	3.0	0.39	0.04	0.09	0	0	0
6	30	100	10	0.70	3.0	15	3.0	0.32	0.06	0.12	0.07	0	0
7	15	15	1.5	0.50	0.70	10	N	0.02	0	0	0	0	0
8	30	70	7.0	0.30	1.5	15	1.5	0.35	0.01	0.05	0.05	0	0
9	15	70	7.0	0.70	1.5	15	1.5	0.50	0.06	0.06	0.02	0.01	0
10	30	100	G	0.30	3.0	30	2.0	0.30	0	0.18	0.07	0	0
11	L	70	2.0	0.50	0.70	7.0	L	0.66	0.02	0.01	0.02	0	0
12	30	150	7.0	0.70	3.0	15	2.0	0.30	0.10	0.10	0.08	0	0
13	15	100	7.0	1.0	1.5	15	1.5	0.35	0.13	0.03	0.04	0	0
Mean	24.8	106	8.12	0.72	2.30	17.5	2.13	0.33	0.04	0.09	0.05	0	0
St. dev.	8.08	41.1	3.86	0.31	.92	6.42	0.90	0.14	0.04	0.05	0.02	0	0
STERLING(?) FORMATION													
14	30	150	G	1.0	3.0	20	3.0	0.34	0.06	0.04	0.03	0	0
15	30	150	7.0	1.5	1.5	15	1.5	0.44	0.07	0.06	0.03	0	0
16	30	100	G	1.5	3.0	30	2.0	0	0.12	0.03	0.20	0.12	0
17	20	100	7.0	0.70	2.0	15	2.0	0.44	0.05	0.07	0.08	0	0
18	70	70	10	0.30	N	15	3.0	0.02	0.03	0	0.02	0	0.12
19	15	150	7.0	0.70	1.5	15	1.5	0.55	0.04	0.03	0.05	2.00	0
20	30	150	7.0	1.0	1.5	15	3.0	0.33	0.11	0.03	0.02	0	0
21	30	150	7.0	0.70	3.0	15	3.0	0.30	0.04	0.14	0.07	0	0
22	10	100	7.0	0.70	2.0	15	1.5	0.36	0.08	0.08	0.03	0	0
23	15	100	7.0	1.0	2.0	15	2.0	0.38	0.03	0.05	0.06	0	0
24	15	100	7.0	1.0	2.0	15	2.0	0.51	0.06	0.07	0.08	0	0
25	10	100	7.0	1.0	2.0	15	1.5	0.48	0.05	0.06	0.07	0	0
26	20	200	7.0	1.0	2.0	15	2.0	0.50	0.04	0.04	0.03	0	0
27	20	150	7.0	1.0	2.0	15	2.0	0.30	0.10	0.03	0.07	0	0
28	100	150	10	0.30	N	15	5.0	0.04	0	0	0	0	0.10
29	20	100	G	1.0	1.5	30	2.0	0.11	0.06	0	0	0	0.20
Mean	29.1	126	8.72	0.90	1.87	17.2	2.31	0.32	0.06	0.05	0.05	0.13	0.03
St. dev.	22.9	33.0	2.84	0.32	0.74	4.99	0.88	0.18	0.03	0.03	0.05	0.48	0.06

APPENDIX 2—MEASURED SECTIONS OF THE TYONEK(?) AND STERLING(?) FORMATIONS OF THE TERTIARY KENAI GROUP

Locations of sections are shown in figure. 2. Section scales are in meters; sample numbers are circled and in bold, alongside scale.

Section 1. Sterling(?) Formation. Along Cottonwood Creek 2.8 km northeast of the junction of Cottonwood and Peters Creeks. SE¼NW¼NW¼ sec. 33, T. 29 N., R. 8 W., Seward Meridian



Claystone, medium- to light-gray, poorly bedded, crumbly; sandy at top, silty zones, wood fragments, horizontal yellowish-brown streaks, and scattered pebbles

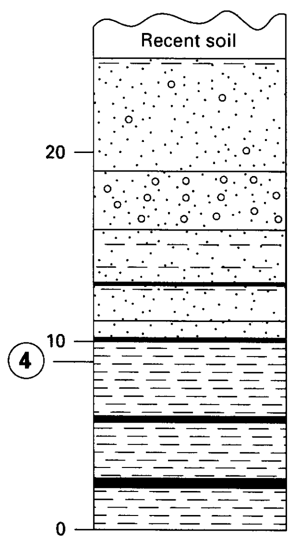
Sandstone, light-gray, fine- to coarse-grained; fines upward; vague bedding marked by pebble zones and lenses

Conglomerate, light-gray; fine-grained sand matrix; fines upward from pebbles to granules; fine- to medium-grained lenticular sandstone interbeds, with channeled bases and tabular-planar crossbeds

Claystone, medium-gray to reddish-brown, massive; silty zones and color laminations

Sandstone, fine-grained, and siltstone, light-brown, massive; interbedded at base and top with light-gray claystone layers 5–10 cm thick

Section 2. Tyonek(?) Formation. On Cottonwood Creek 1.4 km northeast of the junction of Cottonwood and Peters Creeks. SW¼SW¼SE¼ sec. 32, T. 29 N., R. 8 W., Seward Meridian



Sandstone, light-brown, coarse-grained to very coarse grained; scattered granules; vague horizontal bedding; granule-pebble lenses 20 cm–1 m thick; clayey at top

Conglomerate, light-brown; well-rounded pebbles 1–2 cm in diameter; sand matrix; horizontal interbeds of medium-grained sandstone

Conglomerate, light-brown; well-rounded pebbles 1–2 cm in diameter; sand matrix; horizontal interbeds of medium-grained sandstone

Coal, black, shaly; mostly covered

Sandstone, medium-gray, fine-grained, clayey; interbedded claystone layers 5 cm thick; partly covered

Coal, black, shaly; mostly covered

Claystone, medium-bluish-gray, crumbly; mostly covered

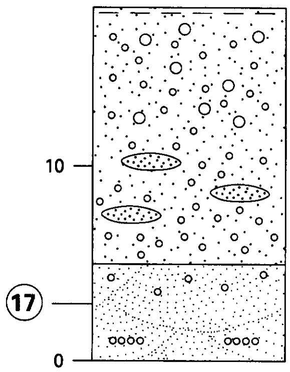
Coal, black, shaly; weathers to orange streaks; wood fragments

Claystone, medium-bluish-gray, poorly bedded, silty, crumbly; mostly covered

Coal, black, shaly; weathers reddish brown; fibrous wood fragments

Claystone, medium-bluish-gray, poorly bedded, silty, crumbly; mostly covered

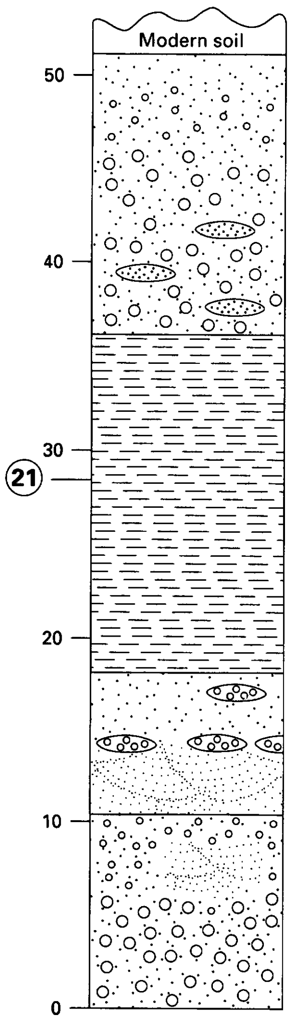
Section 3. Sterling(?) Formation. On Columbia Creek 0.6 km northeast of the junction of Columbia and Cache Creeks. NW¼NW¼NW¼ sec. 14, T. 18 N., R. 9 W., Seward Meridian



Conglomerate, light-grayish-brown; pebbles to cobbles; medium-grained sandstone matrix; interbedded sandstone lenses 2–5 cm thick; fines upward to claystone; imbricated pebbles

Sandstone, light- to reddish-brown, medium- to coarse-grained; conglomeratic at top; interbedded with granule-pebble lenses; tabular-planar crossbeds

Section 4. Sterling(?) Formation. Along Cache Creek at the junction of Cache and Trout Creeks. NE¼SE¼SE¼ sec. 20, T. 28 N., R. 9 W., Seward Meridian



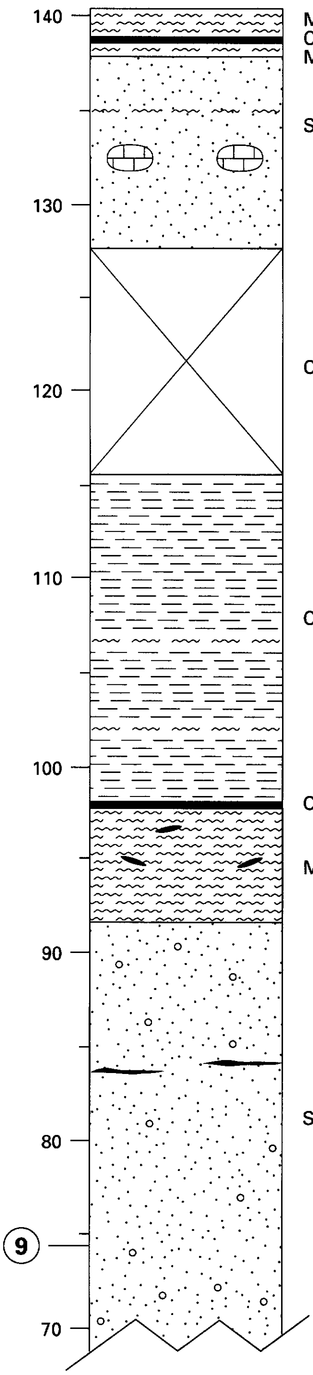
Conglomerate, medium- to grayish-brown; pebbles 3–5 cm in diameter; poorly developed horizontal beds 1–2 m thick; argillaceous sandstone lenses

Claystone, medium- to bluish-gray, massive; vague bedding 2–10 m thick

Sandstone, medium-brown, medium-grained; beds 3–20 cm thick; low-angle foreset crossbeds and granule-pebble lenses 5–10 cm thick

Conglomerate, light- to medium-brown; pebbles to cobbles 3–20 cm in diameter; grain-supported sandstone matrix, sequence fines upward; very low angle foreset crossbeds of longitudinal bar type

Section 5. Tyonek(?)Formation. On Peters Creek 2.4 km south of Petersville. Center sec. 33, T. 28 N., R. 8 W., Seward Meridian



Mudstone, brownish-gray
Coal
Mudstone, brown, crumbly; plant fragments

Sandstone, brown-mottled, reddish-brown, fine-grained, oxidized, soft; calcareous concretions 0.2 m by 1 m at 132.5 m, clay veins, and thinly bedded mudstone at 135.0 m

Covered

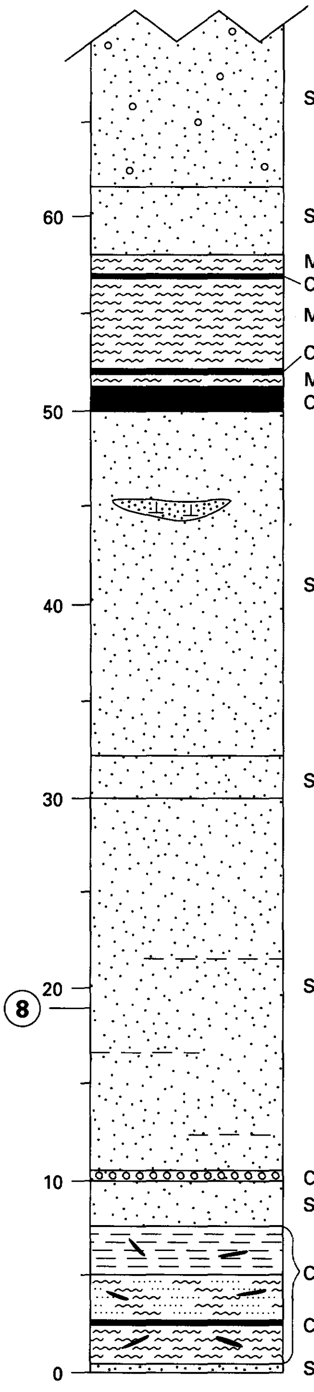
Claystone, medium-gray, dense, chunky; some silty beds and interbedded fine-grained sandstone and mudstone

Coal, black, flaky

Mudstone, brown, crumbly, sandy; carbonaceous fragments; poorly exposed

Sandstone, gray, coarse-grained; pebbly conglomerate; discontinuous thin coal seam

Section 5 (continued)



Sandstone, gray, coarse-grained; pebbly conglomerate; discontinuous thin coal seam

Sandstone, grayish- to light-brown, medium-grained; massive bedding

Mudstone, dark-gray, flaky, very carbonaceous; coal seam at top 2 cm thick

Coal, black, flaky

Mudstone, gray, crumbly

Coal, black, flaky

Mudstone, medium-gray, crumbly

Coal, black, flaky

Sandstone, medium-gray, fine-grained, soft, poorly sorted; flaserlike bedding, thin calcite-cemented pods at 45.0 m and carbonaceous partings at 46.5 m

Sandstone, medium-gray, fine-grained; irregular carbonaceous partings and some fine-grained sandstone

Sandstone, medium-gray, medium-grained, soft; poorly exposed; coarse-grained sand and clayey zones at various horizons

Conglomerate, gray; sandy matrix

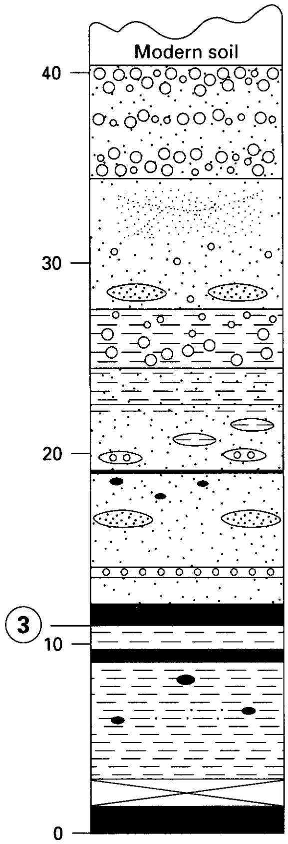
Sandstone, grayish-brown, fine- to medium-grained, soft, micaceous; poorly exposed

Claystone and mudstone, medium- to dark-gray, crumbly; thin bedded in part and dense in part; abundant carbonized wood and coal bed 15 cm thick

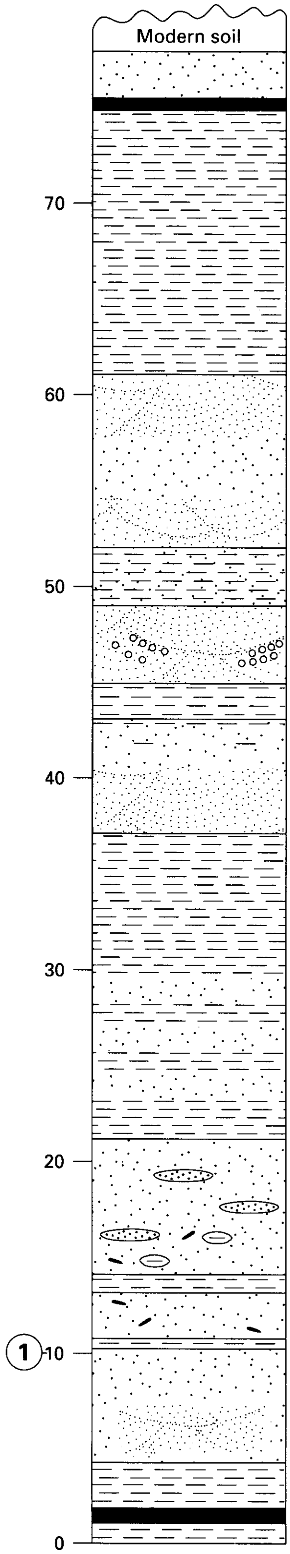
Coal, black, flaky

Sandstone, medium-gray, very fine grained, clayey

Section 6. Tyonek(?) Formation. On the east side of Peters Creek 4.1 km south of Petersville. SE¼NE¼NW¼ sec. 3, T. 27 N., R. 8 W., Seward Meridian



Section 7. Tyonek(?) Formation. On Cache Creek 1.0 km north of the junction of Cache and Spruce Creeks. NE¼SW¼SE¼ sec. 13, T. 27 N., R. 10 W., Seward Meridian



Sandstone

Coal, black, shaly; wood fragments

Claystone; mostly covered

Sandstone, light-gray to reddish-brown, medium- to coarse-grained; partly covered; tabular crossbeds, low-angle foresets, and large tabular-planar crossbeds

Claystone, medium-gray, and interbedded sandstone, light-gray, medium- to coarse-grained; sandstone contains scattered pebbles and tabular-planar crossbeds

Sandstone, medium-gray, medium- to coarse-grained; reddish-brown streaks mark horizontal beds and tabular-planar crossbeds; coarse-grained to very coarse grained granules concentrated in crossbeds

Claystone, light- to brownish-gray, massive; horizontal laminations 1 mm–1 cm thick

Sandstone, medium- to brownish-gray, medium-grained; clayey upward; reddish-brown streaks; tabular-planar and trough crossbeds 1–2 m thick

Claystone, light-gray, poorly bedded, and interbedded sandstone, 1–2 cm thick, fine-grained

Sandstone, medium-gray, medium- to coarse-grained; grades upward to claystone; coarse-grained to very coarse grained sand lenses, claystone clasts, scattered wood fragments, and rock fragments

Claystone, light-gray, massive; reddish-brown streaks

Sandstone, medium-gray, fine-grained

Claystone, light-gray, massive; reddish-brown streaks

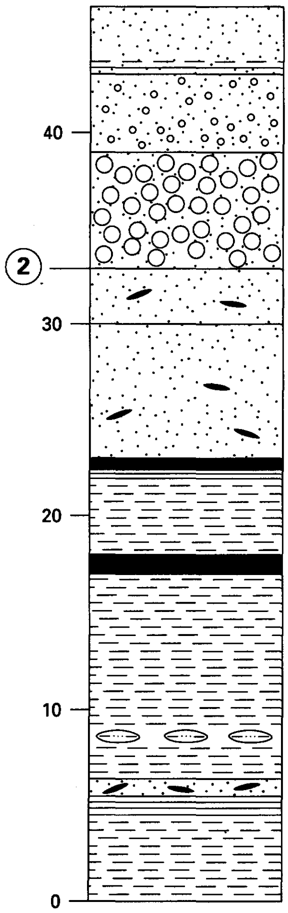
Sandstone, medium-gray, medium- to coarse-grained, massive; ripple-drift crossbeds and coal fragments

Claystone, light-gray, massive, very poorly bedded; reddish-brown streaks

Coal, black, shaly, medium-bedded, very woody

Claystone, medium-bluish-gray; mostly covered

Section 8. Tyonek(?) Formation. On west bank of Cache Creek 0.5 km north of the junction of Cache and Dollar Creeks. SE¼NW¼SE¼ sec. 1, T. 27 N., R. 10 W., Seward Meridian



Sandstone, medium-brown to medium-gray, fine- to coarse-grained; claystone 20 cm thick at base

Conglomerate, light-gray; abundant pebbles 2–4 mm in diameter; medium-grained, grain-supported sand matrix; sandstone lenses 20–30 cm thick

Conglomerate, light- to medium-gray, pebbles, cobbles, and scattered boulders; reddish-brown, coarse-grained, grain-supported sandstone matrix

Sandstone, medium-gray, medium to fine-grained; wood fragments 20 cm by 1 m suspended in sandstone; mostly covered

Sandstone, medium-gray to brown, medium-grained, clayey; scattered wood fragments

Coal, shaly, woody; fibrous plant material

Claystone, medium- to light-gray, massive to crumbly; reddish-brown streaks; shale at top

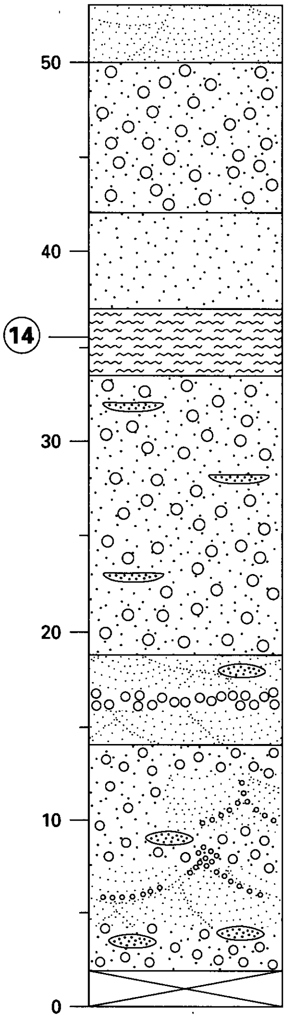
Coal, interbedded with clayey coal in seams 5–10 cm thick and crumbly, light-gray claystone

Claystone, medium-bluish-gray to light-gray, crumbly; a few brown, fine- to medium-grained clayey sandstone lenses

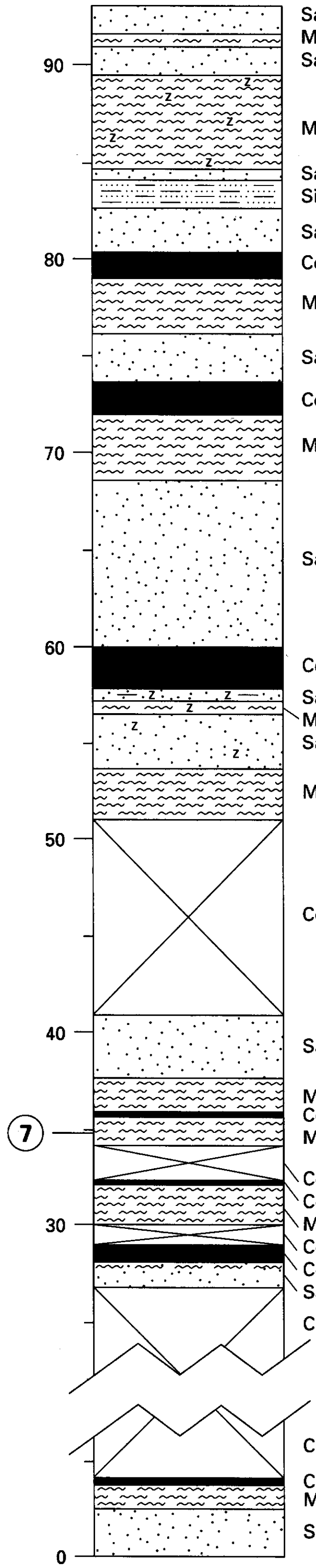
Sandstone, brown, fine- to medium-grained; woody fragments 4 by 40 cm; mostly covered

Claystone, light-gray, massive at base; reddish-brown streaks parallel with bedding; crumbly and shaly at 4.0 m; dark- and light-gray laminations 1–3 cm thick

Section 9. Sterling(?) Formation. On the east bank of Cache Creek 2.6 km south of the junction of Cache and Spruce Creeks and 5.8 km northeast of the junction of Cache Creek and the Kahiltna River. NW¼SW¼NW¼ sec. 30, T. 27 N., R. 9 W., Seward Meridian

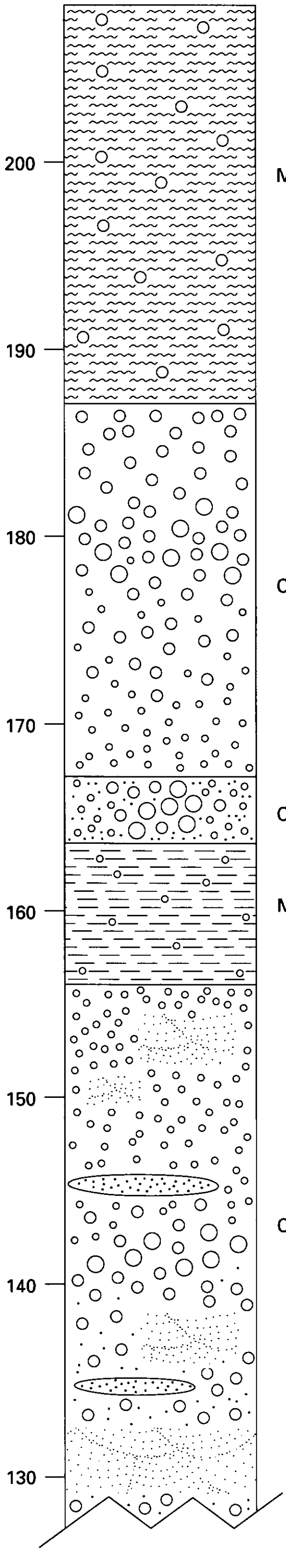


Section 10. Tyonek(?) Formation. On the east bank of Cache Creek 2.8 km south of the junction of Cache and Spruce Creeks and 5.6 km northeast of the junction of Cache Creek and the Kahiltna River. SW¼NW¼ sec. 30, T. 27 N., R. 9 W., Seward Meridian



Sandstone, light-reddish-brown, medium-grained, well-sorted, massive
Mudstone, medium- to light-gray
Sandstone, light-reddish-brown, fine-grained, soft; poorly exposed
Mudstone, gray, crumbly; plant fragments
Sandstone, reddish-brown, fine-grained
Siltstone, brown, soft
Sandstone, brown, fine-grained; poorly exposed
Coal and mudstone; poorly exposed
Mudstone, medium-gray; poorly exposed
Sandstone, brown with gray streaks, fine- to medium-grained; oxidized iron zones; crossbed sets 10–20 cm thick
Coal, black, flaky; wood fragments
Mudstone, gray, micaceous, oxidized; reddish-brown at base; poorly exposed
Sandstone, brown, medium-grained, poorly sorted, soft; no structure apparent; mostly covered by slope wash
Coal, black, flaky; wood; two beds 10–20 cm thick of light-gray, very fine grained, moderately hard sandstone
Sandstone, gray, soft, clayey; abundant plant fragments and mica
Mudstone, medium-grained; grades upward to fine-grained, soft sandstone; plant fragments
Sandstone, brown, fine-grained, soft; gray streaks; reddish-brown oxidized beds, carbonized plant fossils, and traces of mica
Mudstone, medium-gray; few brown streaks
Covered
Sandstone, gray and brown, fine-grained; irregular horizontal beds, carbonized plant matter, and mica
Mudstone, gray, crumbly, carbonaceous
Coal
Mudstone, medium-gray, partly iron stained, carbonaceous, hard, flaky; thin coal bed at 34.4 m, carbonaceous material at 35.0 m, and scattered plant matter
Covered
Coal
Mudstone, medium-gray, flaky; abundant carbonized wood fragments and 6 cm thick coal bed at 31.3 m
Covered
Coal and interbedded mudstone
Sandstone, medium-gray, very fine grained to fine-grained, soft; fines upward to medium-gray, crumbly mudstone
Covered
Covered
Coal, black, crumbly
Mudstone, brown, crumbly
Sandstone, medium-gray, fine- to coarse-grained; interbedded gray and brown oxidized clayey sandstone

Section 11. Tyonek(?) Formation. On Lake Creek 6.3 km west of Shulin Lake. SW¼SE¼NW¼ sec. 30, T. 42 N., R. 9 W., Seward Meridian



Mudstone, light-medium-gray, mostly covered, contains floating pebbles and cobbles 2–20 cm in diameter; zones of grain support

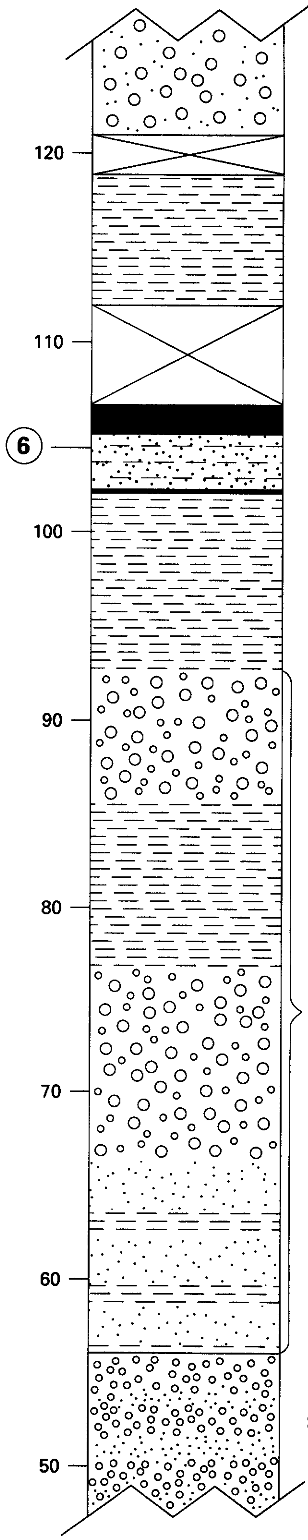
Conglomerate, light-reddish-brown; rounded pebbles and cobbles 1–5 cm in diameter; massive horizontal beds 1–2 m thick; vague suggestion of low-angle crossbeds

Conglomerate, light-gray; pebbles, cobbles, and boulders 1.0–2.0 m in diameter; sandstone-granule matrix

Mudstone, medium-gray, conglomeratic; granules and scattered pebbles; mostly covered

Conglomerate, light-gray to reddish-brown; grain-supported sand matrix; pebbles and cobbles 1–40 cm in diameter; medium- to coarse-grained sandstone lenses 5–10 cm thick and 10–20 m long; low-angle foreset crossbeds

Section 11 (continued)



Conglomerate, light-gray to reddish-brown; grain-supported sand matrix; pebbles and cobbles 1–40 cm in diameter; medium- to coarse-grained sandstone lenses 5–10 cm thick and 10–20 m long; low-angle foreset crossbeds

Covered

Claystone, light-gray, sandy; mostly covered

Covered

Coal to clayey coal, black, massive; seams 2–4 cm thick

Claystone and very fine grained clayey sandstone, light-gray to reddish-brown, streaked, massive

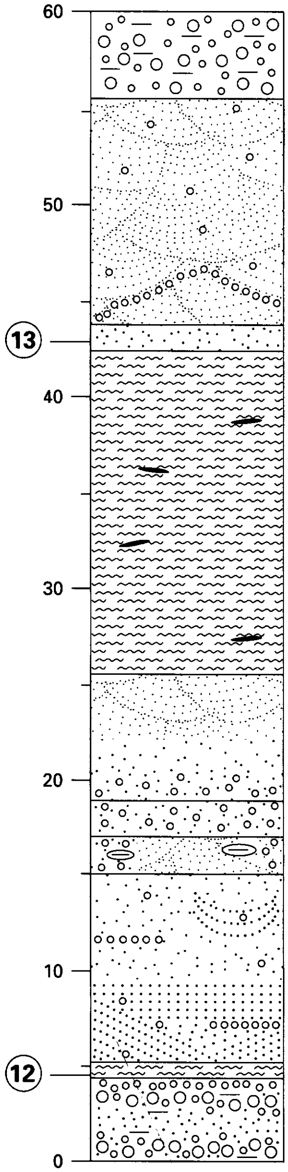
Coal, black, channeled

Claystone, light-gray, arenaceous, partly covered

Sandstone and claystone interbedded with granule-pebble conglomerate, light-gray to light-reddish-brown; horizontal beds 1–2 m thick

Sandstone interbedded with pebble-granule conglomerate, light-brown to light-reddish-brown, and claystone, light-gray, well-sorted

Section 12. Tyonek(?) Formation. On the east bank of Lake Creek 3.3 km west of Shulin Lake. NW¼NW¼NE¼ sec. 33, T. 24. N., R. 9 W., Seward Meridian



Conglomerate, very clayey; maximum grain diameter 30 cm

Sandstone, light-brown, pebbly; trough crossbeds as thick as 1 m, conglomerate layers in troughs; scoured base

Sandstone, brown, fine-grained to very fine grained; iron oxide bands; gray, thin-bedded, fairly well sorted sandstone bed about 0.5 m from top

Mudstone, medium-brown, flaky, soft, crumbly, dense, very sandy; medium- to dark-gray near top; carbonized wood fragments

Sandstone, medium-brown, fine-grained, well-sorted, soft; horizontal beds in lower part, crossbed sets 0.7 m thick near top; gravel in lower part

Conglomerate, brown, pebbly; maximum grain diameter 2 cm; reddish-brown sandy matrix; scoured base

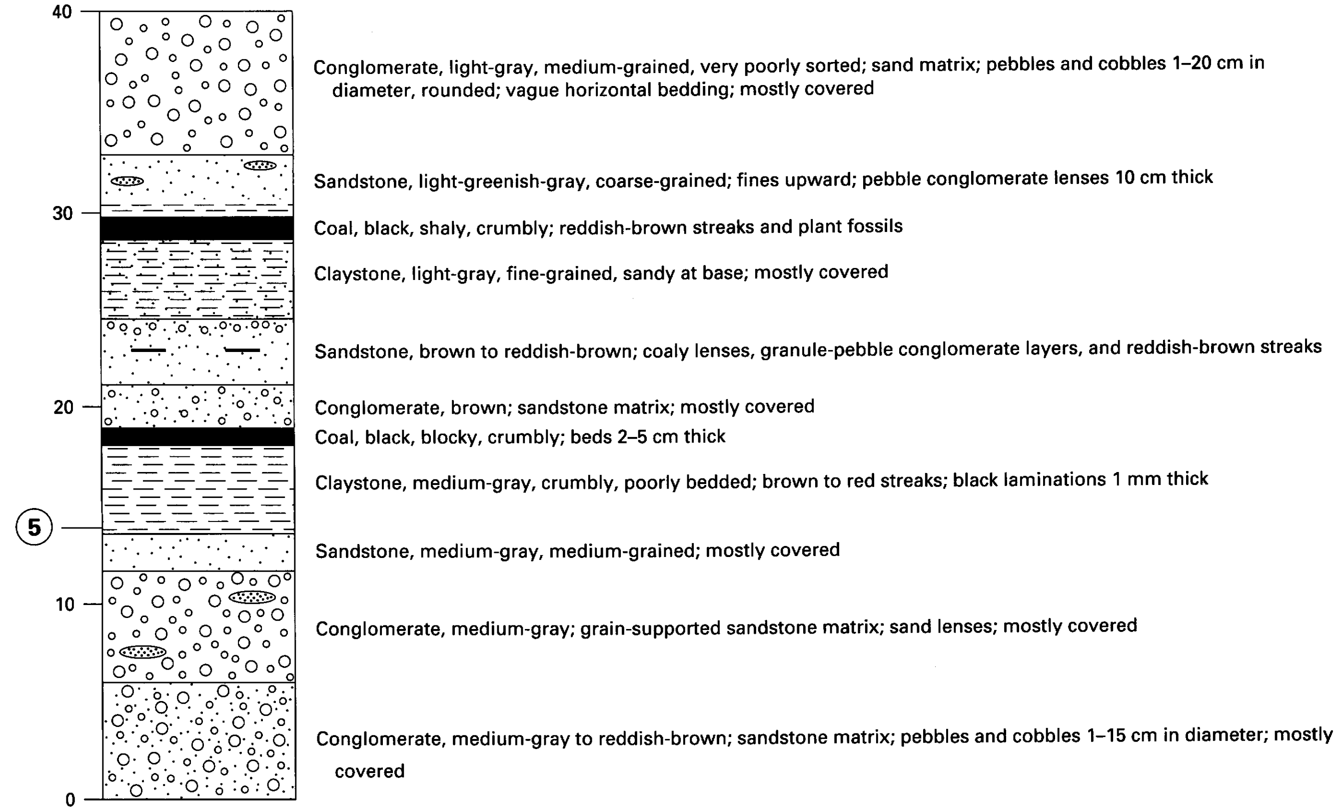
Sandstone and conglomerate, brown, medium- to coarse-grained; crossbed sets 30 cm thick; abundant mudstone clasts

Sandstone, light- to medium-brown, medium-grained, conglomeratic; some near horizontal beds, low-angle crossbeds, and vague troughs

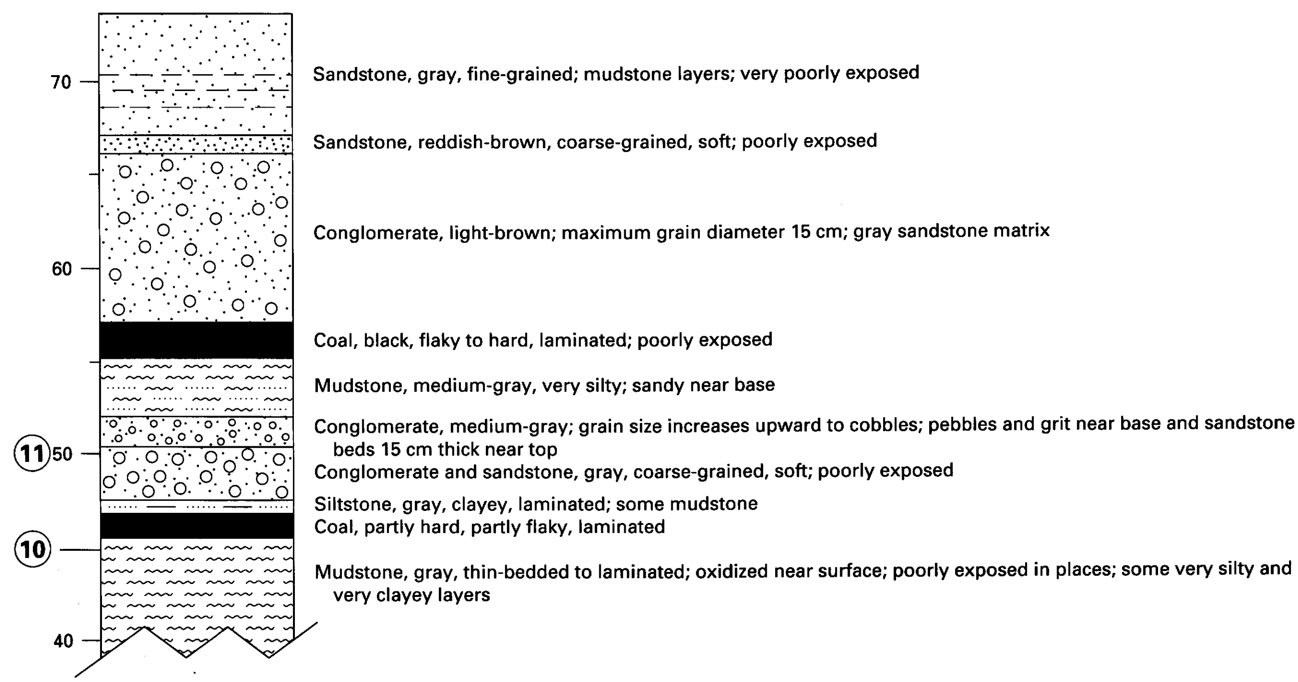
Mudstone, dark-gray, sandy; fine-grained mica and carbonaceous fragments

Conglomerate, brown, moderately hard; maximum grain diameter 7 cm; grades upward to dark fine-grained sandstone; medium-brown, medium-grained sandstone interbeds 30 cm thick

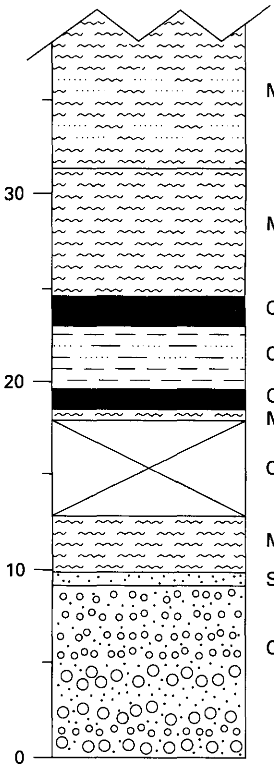
Section 13. Tyonek(?) Formation. On the northwest flank of Fairview Mountain above the head of Cottonwood Creek. SE¼NE¼NE¼ sec. 13, T. 26 N., R. 12 W., Seward Meridian



Section 14. Tyonek(?) Formation. On the west flank of Fairview Mountain at the head of Cottonwood Creek. NE¼NW¼NW¼ sec. 7, T. 26 N., R. 12 W., Seward Meridian



Section 14 (continued)



Mudstone, gray, thin-bedded to laminated; oxidized near surface; poorly exposed in places; some very silty and very clayey layers

Mudstone, medium-gray; dark-gray and carbonaceous at base; surface oxidized brown; laminated, very clayey; a few layers of siltstone and carbonized plant fragments at top

Coal; lower half dense and laminated, upper part flaky

Claystone, medium-gray, crumbly, silty; thinly bedded to laminated, micaceous intervals

Coal, hard, dense, laminated

Mudstone, light-medium-gray, soft, crumbly; some fine-grained mica

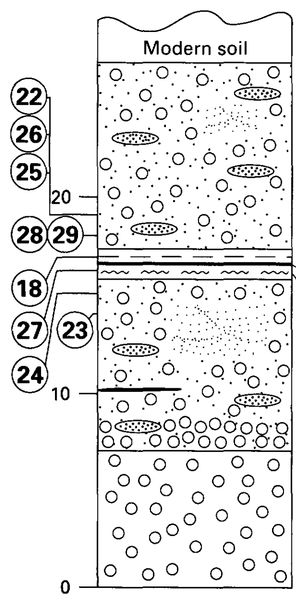
Covered

Mudstone, as above

Sandstone, light-gray, poorly sorted; subangular grains; few dark grains

Conglomerate, light-gray, soft, partly bedded; maximum grain diameter 3–4 cm; coarse sandstone matrix; some horizontal bedding apparent

Section 15. Sterling(?) Formation. On Camp Creek 0.8 km west of the junction of Camp and Pass Creeks. NW¼SE¼NE¼ sec. 29, T. 27 N., R. 12 W., Seward Meridian



Conglomerate and sandstone, light-greenish-gray; pebbles and cobbles 1–10 cm in diameter; horizontal beds of conglomerate interbedded with sandstone lenses; low-angle foreset beds

Claystone, light-orange to brown and pale-yellowish-orange, kaolinitic, uraniferous

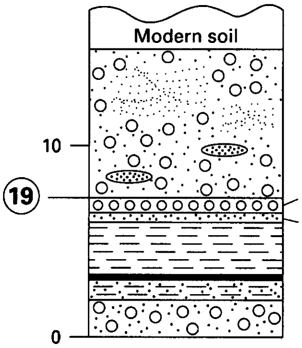
Coal, brown; black streaks; beds 10 cm thick; discontinuous

Mudstone, gray, hard, micaceous

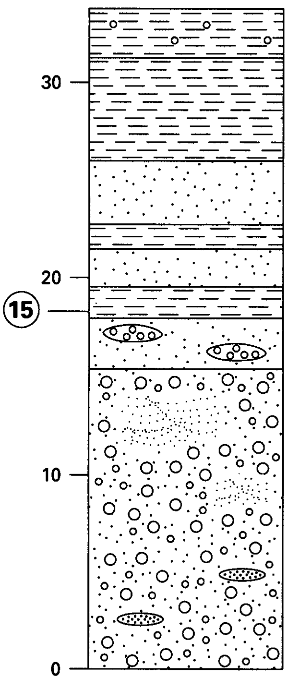
Conglomerate and sandstone, light-brown; interbedded medium- to coarse-grained sandstone lenses; pebbles 1–3 cm in diameter; medium-grained grain-supported sandstone matrix; low-angle foreset beds; oxidized intervals

Conglomerate, light-grayish-brown, massive; pebbles 1–5 cm in diameter; medium-grained to very coarse grained matrix; reddish-brown streaks and scattered clasts; partly covered

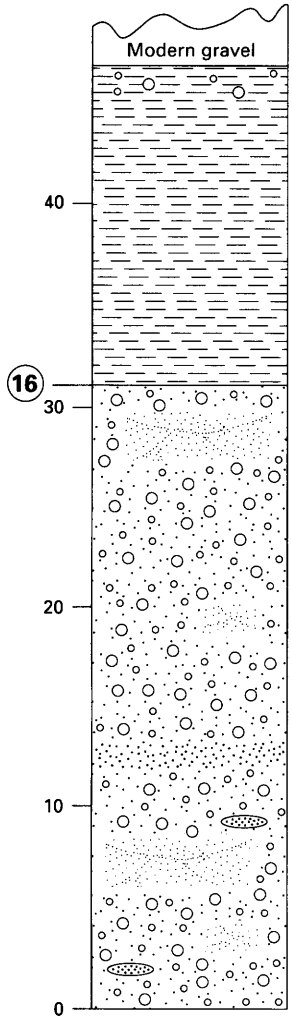
Section 16. Sterling(?) Formation. On Camp Creek 0.8 km north of airstrip. SE¼SE¼SE¼ sec. 20, T. 27 N., R. 12 N., Seward Meridian



Section 17. Sterling(?) Formation. On the Kichatna River on a northwest-facing cliff on the south side of the river. SE¼NW¼NE¼ sec. 33, T. 24 N., R. 14 W., Seward Meridian



Section 18. Sterling(?) Formation. On Johnson Creek on the southwest-facing cliff. SE¼SW¼NW¼ sec. 24, T. 23 N., R. 14 W., Seward Meridian



Claystone, dark-gray, crumbly, silty; very poorly sorted, vague horizontal bedding

Conglomerate, light-brown; reddish-brown streaks; grain-supported, fine- to medium-grained sandstone matrix; pebbles and cobbles 1–20 cm in diameter; reddish-brown, medium-grained sandstone lenses and low-angle and trough crossbeds

Geology, Geochemistry, and Uranium Favorability of Tertiary Continental Sedimentary Rocks in the Northwestern Part of the Cook Inlet Area, Alaska

By Kendell A. Dickinson, John A. Campbell, *and* William F. Dula, Jr.

URANIUM FAVORABILITY OF TERTIARY ROCKS, SOUTH-CENTRAL ALASKA

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Geology, Geochemistry, and Uranium Favorability of Tertiary Continental Sedimentary Rocks in the Northwestern Part of the Cook Inlet Area, Alaska

By Kendell A. Dickinson,[1] John A. Campbell,[2] and William F. Dula, Jr.[3]

ABSTRACT

The Paleocene and Eocene West Foreland Formation, the Oligocene and Miocene Tyonek Formation, and the Miocene Beluga Formation are present in the Tyonek–Capps Glacier area northwest of Cook Inlet, south-central Alaska. Several thousand feet of Tertiary continental sedimentary rocks having many characteristics favorable for uranium deposits are present in these units. These rocks consist mainly of mudstone, sandstone, and conglomerate that contain abundant carbonaceous material.

Samples of mudstone, sandstone, and conglomerate collected from 21 localities were analyzed for uranium, thorium, and 19 other elements, and minerals were determined by X-ray diffraction. Analysis of chemical and mineralogical data suggests that the primary source area for the West Foreland Formation is the Alaska Range to the northwest and for the Tyonek and Beluga Formations the Chugach and Kenai Ranges to the east. Smectite and zeolite formed diagenetically from volcanic materials in the sediments. The West Foreland Formation contains more volcanic material, zeolite, and smectite than the overlying units. Although the potential for commercial-sized uranium deposits is low, the West Foreland Formation is believed to be more favorable for significant uranium deposits than the other units because of the greater amount of volcanic detritus within it and the greater amount of alteration that took place in this unit.

INTRODUCTION

The Cook Inlet area in south-central Alaska (fig. 1) contains a thick sequence of Tertiary continental sedimentary rocks that includes, in ascending order, the Paleocene to Eocene West Foreland Formation, the Oligocene Hemlock Conglomerate, the Oligocene to Miocene Tyonek Formation, the Miocene Beluga Formation, and the Miocene and Pliocene Sterling Formation. Except for the West Foreland Formation, these formations are included in the Kenai Group. Interest in the possibility of uranium deposits in these rocks developed mainly because the sequence contains thick arkosic sandstone beds and abundant carbonaceous material and has possible sources of uranium in volcanic rocks of the Aleutian and Alaska Ranges to the northwest.

Early interest in the Tertiary sedimentary rocks of Cook Inlet was motivated by the demand for coal. Coal resources of the northwestern part of the Cook Inlet area were described by Barnes (1966). Oil was discovered in the area in 1957 (Parkinson, 1962), and much of the later interest in the area was stimulated by the search for petroleum (Calderwood and Fackler, 1966, 1972; Crick, 1971; Kirschner and Lyon, 1973; Hayes and others, 1976). Interest in uranium during the late 1970's resulted in further study of the Tertiary sedimentary sequence (Croff and others, 1977; Dickinson and Campbell, 1978). The Beluga and Sterling Formations were described by Kremer and Stadnicky (1985) and Magoon and Egbert (1986).

The area as discussed herein extends from the vicinity of Tyonek on the northwest shore of Cook Inlet inland northwestward along the Chuitna and Beluga Rivers to the area of Capps and Triumvirate Glaciers. Samples of Tertiary rocks were collected during a reconnaissance survey by helicopter between August 6 and 13, 1977. Twenty-six sections (fig. 2) were measured in the study area, and samples were collected. The present report is based on chemical and mineralogical analyses of the samples (appendix 1) and on the measured sections (appendix 2). These data provide new insight into the depositional and diagenetic history of these units as well as their favorability for uranium deposits.

Acknowledgments.—Gary Skipp prepared oriented clay mineral mounts for X-ray diffraction studies and operated

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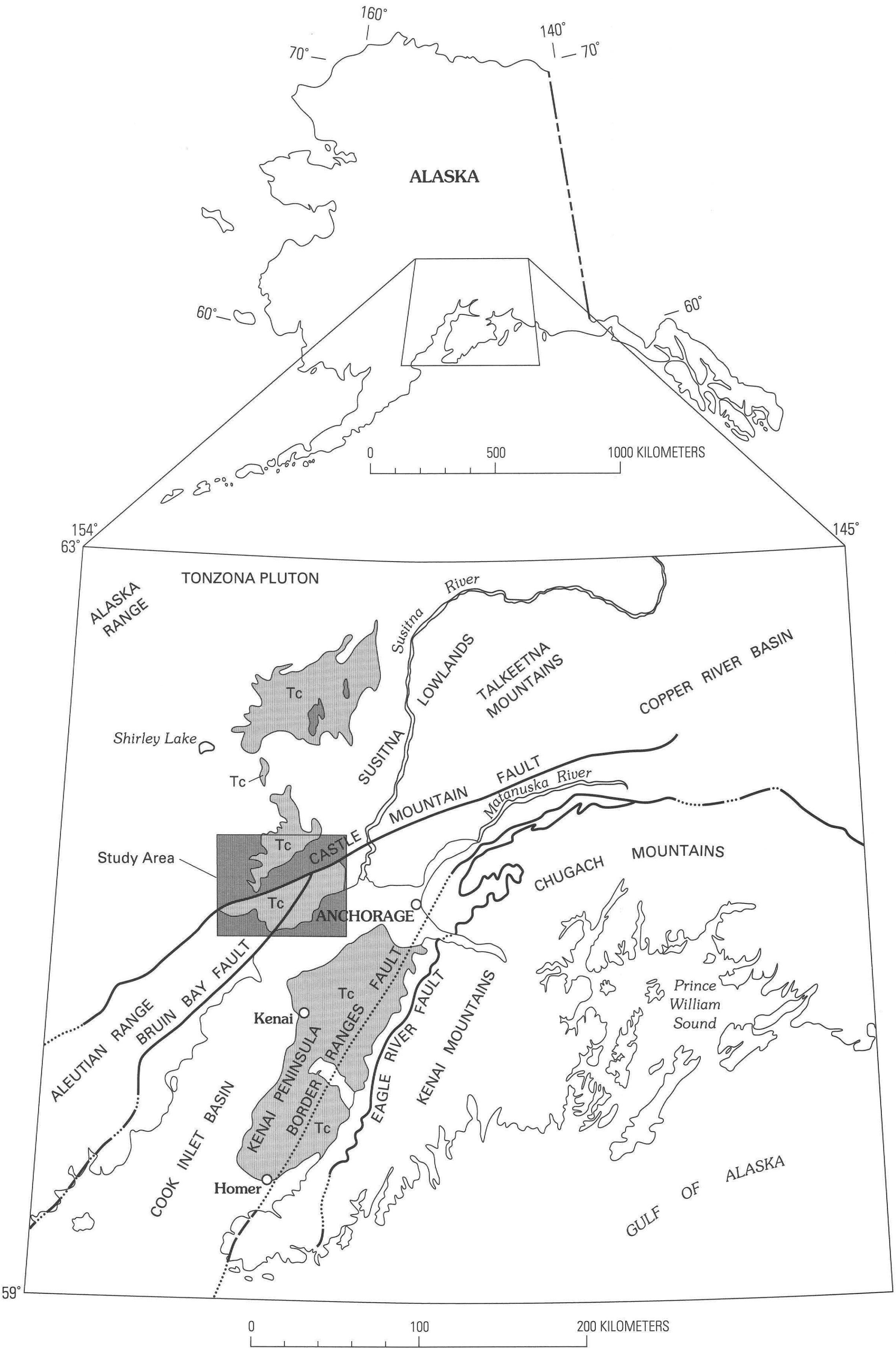


Figure 1. Index map of south-central Alaska showing study area (dark screen) and areas of Tertiary continental sedimentary rocks (unit Tc). Geology modified from Biekman (1980).

the X-ray diffraction machine. Samples were chemically analyzed in the analytical laboratories of the U.S. Geological Survey at Lakewood, Colorado. Radiochemical and X-ray fluorescence analyses were made under the supervision of D.M. McKown and J.E. Taggart. X-ray spectroscopy analyses were made under the supervision of D.E. Detra and L.R. Layman.

GEOLOGY

Scattered outcrops of the Tertiary continental sedimentary rocks are present along the northwest edge of the Cook Inlet Basin (fig. 2) (Magoon and others, 1976). Much of the study area is covered by Quaternary sediments, glacial ice, and the waters of Cook Inlet. The area also contains Tertiary and Quaternary volcanic rocks of basaltic and andesitic composition, Cretaceous and Tertiary felsic igneous rocks, and Jurassic and Cretaceous metamorphic and sedimentary rocks. The Tertiary sedimentary rocks generally dip at low angles southeastward into the Cook Inlet Basin.

The Cook Inlet Basin, in the coastal area of south-central Alaska, separates the Aleutian and Alaska Ranges to the northwest from the Kenai and Chugach Ranges to the southeast (fig. 1). The Talkeetna Mountains and the Copper River Basin are to the northeast. The Cook Inlet basin is about 100 by 300 km in area; its long axis is oriented about N. 25° E. It contains about 8,500 m of mostly nonmarine Tertiary sedimentary rocks that comprise the Oligocene to Pliocene Kenai Group and the underlying Paleocene and Eocene West Foreland Formation (fig. 3). The Tertiary rocks overlie Jurassic and Cretaceous rocks (Kremer and Stadnicky, 1985) and underlie Quaternary alluvium and glacial deposits.

The Cook Inlet Basin is generally bounded on the east by the Border Ranges fault (Knik fault of Magoon and others, 1976), which trends about N. 30° E. (fig. 1). The Bruin Bay fault, which forms the western margin of the basin, extends northward about N. 45° E. It intersects the Castle Mountain fault in the northern part of the basin. The Castle Mountain fault trends about N. 60° E. and generally forms the northwestern boundary of the basin (fig. 1). Undifferentiated lithic equivalents of the Kenai Group and the West Foreland Formation extend north of the Castle Mountain fault into the Susitna Lowlands. Other minor faults and lineaments have been mapped on the Kenai Peninsula. Several anticlines and synclines, whose axes approximately parallel the long axis of the basin, were mapped by Magoon and others (1976) in the eastern half of the Cook Inlet Basin. Water of Cook Inlet covers most of the northwest half of the basin.

TERTIARY SEDIMENTARY ROCKS

Tertiary sedimentary rocks of the Cook Inlet Basin were named the Kenai Group by Dall and Harris (1892), who assigned the group to the Miocene. Barnes and Cobb (1959) and Parkinson (1962) called these same rocks the Kenai Formation. Subsequently, the Kenai Group was divided into five formations, in ascending order, the West Foreland Formation, Hemlock Conglomerate, Tyonek Formation, Beluga Formation, and Sterling Formation (Calderwood and Fackler 1966, 1972; Crick, 1971). Later, Magoon and others (1976) removed the West Foreland Formation from the Kenai Group (fig. 3).

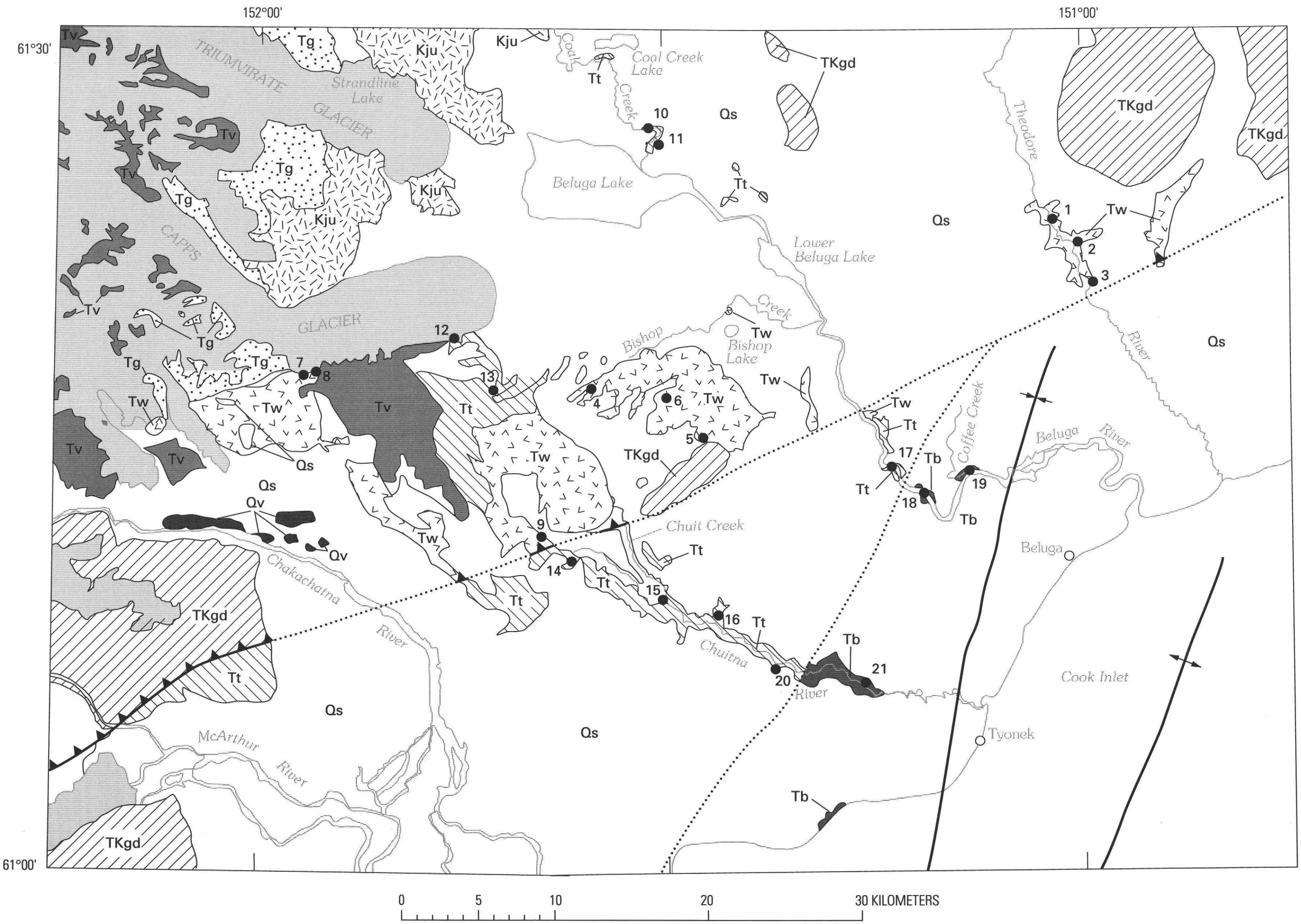
In the study area the Tertiary sequence, in ascending order, consists of the West Foreland Formation (Paleocene and Eocene) and the Tyonek (Oligocene and Miocene) and Beluga (Miocene) Formations of the Kenai Group (fig. 3). The Hemlock Conglomerate was not identified, and the Sterling Formation does not crop out in the Tyonek–Capps Glacier area. Basal rocks of the Kenai Group are separated in places from the underlying West Foreland Formation by an angular unconformity.

WEST FORELAND FORMATION

The Paleocene and Eocene West Foreland Formation consists mostly of claystone and tuffaceous sandstone at the type section, which was established by Calderwood and Fackler (1972) in the subsurface in Pan American Oil Company's West Foreland no. 1 well, in sec. 21, T. 8 N., R. 14 W., Seward Meridian. The thickness at the type section, which is at West Foreland on the west shore of Cook Inlet about 25 km south of the study area, is 271 m. In the study area the Hemlock Conglomerate has not been identified, and the West Foreland is unconformably overlain by the Tyonek Formation. In some areas the West Foreland Formation overlies the Paleocene Arkose Ridge Formation (Magoon and others, 1976), but at the type section and in the report area it unconformably overlies Jurassic rocks (Calderwood and Fackler, 1972; Kremer and Stadnicky, 1985).

About two-thirds of the outcrops of the West Foreland Formation in the study area consists of brown to grayish-brown polymictic conglomerate. The remaining one-third consists mostly of light-brown lithic sandstone but also includes small amounts of claystone and coal (sections 1–9, appendix 2). The conglomerate clasts are mostly granite, volcanic rocks, and metamorphic rocks (Adkison and others, 1975). Barnes (1966) reported a tuff bed more than 9 m thick in the southern part of the study area. An ash bed 7 m thick is also present at the type section (Calderwood and Fackler, 1976). The volcanic beds were not sampled for this study. Descriptions of the West Foreland are given in Barnes (1966), who considered it part of the Kenai Formation, and in Adkison and others (1975) and Calderwood and Fackler (1972).

In the study area the West Foreland was deposited primarily as alluvial fans. The massive conglomerate beds were deposited close to the mountain front and may have formed as debris flows on alluvial fans while uplift was occurring. The remaining sandstone and mudstone beds are fluvial deposits.


152°00'
151°00'
61°30'
61°00'
TRIUMVIRATE GLACIER
Strandline Lake
CAPPS GLACIER
Coal Creek
Coal Creek Lake
Beluga Lake
Lower Beluga Lake
Bishop Creek
Bishop Lake
Theodore River
Coffee Creek
Beluga River
Chuit Creek
Chakachatna River
Chuitna River
McArthur River
Beluga
Tyonek
Cook Inlet
Tv
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Kju
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0 5 10 20 30 KILOMETERS

EXPLANATION

- Glacier or ice field
- Qs — Glacial, alluvial, and mass-wasting deposits, undivided (Quaternary)
- Qv — **Volcanic rocks (Quaternary)**—Lava, breccia, and associated pyroclastic rocks; as mapped, may include Tertiary volcanic rocks
- Tb — **Beluga Formation (Miocene)**—Sandstone, siltstone, and coal
- Tt — **Tyonek(?) (Miocene and Oligocene)**—Sandstone, siltstone, coal, and conglomerate
- Tw — **West Foreland Formation (Eocene and Paleocene)**—Conglomerate, sandstone, and siltstone, mostly tuffaceous
- Tv — **Volcanic rocks (Tertiary)**—Basaltic lava, tuff, and breccia; as mapped, may include Quaternary volcanic rocks
- Tg — **Granite, quartz monzonite, and syenite (Tertiary)**
- TKgd — **Granodiorite, quartz diorite, and diorite (Tertiary and Cretaceous)**
- KJu — **Metasedimentary rocks, undivided (Cretaceous and Jurassic)**—Mainly slate and graywacke; locally includes volcanic and intrusive rocks
- **Contact**
- **Anticline**
- **Syncline**
- **Thrust or reverse fault**—Dotted where concealed. Sawteeth on upper plate
- U D **Fault**—Dotted where concealed. U (up) and D (down) indicate relative movement
- 9 **Location of measured section**—Measured sections are shown in appendix 2

Figure 2. Geology of the Tyonek-Capps Glacier area, Cook Inlet Basin, south-central Alaska. Locations of measured sections (appendix 2) are also shown. Map area is shown in figure 1. Geology modified from Magoon and others (1976).

Age		Unit
Quaternary		Alluvium and glacial deposits
Pliocene	Kenai Group	Sterling Formation
Miocene	Kenai Group	Sterling Formation
Miocene	Kenai Group	Beluga Formation
Oligocene	Kenai Group	Tyonek Formation
Oligocene	Kenai Group	Hemlock Conglomerate
Eocene		West Foreland Formation
Paleocene		West Foreland Formation
Paleocene		Arkose Ridge Formation
Mesozoic and older rocks		

Figure 3. Stratigraphy of Tertiary sedimentary rocks in Cook Inlet Basin area. Ages from Magoon and others (1976).

TYONEK FORMATION

The type section of the Tyonek Formation designated by Calderwood and Fackler (1972) is the sequence from 1,311 to 3,642 m depth in the Pan American Petroleum Corporation's Tyonek State 17587 Number 2 well in sec. 30, T. 11 N., R. 11 W., Seward Meridian. Almost two-thirds of this 2,331-meter-thick unit consists of massive gray fine- to medium-grained sandstone and interbedded gray claystone. The remainder of the unit consists mostly of light-to dark-gray partly carbonaceous thin-bedded claystone. The Tyonek was placed in the Seldovian (provincial) Stage by Wolfe and others (1966). The Tyonek conformably overlies the Hemlock Conglomerate and is conformably overlain by the Beluga Formation.

Measured sections of the Tyonek Formation in the study area are about 45 percent sandstone, 40 percent claystone or mudstone, and 15 percent coal (sections 10–16, appendix 2). The sandstone is light gray or brown and fine to medium grained, the claystone is light to medium gray, and the coal is black and flaky or shaly. Typical sequences are fining upward, generally starting with crossbedded medium- to coarse-grained sandstone at the bottom, extending upward into mudstone or claystone, and, finally, to coal (figs. 4, 5). According to Hite (1976) the Tyonek was deposited in a poorly drained alluvial valley. The fining-upward sequences probably represent deposition in and near meandering fluvial channels.

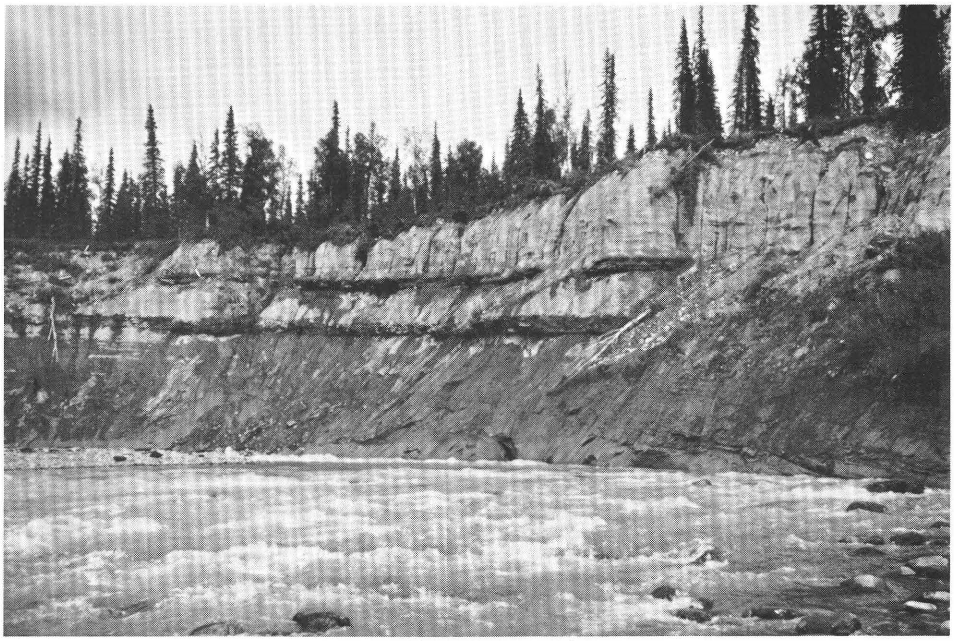

Figure 4. Tyonek Formation along Coal Creek 3 km north of Beluga Lake. Near measured section 13 (fig. 2, appendix 2).

BELUGA FORMATION

The type section of the Beluga Formation consists of 1,265 m of thin interbedded sandstone, siltstone, claystone, and lignitic to subbituminous coal. The type section is the Beluga River No. 1 well in sec. 35, T. 13 N., R. 10 W., Seward Meridian, drilled in 1962 by Standard Oil Company of California at the village of Beluga (fig. 2) (Crick, 1971; Calderwood and Fackler, 1972). The composition of the Beluga at the type section is similar to exposures near Homer at the south end of the Kenai Peninsula (Adkison and others, 1975). Rock types similar to those of the type section are present in the Deep Creek Unit well on the Kenai Peninsula (Adkison and Newman, 1973). Outcrops of the Beluga on the Kenai Peninsula were assigned to the Homerian (provincial floristic) Stage by Wolfe and others (1966). Wolfe and Tanai (1980) determined that these rocks are middle and late Miocene in age based mainly on plant fossils.

Outcrops of the Beluga Formation in the lower reaches of the Chuitna and Beluga Rivers consist of mudstone and claystone, sandstone, conglomerate, and coal in order of decreasing proportions (sections 17–21, appendix 2). The mudstone and claystone are medium gray and are intercalated with thin wavy beds of coal and carbonized plant debris. The sandstone is light gray to brown, fine to coarse grained, and partly crossbedded and has a clayey matrix. The formation was probably also deposited on a poorly drained alluvial plain, but fining-upward sequences are lacking and the units are thicker than those in the Tyonek Formation.

METHODS

Nine sections of the West Foreland Formation, seven sections of the Tyonek Formation, and five sections of the Beluga Formation were described and sampled (fig. 2, appendix 2). Twenty-eight samples, intended to be representative of the formations, were collected. Samples were collected from the predominant litologic types at each measured section. The samples were analyzed for 21 elements and 6 minerals (appendix 1). Sample localities are shown in figure 2 and in measured sections in appendix 2.

Uranium and thorium contents of the samples were determined using the delayed-neutron method (Millard, 1976). Elemental abundances were determined using six-step semiquantitative spectroscopy (Myers and others, 1961). Beryllium, boron, and lead were omitted in the statistical calculations because of the large number of qualified values in these analyses. Mineralogical determinations were made by X-ray diffraction of whole-rock cell mounts. Oriented mounts of the <2-micron clay fractions for a few samples were X-rayed after air-drying, glycolation, and heating to 550°C. The whole-rock X-ray diffraction data were obtained under conditions made as uniform as possible for all of the runs. The same preparation procedures and instrument settings were used for all samples. All the runs were made continously, and a standard sample was X-rayed before and after each daily run. All analyses were made from sample splits.

The relative abundances of quartz, feldspar, chlorite, illite, smectite, and a zeolite were determined by measuring

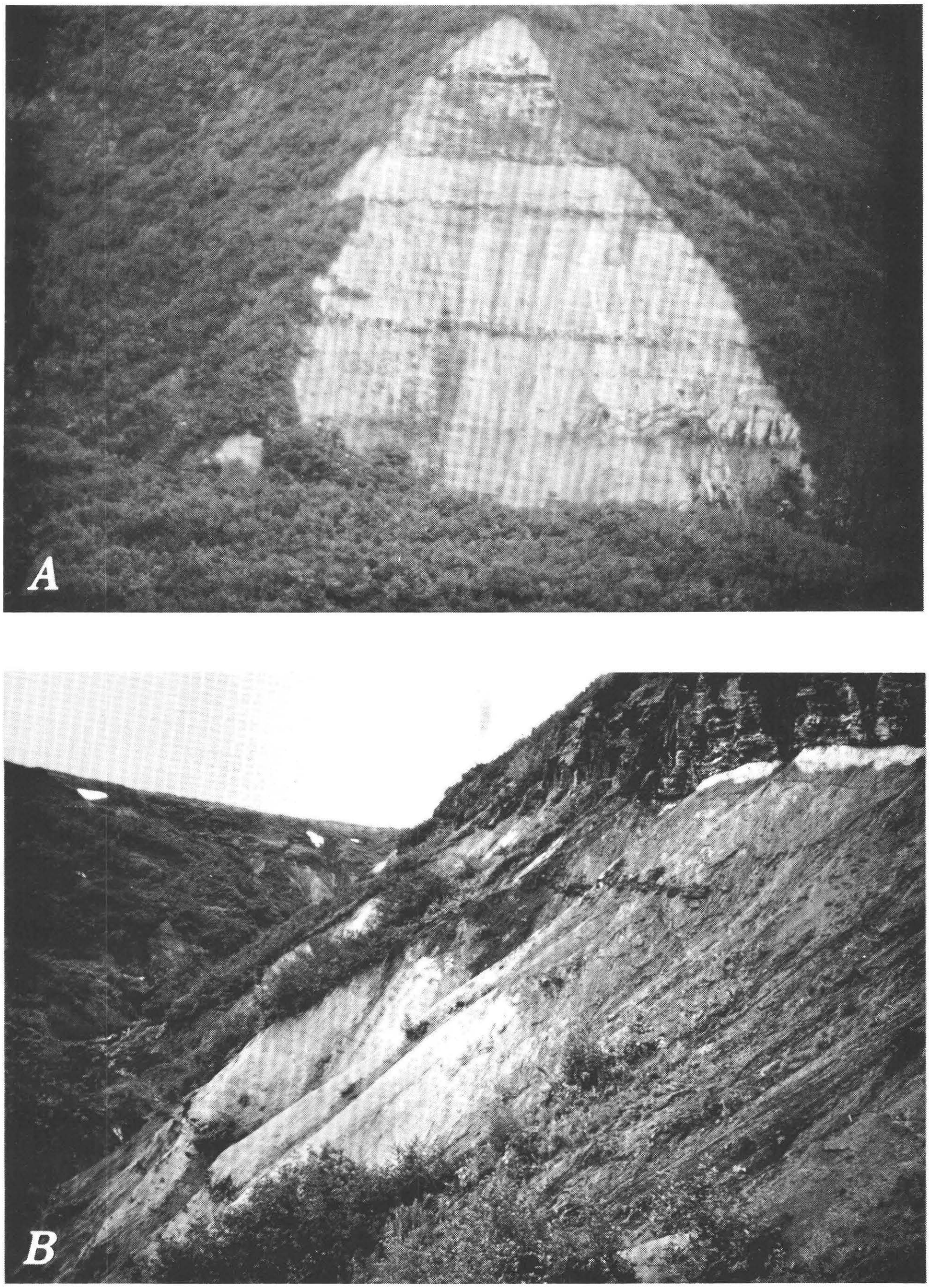

Figure 5. Tyonek Formation near toe of Capps Glacier. Fining-upward sequences containing coal beds (dark layers) at the top of each sequence. Near measured section 14 (fig. 2, appendix 2). *A*, Outcrop is approximately 80 m thick. *B*, Closer view of *A*. Sequence is about 20 m thick.

the areas of selected X-ray diffraction peaks (in square inches) as recorded on the whole-rock diffractograms. The zeolite is clinoptilolite or heulandite and perhaps a mixture of the two. Illite, as determined, includes mica and the clay mineral illite. The peaks measured for each mineral are listed in table 1. The areas of individual X-ray diffraction peaks provide estimates of the relative abundances of minerals. The data do not, however, represent the absolute abundances of minerals. Two thin sections also were made, and two samples of clay-bearing mudstone were examined using a scanning electron microscope.

A factor analysis was calculated using a commercial program (Hintze, 1992). The analysis suggests many interesting relationships that otherwise might be missed when perusing the data. Some of the results, however, seem to defy interpretation; this may reflect lack of randomness in sample

Table 1. X-ray diffractogram peaks (Cu, Kα radiation) measured for the rock samples in the study.

Mineral	X-ray diffraction peak (degrees 2θ)	Crystallographic index
Feldspar	26.9–27.9	002
Quartz	20.8	100
Illite	8.8	001
Smectite	10.2	002
Chlorite	12.5	002
Clinoptilolite-heulandite	9.8	800

collection, too few samples, or various degrees of departure from normal distribution of the data.

STATISTICAL ANALYSIS

Mineralogical and chemical data for the West Foreland, Tyonek, and Beluga Formations in the Tyonek–Capps Glacier area are given in appendix 1. Arithmetic means and standard deviations are given for the minerals and elements for each of the three stratigraphic units. A correlation coefficient matrix (table 2) and a five-factor model of an R-mode factor analysis (table 3) (Harmon, 1960) are presented for the data in appendix 1. The degree of correlation for all pairs of variables is shown by the correlation coefficients. The purpose of the factor analysis is to group related variables to reduce the amount of variation that must be interpreted and to investigate the underlying causes. The factors are calculated from the correlation matrix. The factor analysis includes the varimax rotation, which is rotation of the factors around the orthogonal axes. Varimax rotation enhances differences in factor loadings (Hintze, 1992). Factor loadings are the correlations between each variable and the factors. The sum of the squares of the factor loadings for each variable is equal to the communality, the proportion of each variable explained by the analysis. For more complete descriptions of factor analysis and its geological application see Davis (1986) and Koch and Link (1971). A five-factor analysis was chosen for presentation because of its relative simplicity and because reasonably high communalities were obtained for the variables of primary interest including uranium, thorium, smectite, and chlorite.

The geologic conditions that control the calculated factors are believed to be source area, sorting and alteration during transport and deposition, and postdepositional alteration (diagenesis). Differences in mineralogical and chemical makeup of rocks of the source area result in differences in the composition of the sediments produced. During transport, the sediments are sorted into finer clay and coarser feldspathic and lithic sand. Chemical and mineralogical alteration may also occur during sediment transport. Diagenesis, such as alteration of volcanic materials to clay and zeolite, may also result in differences in mineralogical and chemical makeup of the rocks. The calculated factors represent combinations of the above processes that in some cases make interpretation speculative.

Factor one.—Factor one consists of Th, Yb, U, Y, Al, K, Ga, Sc, and Zr (table 3). Uranium and thorium are in minerals such as monazite or uranothorianite that are commonly present in heavy-mineral concentrates. This factor probably represents sandstone and conglomerate that have concentrations of heavy minerals. Many examples of uranium and thorium concentrations have been found in heavy-mineral deposits in modern stream sediments in Alaska (Eakins, 1969). Yttrium and ytterbium are rare earth elements commonly present in monazite, a placer constituent. Zirconium is present in zircon, which is also common in placer concentrates. Potassium, gallium, scandium, and aluminum are concentrated in the silicate phases that are present in sandstone and conglomerate.

Factor two.—Factor two consists of copper, illite, chlorite, nickel, vanadium, and chromium (table 3). This factor apparently represents fine-grained sediments from a terrane rich in metamorphic and basic igneous rocks. According to Hayes and others (1976), illite and chlorite in the Beluga Formation on the Kenai Peninsula suggest a sediment source from metamorphic rocks in the Chugach Mountains. Illite and chlorite are also concentrated in the finer grained mudstone and claystone. The copper, nickel, and chromium commonly are present together in sulfide minerals and suggest a mafic source of the sediments. Vanadium is associated with carbonaceous materials, abundant in most of these rocks but more abundant in the Tyonek and Beluga Formations than in the West Foreland Formation (appendix 1).

Factor three.—Factor three contains smectite, iron, strontium, and titanium (table 3). Smectite apparently formed diagenetically from volcanic materials either before or after deposition of the sediments (fig. 6). The occurrence of strontium in this factor suggests that the strontium may have been involved in the diagenetic alteration, perhaps in the smectite as an exchangeable cation. Iron and titanium are present together in the mineral ilmenite, a heavy-mineral constituent. The association of ilmenite with smectite and strontium in this sample set is not understood.

Factor four.—Factor four includes calcium, manganese, and magnesium at the positive pole and barium at the negative pole (table 3). The calcium, manganese, and magnesium probably represent plagioclase and chlorite from a predominantly mafic source. Barium may have substituted for potassium in feldspar from a more felsic source. A relatively strong secondary loading of barium in factor five suggests involvement in diagenesis.

Factor five.—Factor five contains zeolite, feldspar, and sodium with positive loadings and quartz with a negative loading (table 3). This factor probably represents feldspathic volcanic clastic rocks in which zeolite has grown in the interstices (fig. 6). The relatively low primary loading and

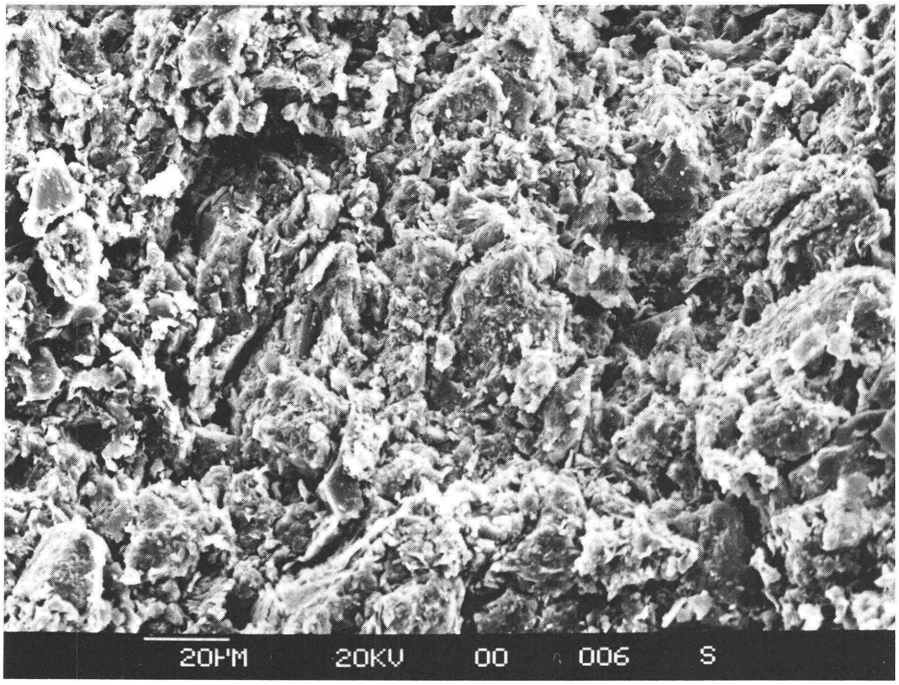

Figure 6. Electron micrograph showing detrital texture in mudstone of the Beluga Formation. Sample 2 (table 4, appendix 1).

communality for sodium indicate that the distribution of sodium is not well explained by the factor model. The presence at the opposite pole of quartz, which is complexly distributed among most sediments, suggests, perhaps, that the sediment source high in volcanic materials was low in quartz or that quartz was dissolved during diagenesis.

SEDIMENT SOURCES

Some obviously important sediment sources for the various Tertiary stratigraphic units in the Cook Inlet Basin are the Aleutian and Alaskan Ranges to the northwest and the Kenai and Chugach Ranges to the southeast (Hayes and others, 1976). Other possible sources include the ancestral drainages of the Matanuska and Susitna Rivers (fig. 1), which drain the Talkeetna Mountains and the Copper River Basin. All of these sources probably contributed sediments to the Tertiary stratigraphic units during the Tertiary; however, certain generalizations can be made as to the relative importance of each (Dickinson and Skipp, 1992). The Aleutian-Alaskan Ranges source has been characterized as granitic and felsic volcanic in character and the Kenai-Chugach Ranges source as metamorphic in character (Hayes and others, 1976). Heavy minerals also have been used to distinguish the two major sediment source areas (Hite, 1976; Biddle, 1977). The Aleutian-Alaska Ranges sediment sources contain more hornblende and the Kenai-Chugach Ranges sources contain more epidote and possibly more garnet. The heavy-mineral contributions of the Talkeetna Mountains and the Copper River Basin sources are unknown.

The distribution of minerals and elements in the data for the study area suggests that the Beluga and Tyonek Formations received their sediments primarily from the Kenai and Chugach Ranges to the southeast and that the West Foreland Formation received its sediments primarily from the Aleutian and Alaska Ranges to the northwest. The low chlorite-illite content and the volcanic component in the West Foreland (appendix 1) suggest the Aleutian-Alaskan Ranges source to the northwest. If the West Foreland Formation was deposited on alluvial fans near the mountain front, the sediment source would have necessarily been the Aleutian-Alaska Ranges. On the other hand, if we follow Hayes and others (1976), the high chlorite and illite content in the Tyonek and Beluga Formations suggests a predominant sediment source in the Kenai-Chugach Ranges to the southeast. The setting of the surrounding terrane and the location of the deposits suggest that the source was valleys drained by the ancestral Susitna and Matanuska Rivers. Either of these areas could have supplied a large variety of igneous, metamorphic, and sedimentary source materials.

Certain chemical and mineralogic differences are noted between the stratigraphic units described herein. Based on the data presented in appendix 1, the West Foreland Formation is different from the Kenai Group in that it contains more postassium, gallium, uranium, thoriium, ytterbium, sodium, barium, feldspar, smectite, and zeolite and less

Table 2. Correlation coefficient matrix for data.
[Data set isgiven in appendix 1]

	Uranium	Thorium	Iron	Magnesium	Calcium	Titanium
Uranium	1.00					
Thorium	0.81	1.00				
Iron	0.35	0.29	1.00			
Magnesium	−0.11	−0.11	0.38	1.00		
Calcium	−0.31	−0.39	0.12	0.35	1.00	
Titanium	0.27	0.32	0.66	0.28	0.07	1.00
Manganese	−0.09	−0.17	0.34	0.37	0.64	0.17
Barium	0.47	0.30	0.27	−0.29	−0.48	0.15
Chromium	0.37	0.29	0.24	0.07	−0.12	0.32
Copper	0.48	0.30	0.42	0.27	0.11	0.49
Nickel	0.39	0.36	0.47	0.38	−0.11	0.54
Scandium	0.46	0.41	0.71	0.37	0.15	0.86
Strontium	−0.30	−0.32	0.35	0.14	0.27	0.32
Vanadium	0.51	0.37	0.61	0.35	−0.05	0.72
Yttrium	0.63	0.65	0.70	0.21	−0.07	0.58
Zirconium	0.26	0.49	−0.05	−0.25	−0.15	0.10
Aluminum	0.58	0.58	0.74	0.16	−0.03	0.69
Sodium	0.07	0.11	0.19	0.03	0.26	0.41
Potassium	0.75	0.60	0.34	−0.18	−0.20	0.27
Gallium	0.78	0.64	0.32	−0.11	−0.12	0.40
Ytterbium	0.65	0.68	0.52	−0.04	−0.10	0.42
Quartz	−0.32	−0.09	−0.53	−0.03	−0.33	−0.45
Feldspar	−0.04	−0.02	−0.08	−0.16	−0.03	−0.04
Illite	0.26	0.12	0.18	0.31	−0.12	0.25
Chlorite	0.34	0.11	0.08	0.14	−0.07	0.11
Smectite	−0.08	−0.02	0.34	0.06	0.12	0.24
Zeolite	−0.10	−0.05	0.13	−0.13	0.06	0.11
	Manganese	**Barium**	**Chromium**	**Copper**	**Nickel**	**Scandium**
Manganese	1.00					
Barium	−0.33	1.00				
Chromium	0.10	0.08	1.00			
Copper	0.30	0.20	0.64	1.00		
Nickel	0.15	0.19	0.68	0.78	1.00	
Scandium	0.25	0.13	0.34	0.50	0.55	1.00
Strontium	0.05	0.05	−0.33	−0.23	−0.37	0.28
Vanadium	0.20	0.19	0.63	0.83	0.77	0.74
Yttrium	0.17	0.35	0.20	0.31	0.43	0.73
Zirconium	−0.16	0.17	−0.27	−0.29	−0.30	0.05
Aluminum	0.12	0.30	0.19	0.31	0.36	0.79
Sodium	0.14	0.07	−0.03	0.11	0.06	0.37
Potassium	−0.10	0.37	0.24	0.31	0.19	0.42
Gallium	−0.05	0.26	0.30	0.38	0.18	0.56
Ytterbium	−0.01	0.41	−0.11	−0.01	0.05	0.55
Quartz	−0.20	−0.32	0.10	−0.30	0.04	−0.51
Feldspar	−0.11	0.10	−0.44	−0.28	−0.33	−0.03
Illite	0.15	0.09	0.67	0.68	0.73	0.27
Chlorite	0.14	0.22	0.58	0.68	0.59	0.23
Smectite	−0.06	0.18	−0.24	−0.27	−0.24	0.23
Zeolite	−0.09	0.30	−0.34	−0.03	−0.30	−0.13

manganese, chromium, copper, vanadium, chlorite, and illite. These differences, although slight for some minerals or elements, reflect differences in source area, lithology, and alteration of the sediments during transport or after deposition.

CLAY MINERALS AND ZEOLITES

Clay minerals in the Kenai Group and West Foreland Formation in the Cook Inlet Basin can be divided into detrital and diagenetic groups (table 4). The zeolite, which

Table 2. Correlation coefficient matrix for data set—Continued.

	Strontium	Vanadium	Yttrium	Zirconium	Aluminum	Sodium
Strontium	1.00					
Vanadium	–0.01	1.00				
Yttrium	0.09	0.44	1.00			
Zirconium	0.17	–0.28	0.30	1.00		
Aluminum	0.26	0.60	0.72	0.22	1.00	
Sodium	0.18	0.05	0.40	0.40	0.35	1.00
Potassium	0.07	0.41	0.56	0.35	0.63	0.22
Gallium	0.07	0.50	0.49	0.35	0.66	0.18
Ytterbium	0.17	0.16	0.81	0.55	0.75	0.39
Quartz	–0.49	–0.28	–0.50	–0.10	–0.50	–0.40
Feldspar	0.26	–0.21	0.09	0.40	0.10	0.40
Illite	–0.34	0.68	0.05	–0.32	0.02	–0.14
Chlorite	–0.46	0.51	0.03	–0.42	0.05	–0.18
Smectite	0.48	–0.12	0.26	0.15	0.16	0.04
Zeolite	0.41	–0.25	0.10	0.40	–0.08	0.30
	Potassium	**Gallium**	**Ytterbium**	**Quartz**	**Feldspar**	**Illite**
Potassium	1.00					
Gallium	0.68	1.00				
Ytterbium	0.61	0.56	1.00			
Quartz	–0.41	–0.40	–0.53	1.00		
Feldspar	0.30	–0.04	0.25	–0.36	1.00	
Illite	0.01	0.08	–0.29	0.24	–0.41	1.00
Chlorite	–0.01	0.21	–0.21	–0.01	–0.48	0.67
Smectite	–0.27	0.06	0.34	–0.38	0.02	–0.31
Zeolite	0.09	–0.03	0.20	–0.45	0.28	–0.44
	Chlorite	**Smectite**	**Zeolite**			
Chlorite	1.00					
Smectite	–0.34	1.00				
Zeolite	–0.40	0.33	1.00			

probably is mostly heulandite but may also contain some clinoptilolite, is diagenetic.

Chlorite and illite are interpreted as detrital in origin because they are abundant in the unconsolidated, unaltered, or slightly altered rocks of the Tyonek and Beluga Formations and common in the West Foreland Formation over a wide area, and because they are abundant in the Chugach-Kenai Ranges source rocks (Hayes and others, 1976; Dickinson and Skipp, 1992). In addition, they display a detrital texture in electron micrographs (fig. 6). Chorite and illite are strongly correlated in the sample set (r=+0.67, table 2), probably because both chlorite and illite were deposited in the fine-grained fraction of the fluvial mudstone and claystone.

Some of the smectite may also be detrital, but most of it formed diagenetically from tuffaceous material originally a part of the sediments. Volcanic grains in the mudstone are coated by smectite in the West Foreland Formation (fig. 7). Smectite has a negative correlation with chlorite (r=–0.34) and illite (r=–0.31) (table 2) in the sample set (appendix 1). This relation could not be explained if the smectite was deposited as part of the fine fraction of the detrital component; therefore, much of the smectite must be diagenetic.

Abundant kaolinite and small amounts of montmorillonite (smectite), together with mixed-layer (layers not specified) clay, have been reported from the Capps and Chuitna coal fields (Odum and others, 1988). The absence of kaolinite in the samples of this report is probably because the kaolinite is in rocks related to the coals, and samples of these rocks were not analyzed for clay minerals.

The zeolites, which consist of clinoptilolite and (or) heulandite, are in the interstices of sandstone and mudstone and are diagenetic (fig. 7). X-ray energy-dispersive spectrometry indicates that the zeolite is rich in calcium relative to potassium, which favors heulandite rather than clinoptilolite.

In the study area (fig. 1) the West Foreland Formation contains more volcanic material than do units of the overlying Kenai Group (Adkison and others, 1975; Magoon and others, 1976, Croff and others, 1977), and it also contains more zeolite and smectite (table 4, appendix 1). The West Foreland contains less chlorite and illite than do the overlying units. Perhaps some smectite and zeolite formed from the volcanic component of the sediments, and the sediments were diluted by illite- and chlorite-barren volcanic materials.

Table 3. Varimax factor analysis for five factors.
[Primary factor loadings are underlined]

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Communality
Uranium	<u>0.81</u>	0.34	–0.11	–0.27	0.03	0.86
Thorium	<u>0.87</u>	0.11	–0.09	–0.24	–0.18	0.87
Iron	0.44	0.33	<u>0.66</u>	0.19	0.13	0.80
Magnesium	–0.03	0.26	0.37	<u>0.56</u>	–0.22	0.57
Calcium	–0.20	–0.05	0.09	<u>0.80</u>	0.25	0.76
Titanium	0.46	0.38	<u>0.54</u>	0.22	0.17	0.73
Manganese	–0.01	0.19	0.05	<u>0.76</u>	0.09	0.63
Barium	0.26	0.22	0.21	<u>–0.70</u>	0.36	0.78
Chromium	0.19	<u>0.76</u>	–0.10	–0.02	–0.18	0.65
Copper	0.22	<u>0.89</u>	–0.03	0.13	0.24	0.92
Nickel	0.28	<u>0.82</u>	0.09	0.09	–0.18	0.80
Scandium	<u>0.62</u>	0.39	0.48	0.32	0.07	0.88
Strontium	–0.06	–0.31	<u>0.64</u>	0.14	0.42	0.70
Vanadium	0.40	<u>0.81</u>	0.24	0.12	0.02	0.88
Yttrium	<u>0.79</u>	0.14	0.37	0.08	0.09	0.79
Zirconium	<u>0.55</u>	–0.53	–0.11	–0.12	0.18	0.65
Aluminum	<u>0.79</u>	0.17	0.38	0.12	0.09	0.83
Sodium	0.38	–0.11	–0.02	0.35	<u>0.52</u>	0.54
Potassium	<u>0.77</u>	0.13	–0.18	–0.14	0.33	0.77
Gallium	<u>0.76</u>	0.20	0.02	–0.10	0.12	0.64
Ytterbium	<u>0.86</u>	–0.23	0.30	–0.07	0.15	0.90
Quartz	–0.33	–0.06	–0.40	–0.12	<u>–0.73</u>	0.82
Plagioclase	0.18	.45	–0.15	0.04	<u>0.54</u>	0.55
Illite	–0.01	<u>0.84</u>	–0.08	0.03	–0.24	0.76
Chlorite	–0.03	<u>0.83</u>	–0.17	–0.07	–0.09	0.73
Smectite	0.01	–0.32	<u>0.80</u>	–0.11	0.03	0.75
Zeolite	–0.06	–0.29	0.24	–0.20	<u>0.69</u>	0.66

Table 4. X-ray diffraction counts of oriented, glycolated mounts for clay minerals and zeolites from samples having high clay contents.
[Sample descriptions, analyses, and locations are given in appendixes 1 and 2. Cystallographic index for peak measured is given in parentheses (table 1). Leaders (--) indicate peak not detected]

Sample number	Stratigraphic unit	Smectite (001)	Illite (001)	Chlorite (002)	Zeolite and (or) heulandite (800)
1	Beluga Formation	113	63	123	--
2	Beluga Formation	79	116	255	--
9	Tyonek Formation	100	45	54	--
12	Tyonek Formation	127	48	230	--
21	West Foreland Formation	139	28	27	106
22	West Foreland Formation	87	--	--	29
24	West Foreland Formation	656	28	24	--

URANIUM FAVORABILITY

Tertiary sedimentary rocks in the study area probably have relatively low favorability for uranium deposits. This estimation is based on lack of evidence for widespread alteration of the potential host rocks in the study area and the lack of known uranium deposits. The high correlation between uranium and thorium (fig. 8, table 2) and the low Th/U ratio (<2 for each of the three formations) are regarded as unfavorable. The U/Th ratio is erratic in rocks that have been subjected to epigenesis because uranium is mobilized by oxidizing ground water and thorium is not. The uranium content of the samples analyzed for this study ranges from 2.0 to 4.9 ppm for the West Foreland Formation, from 1.4 to 5 ppm for the Tyonek Formation, and from 1.7 to 4.9 ppm for the Beluga Formation (appendix 1).

The West Foreland Formation may have a slightly higher favorability for uranium deposits in the study area than the overlying Tyonek and Beluga Formations. The West Foreland Formation has a more granitic and felsic volcanic source than the Tyonek and the Beluga. In addition, more samples of the West Foreland contain diagenetic minerals, especially montmorillonite and zeolite (table 4, appendix 1). The presence of diagenetic minerals in the West

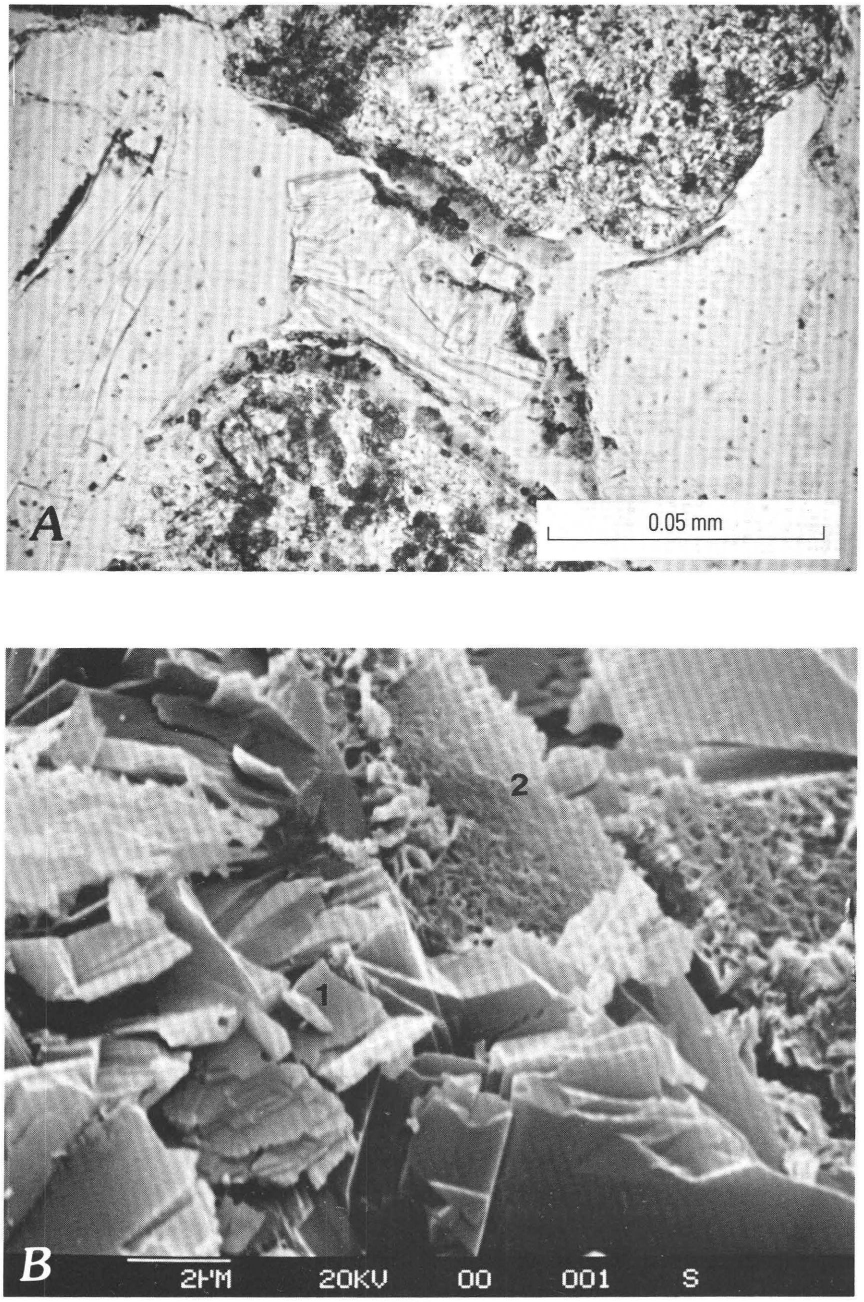

Figure 7. Tuffaceous sedimentary rocks of West Foreland Formation. *A*, Photomicrograph showing zeolite crystals that grew in interstices of tuffaceous sandstone. Sample 27 (table 4, appendix 1). *B*, Electron micrograph of siltstone showing zeolite (1) and smectite (2). Sample 22 (table 4, appendix 1).

Foreland Formation increases the likelihood that epigenetic uranium mineralization occurred in these rocks.

The overall favorability for uranium in the Cook Inlet Basin was rated as low by Croff and others (1977). They stated (p. 3, v. 1), however, "that certain formations contain favorable environments for sandstone-type uranium deposits." Of the formations studied herein, they ranked the Tyonek Formation first in uranium favorability, the West Foreland Formation second, and the Beluga Formation third. Their ratings were based on numerous factors including geologic age, depositional environment, provenance, and lithofacies of potential host rocks. Dickinson and Campbell (1978) rated the undivided Kenai Group and the West Foreland Formation in the Tyonek–Capps Glacier area higher in uranium favorability than corresponding rocks on the Kenai Peninsula and lower than generally correlative rocks in the

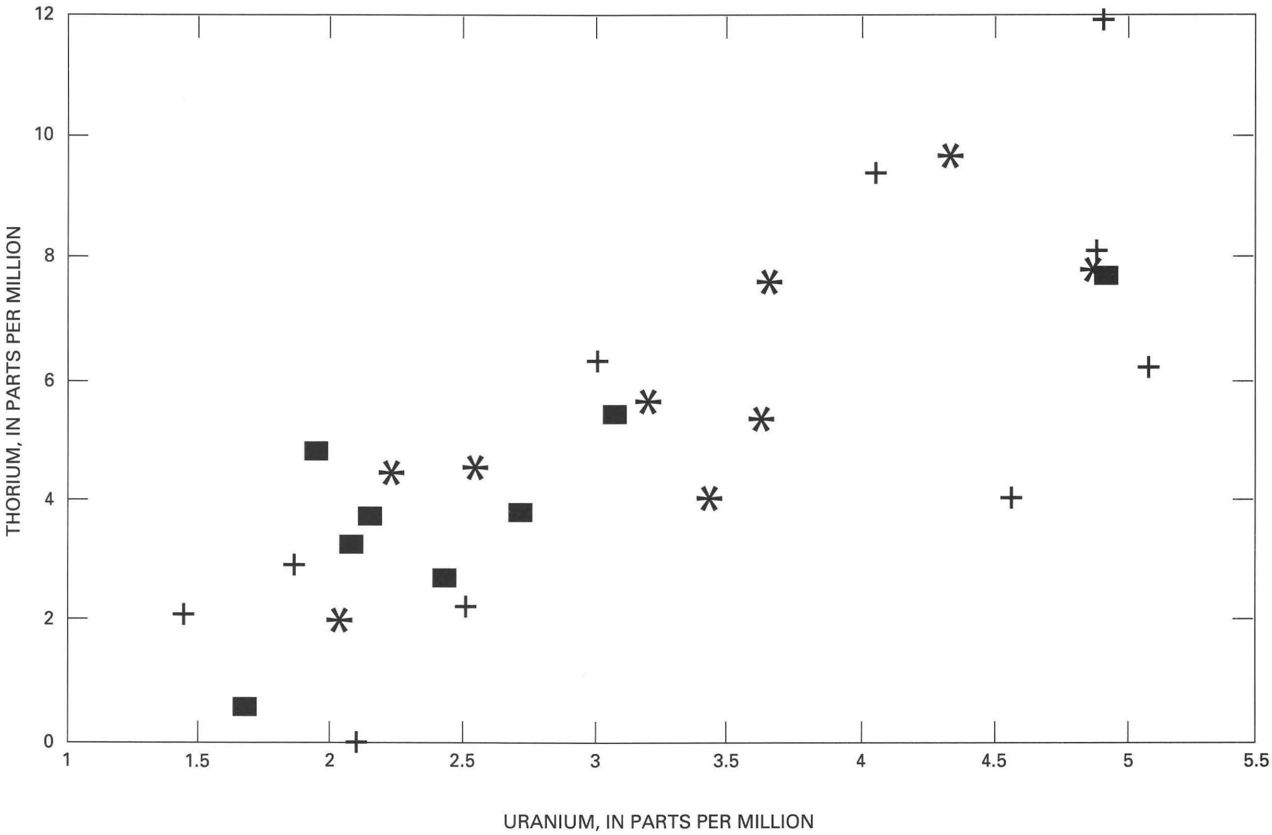

Figure 8. Scatterplot of uranium and thorium from samples of the West Foreland (asterisks), Tyonek (pluses), and Beluga Formations (rectangles) in the Cook Inlet Basin area.

Susitna Lowlands, based primarily on uranium and thorium content of the potential host rocks.

In a study of the Tyonek 1:250,000-scale quadrangle area, Manning and Hinderman (1982) found no geologic environments favorable for uranium; however, they included the Cook Inlet Basin in their category of "unevaluated environments." They listed two uranium occurrences in the Tyonek quadrangle. One of these is near Shirley Lake in the northwestern part of the quadrangle, about 55 km north of the northwest corner of the present study area. At Shirley Lake the uranium is on and adjacent to joints or fractures in basaltic and andesitic tuff and breccia (Freeman, 1963) and most likely was precipitated from ground water. The second uranium occurrence is in the Tyonek Formation along the Kahiltna River, about 52 km north of the northeast corner of the present study area; no geologic or geochemical information is available. A radioactive spring has been reported near Beluga Lake (Sainsbury, 1990). Neither the exact location of the spring nor its relation to the Tyonek Formation, which crops out northeast of the lake, is known to the authors. Sainsbury (1990) claimed that both the spring water and the spring sediments are high in uranium and that the spring water is high in radon.

CONCLUSIONS

1. Uranium potential for the Tertiary Kenai Group and the Paleocene and Eocene West Foreland Formation is low in the study area.
2. Uranium potential is higher for the West Foreland Formation than for the overlying Kenai Group because the West Foreland contains more volcanic materials and more evidence of epigenesis.
3. Volcanic materials in the Tertiary sedimentary rocks in the study area have altered to a zeolite and to smectite.
4. A strong correlation between thorium and uranium (r=+0.81) in samples of Tertiary sedimentary rocks in the study area suggests that substantial amounts of uranium have not been mobilized in oxidizing ground water.
5. Association of uranium with other rare earth elements including ytterbium suggests that uranium is abundant in a placer constituent of the sandstone.
6. Three principal clay mineral suites are present in Tertiary sedimentary rocks of the study area: kaolinite, which is related to coal beds; chlorite and illite, which are closely associated (r=+0.67) detrital clays common in all of the sediment source areas but more abundant in the

Kenai-Chugach Ranges-derived sediments than in the Aleutian-Alaska Ranges-derived sediments; and smectite, which resulted from alteration of the volcanic materials derived from the Aleutian-Alaska Ranges.

7. Copper, nickel, and chromium, which are more abundant in mafic rocks and which are present in sulfide minerals, are associated with the illite-chlorite clays of the study area. The clays suggest a relation to the Kenai-Chugach Ranges source, which is probably more mafic than the Aleutian-Alaska Ranges source.

8. Titanium and iron are closely associated (r=+0.66) and probably are present together in the mineral ilmenite. Ilmenite represents a more felsic source, probably the Aleutian-Alaska Ranges. Titanium and iron are also associated with smectite, which is an alteration product of the volcanic materials more common in the Aleutian-Alaska Ranges source.

9. The cations of calcium, manganese, and magnesium are associated with and probably represent the plagioclase and chlorite from mafic igneous rocks and metamorphic rocks of the Chugach-Kenai Ranges sediment source area.

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APPENDIX 1—CHEMICAL AND MINERALOGICAL DATA FOR SAMPLES OF THE WEST FORELAND, TYONEK, AND BELUGA FORMATIONS

Samples are shown by number in measured sections of appendix 2. Elements are in parts per million (ppm) or percent, as indicated at top of column. Values for quartz, feldspar, chlorite, illite, smectite, and zeolite are peak areas in square inches; the crystallographic indices of the peaks measured are given in table 1. Mean is the arithmetic mean; St. dev. is standard deviation.

A. Description of samples

Sample number	Measured section	Rock type
		BELUGA FORMATION
1	19	Mudstone, gray to brown, calcareous, conglomeratic
2	17	Siltstone, gray, dense, calcareous
3	17	Siltstone, gray, platy, calcareous, carbonaceous
4	18	Siltstone, light-brown, dense, micaceous
5	18	Sandstone, light-brown, fine- to medium-grained, unconsolidated
6	21	Conglomerate, light-brown, silty, soft
7	20	Sandstone, fine-grained, gray, silty, friable
8	20	Sandstone, reddish-brown, medium-grained, poorly sorted
		TYONEK FORMATION
9	10	Siltstone, brown to gray, dense
10	11	Siltstone, brown to gray, micaceous, iron-oxide-stained
11	14	Sandstone, gray, soft, conglomeratic, noncalcareous
12	13	Conglomerate, soft, sandy, silty
13	13	Sandstone, tan, fine-grained, silty
14	13	Claystone, brown-gray to gray, carbonaceous
15	16	Siltstone, light-brown, micaceous, clayey
16	15	Siltstone, brown, dense, micaceous, noncalcareous
17	9	Siltstone, brown, dense, micaceous, noncalcareous
18	12	Siltstone, tan, crumbly, trace carbon
		WEST FORELAND FORMATION
19	2	Conglomerate, brown, soft, sandy
20	3	Conglomerate, brown, hard, lithic
21	8	Conglomerate, brown, hard, clayey, noncalcareous, volcanic grains
22	8	Siltstone, brown, dense, noncalcareous
23	6	Sandstone, light-brown, coarse-grained, noncalcareous
24	6	Claystone, light-gray, brown, crumbly
25	4	Siltstone, tan, dense, trace iron oxide stain
26	7	Conglomerate, brown, soft, sandy, silty
27	5	Sandstone, brown, fine- to coarse-grained, hard, tuffaceous
28	1	Conglomerate, brown, hard, calcareous

B. Chemical and mineralogical data

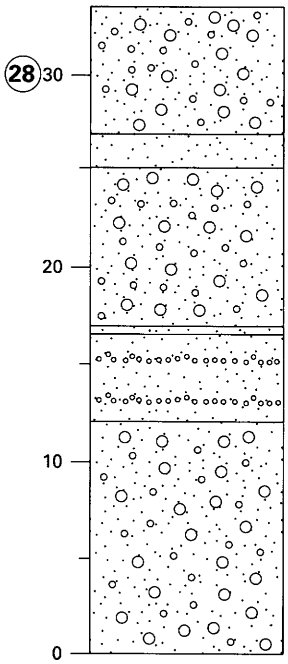
Sample number	U (ppm)	Th (ppm)	Fe (percent)	Mg (percent)	Ca (percent)	Ti (percent)	Mn (ppm)	Ba (ppm)	Cr (ppm)	Cu (ppm)	Ni (ppm)	Sc (ppm)	Sr (ppm)	V (ppm)
BELUGA FORMATION														
1	2.1	3.3	3.0	1.5	2.0	0.50	700	700	50	50	30	15	300	150
2	3.1	5.4	3.0	1.5	0.30	0.50	700	700	150	70	70	20	200	150
3	2.4	2.7	2.0	1.0	7.0	0.30	300	500	70	50	30	15	200	70
4	4.9	7.7	5.0	0.70	0.70	0.50	700	1,000	100	70	70	20	200	150
5	2.1	3.7	1.5	0.70	0.70	0.30	300	700	30	15	20	7.0	150	70
6	1.9	4.8	2.0	1.5	1.5	0.30	700	700	30	30	30	15	200	70
7	2.7	3.8	3.0	2.0	0.30	0.30	300	700	70	50	50	15	150	100
8	1.7	0.59	3.0	1.5	2.0	0.30	300	700	15	15	7.0	15	700	100
Mean	2.62	4.00	2.81	1.30	1.81	0.38	500	713	64.4	43.8	38.4	15.3	263	80.0
St. dev.	0.97	1.95	1.00	0.43	2.07	0.10	200	127	41.3	20.4	1.41	3.77	171	54.3
TYONEK FORMATION														
9	4.9	8.1	3.0	1.0	0.30	0.30	300	1000	100	70	50	15	150	150
10	2.5	2.3	3.0	1.5	7.0	0.30	3,000	500	70	70	30	15	150	100
11	1.9	2.9	0.70	0.30	0.15	0.15	70	700	20	15	15	5.0	70	30
12	2.1	0	0.50	0.15	0.15	0.07	70	1,000	15	30	7.0	3.0	50	30
13	1.4	2.1	0.70	0.20	0.20	0.15	70	700	150	10	15	3.0	70	30
14	5.1	6.2	1.0	0.50	0.30	0.30	30	700	100	70	15	15	150	150
15	3.0	6.3	3.0	1.5	0.50	0.50	300	700	70	70	70	20	15	150
16	4.6	4.0	5.0	1.5	0.70	0.30	700	1,000	100	70	70	15	15	150
17	5.0	11.9	3.0	1.5	0.30	0.50	150	1,000	100	70	70	20	20	150
18	4.1	9.4	5.0	0.70	0.30	0.30	700	700	70	30	15	15	200	100
Mean	3.45	5.32	2.49	0.89	0.99	0.29	539	800	79.5	50.5	30.7	12.6	89.0	104
St. dev.	1.35	3.52	1.62	0.55	2.01	0.13	854	173	38.2	24.5	26.7	6.17	64.4	52.0
WEST FORELAND FORMATION														
19	2.5	4.5	1.5	0.50	0.50	0.15	300	700	15	10	10	7.0	150	30
20	3.7	7.6	1.5	0.50	0.70	0.20	300	700	15	15	7.0	10	200	30
21	3.2	5.6	3.0	0.70	1.5	0.30	300	1,000	30	70	15	7.0	300	70
22	2.0	2.1	5.0	1.5	3.0	0.50	500	1,000	15	15	5.0	20	700	70
23	3.6	5.3	1.0	0.15	0.50	0.15	150	1000	7.0	7.0	3.5	10	150	30
24	4.3	9.7	3.0	0.70	0.70	0.30	150	700	30	15	15	15	100	70
25	4.9	7.9	2.0	0.70	0.30	0.30	200	1,000	70	30	20	15	150	70
26	3.4	4.0	3.0	1.0	2.0	0.50	700	700	15	15	7.0	20	300	70
27	2.2	4.2	1.5	0.50	0.70	0.30	150	700	15	15	15	7.0	200	30
28	2.4	2.7	1.5	3.0	3.0	0.07	700	500	15	15	15	5.0	70	30
Mean	3.23	5.36	2.30	0.93	1.29	0.28	345	800	22.7	20.7	11.3	11.6	232	44.0
St. dev.	0.89	2.28	1.14	0.77	0.98	0.14	204	173	17.2	17.4	5.19	5.26	172	28.0

Sample number	Y (ppm)	Zr (ppm)	Al (percent)	Na (percent)	K (percent)	Ga (ppm)	Yt (ppm)	Quartz (in.^{2})	Feldspar (in.^{2})	Chlorite (in.^{2})	Illite (in.^{2})	Smectite (in.^{2})	Zeolite (in.^{2})
							BELUGA FORMATION						
1	15	100	10	3.0	1.5	15	1.5	0.33	0.12	0.05	0.05	0	0
2	30	100	7.0	3.0	2.0	15	1.5	0.36	0.10	0.10	0.07	0	0
3	15	70	7.0	3.0	2.0	15	1.5	0.20	0.06	0.07	0.02	0	0
4	30	100	13	2.0	3.0	20	3.0	0.17	0.05	0.09	0.04	0	0
5	7.0	70	7.0	1.0	1.5	10	1.5	0.46	0.09	0.02	0.02	0	0
6	20	100	7.0	2.0	1.5	10	1.5	0.50	0.06	0.04	0.02	0	0
7	15	100	7.0	1.5	1.5	15	1.5	0.38	0.07	0.14	0.05	0	0
8	15	70	10	0.30	3.0	15	1.5	0.16	0.24	0	0	0	0
Mean	18.4	88.8	8.44	1.98	2.00	14.4	1.69	0.32	0.10	0.06	0.03	0	0
St. dev.	7.48	14.5	1.99	0.94	0.61	3.00	0.50	0.12	0.06	0.04	0.02	0	0
							TYONEK FORMATION						
9	30	100	7.0	0.70	.0	20	2.0	0.32	0.06	0.10	0.07	0	0
10	20	70	7.0	1.5	1.5	15	1.5	0.17	0.06	0.11	0.03	0	0
11	7.0	70	3.0	0.50	0.70	7.0	1.0	0.60	0.03	0.04	0.01	0	0
12	7.0	30	1.5	0.30	0.70	5.0	0.70	0.24	0.09	0.17	0.03	0	0
13	7.0	70	3.0	0.70	1.5	7.0	0.70	0.59	0.04	0.04	0.02	0	0
14	10	70	7.0	0.30	3.0	30	1.5	0.25	0.0	0.11	0.04	0	0
15	30	15	10	2.0	2.0	15	2.0	0.25	0.09	0.09	0.02	0	0
16	30	10	10	1.0	3.0	15	2.0	0.29	0.04	0.10	0.05	0	0
17	30	150	13	0.70	3.0	20	3.0	0.36	0.03	0.13	0.05	0	0
18	30	100	13	1.0	3.0	20	3.0	0.29	0.02	0.06	0.01	0	0
Mean	20.1	68.5	7.35	0.87	2.14	12.4	1.74	0.34	0.05	0.10	0.03	0	0
St. dev.	10.5	40.5	3.74	0.51	0.93	6.79	0.79	0.14	0.03	0.04	0.02	0	0
							WEST FORELAND FORMATION						
19	15	150	7.0	1.5	2.0	15	1.5	0.58	0.10	0.01	0.03	0	0
20	30	150	7.0	2.0	3.0	15	3.0	0.24	0.11	0	0	0	0.05
21	20	150	7.0	3.0	3.0	15	2.0	0	0.23	0.02	0	0	0.23
22	30	100	10	2.0	1.0	15	3.0	0	0.02	0	0	0.81	0.12
23	20	150	7.0	3.0	3.0	15	3.0	0.30	0.30	0	0	0	0.03
24	30	150	10	1.5	2.0	20	3.0	0.16	0.25	0	0	0.46	0
25	30	150	13	3.0	3.0	30	3.0	0.23	0.07	0.11	0	0	0
26	30	150	10	3.0	3.0	15	3.0	0.10	0.21	0.01	0	0	0.05
27	15	150	3.0	0.70	1.5	15	1.5	0.48	0.05	0.01	0	0.11	0.10
28	15	70	3.0	0.70	1.0	7.0	1.5	0.50	0.05	0.03	0.02	0	0
Mean	23.5	137	7.65	2.04	2.25	16.2	2.45	0.26	0.14	0.02	0.01	0.14	0.06
St. dev.	6.73	26.9	2.92	0.89	0.81	5.47	0.69	0.20	0.09	0.03	0.01	0.26	0.07

APPENDIX 2—MEASURED SECTIONS OF THE WEST FORELAND, TYONEK, AND BELUGA FORMATIONS

Locations of sections are shown in figure. 2. Section scales are in meters; sample numbers are circled and in bold, alongside scale.

Section 1. West Foreland Formation. Theodore River. NW1/4 sec. 22, T. 15 N., R. 10 W., Seward Meridian



Conglomerate, brown, hard, sandy; poorly exposed

Sandstone, brown, fine-grained, hard, dense; coarse and gritty near top; interbedded conglomerate, brown, hard, rounded pebbles, poorly exposed, maximum grain size 3 cm

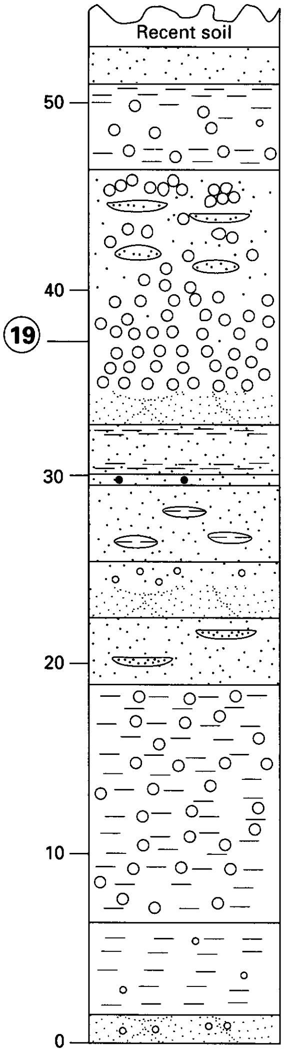
Conglomerate, brown, hard, sandy; poorly exposed

Sandstone, brown, hard, medium-grained, lenticular; poorly exposed

Sandstone, brown, fairly hard; poorly exposed; conglomerate beds at various intervals

Conglomerate, grayish-brown, thick-bedded; well-rounded grains as much as 6 cm in diameter; some beds hard

Section 2. West Foreland Formation. East bank of the Theodore River. SE1/4 sec. 23, T. 15 N., R. 10 W., Seward Meridian



Sandstone, light-brown, friable, covered

Conglomerate claystone, bluish-gray; rounded pebbles 1–5 cm in diameter suspended in matrix; top 1.0 m dark-gray mudstone

Conglomerate, orangish-red; horizontal beds 0.5–1.0 m thick; abundant rounded pebbles 2–5 cm in diameter; grain-supported medium- to coarse-grained sand matrix; foreset and tabular-planar crossbeds; coal clasts; channel deposits and sand lenses 1.0–2.0 m thick; crossbeds typical of longitudinal bars

Sandstone, brown, fine-grained; silty, light-gray claystone interbeds 1.0–2.0 cm thick

Conglomerate, yellowish-brown; granules to pebbles; coarse-grained sand matrix

Sandstone, reddish-brown, fine-grained; silty clay lenses

Conglomerate, yellowish-brown; granules and pebbles; grain-supported medium-grained sand matrix; coal clasts in channels

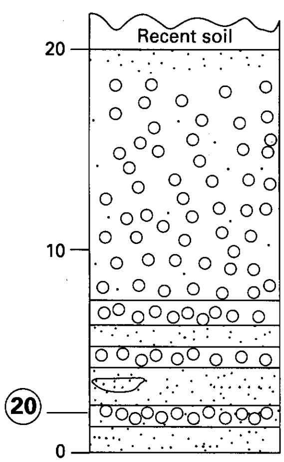
Sandstone, light-brown, fine-grained, friable; thickens laterally; pebble conglomerate lenses 0.5 cm thick

Claystone, conglomeratic, dark-gray, massive; pebbles and cobbles 2–10 cm in diameter suspended in matrix; pebbles 1–3 cm in diameter at top; locally oxidized to deep orange red; local zones of grain support

Claystone, dark-bluish-gray; dark and light horizontal laminations 2–4 cm thick (organic rich); scattered granules and pebbles as large as 5 cm; few reddish-brown streaks

Conglomerate, yellowish-brown, moderately well rounded; grain supported; oxidized, granules, pebbles, and cobbles 2.0 mm–10 cm in diameter; tabular planar crossbeds 1.0 m thick

Section 3. West Foreland Formation. West bank of the Theodore River 15.5 km upstream from its mouth. SW1/4 sec. 36, T. 15 N., R. 10 W., Seward Meridian



Conglomerate, same as below; cliff-forming; top 1.0 m is dark-brown, medium to coarse-grained sandstone

Conglomerate, reddish-brown, granular, crumbly; partly covered

Sandstone, dark-brown, medium- to coarse-grained, poorly bedded

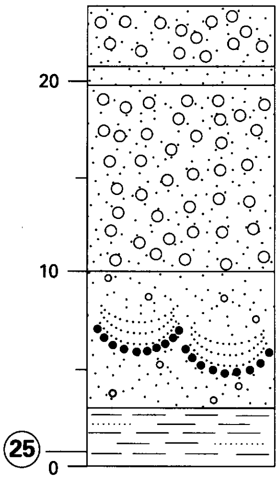
Conglomerate, light-gray; well-rounded pebbles in 1.0 by 10.0 m channels

Sandstone, dark-brown, medium-grained, poorly bedded; conglomeratic lenses, channels, and pebbles

Conglomerate, medium-gray; pebbles and cobbles 2–8 cm in diameter; grain-supported sand matrix

Sandstone, dark-gray, coarse-grained, poorly bedded; rounded pebbles; lenses 20–30 cm thick; channels 2–3 m long

Section 4. West Foreland Formation. On Bishop Creek 9.0 km southwest of Bishop Lake. SW1/4 sec. 22, T. 14 N., R. 13 W., Seward Meridian



Conglomerate, yellowish-brown (oxidized), well-rounded pebbles 1–3 cm in diameter; coarse-grained sandstone matrix; mostly covered

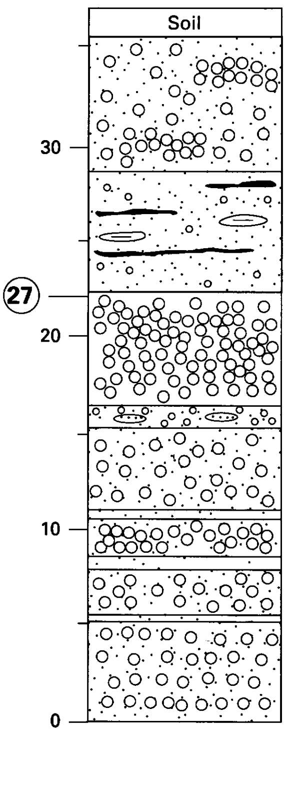
Sandstone, oxidized yellowish- to orangish-brown, medium- to coarse-grained

Conglomerate, yellowish-red; rounded pebbles 1–3 cm in diameter; coarse-grained to very coarse grained matrix; oxidized sand lenses

Sandstone, reddish-brown (oxidized), coarse-grained; pebbles; channels containing horizontal laminations of pebbles and granules

Claystone, light-brown, poorly bedded, locally silty, crumbly; abundant oxidized yellowish-orange to reddish-brown streaks; mostly covered

Section 5. West Foreland Formation. 1.5 km north of Lone Ridge and 6.4 km south of Bishop Lake. SE1/4 sec. 32, T. 14 N., R. 12 W., Seward Meridian



Conglomerate, light-gray to brown; vague horizontal bedding; fine-grained sandstone matrix, variable grain to matrix support; pebbles generally–5 cm in diameter; maximum clast size 10.0 cm

Sandstone to conglomerate, reddish- to yellowish-brown, tuffaceous, oxidized; granule-sized clasts; thin clay lenses and coaly layers

Conglomerate, light-brown; vague horizontal bedding; mostly covered; well-rounded pebbles 2–3 cm in diameter

Sandstone and interbedded conglomerate, light-brown; medium-grained sand in lenses; pebble conglomerate 0.5 m thick in middle

Conglomerate, light-reddish-brown, oxidized; pebbles 1–3 cm in diameter; matrix supported; massive horizontal layers

Sandstone, light-tan, medium-grained, hard; reddish-orange streaks

Conglomerate, light-gray to dark-brown; fine- to medium-grained grain-supported sand matrix

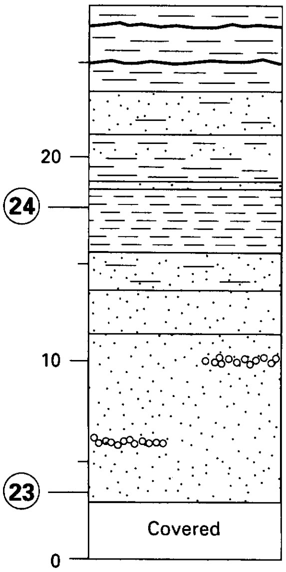
Sandstone, light-tan, medium-grained, hard, lenticular

Conglomerate, dark-reddish-brown; medium-grained sand matrix, pebbles 2–5 cm in diameter

Sandstone, light-gray, medium- to coarse-grained, thick-bedded; reddish-brown streaks

Conglomerate, dark-reddish-brown, horizontally bedded; medium-grained sand matrix; oxidized pebbles 1–3 cm in diameter

Section 6. West Foreland Formation. 5.4 km north of Lone Ridge. Section 30, T. 14 N., R. 12 W., Seward Meridian



Clay, gray, crumbly, soft; interbedded with 0.5-cm-thick layers of carbonized wood

Sandstone, light-brown, fine-grained, soft, clayey

Clay, light-brown, soft; interbedded black carbonaceous clay and light-brown sandstone

Sandstone, light-brown, soft, clayey, micaceous

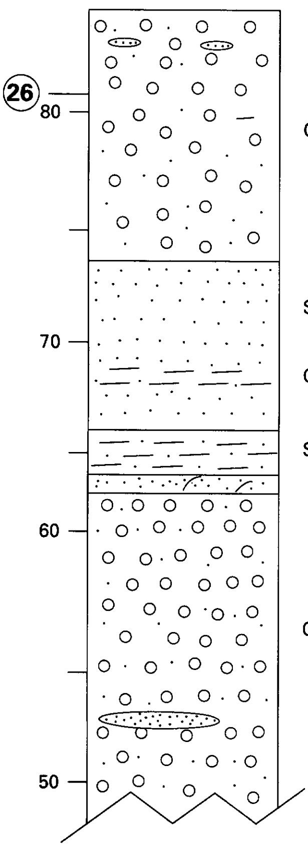
Clay, light-brown, crumbly

Sandstone, light-brown, fine-grained, clayey

Sandstone, light-brown, fine- to medium-grained

Sandstone, light-brown, medium- to coarse-grained; conglomerate beds and lenses as thick as 30 cm

Section 7. Lower part of the West Foreland Formation. South side of Capps Glacier. NW1/4 sec. 22, T. 14 N., R. 15 W., Seward Meridian



Conglomerate, yellow to brown and yellowish-orange; oxidized zones; coarse-grained to very coarse grained sand matrix; rounded pebbles, cobbles, and boulders 1–40 cm in diameter

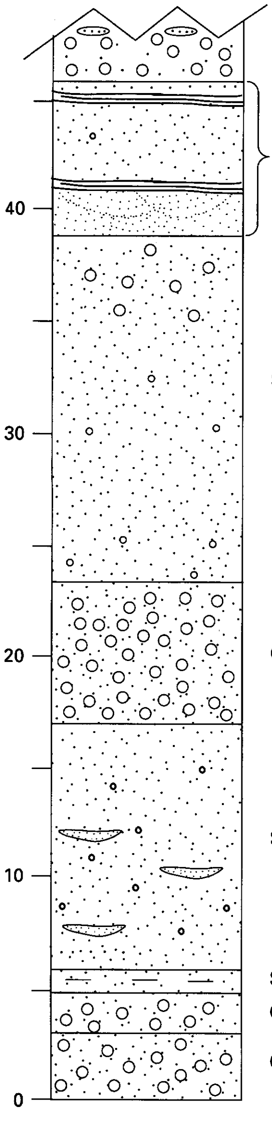
Sandstone, brown to grayish-brown, medium-grained to very coarse grained, crumbly, friable, massive; poor horizontal bedding; light-brown to green, very fine grained sandstone and claystone lens, 0.5–40. cm thick

Claystone, dark-reddish-brown, silty, very poorly bedded, sparsely carbonaceous

Sandstone, green to buff, very fine grained, poorly bedded, well-cemented, noncalcareous, shaly; horizontal layers of wood fragments, green patches, and layers of clay clasts

Conglomerate, light-brown, medium-grained to very coarse grained; sand matrix, massive horizontal beds 4 m thick; conglomeratic sandstone lenses 0.5 m thick by about 15 m wide

Section 7 (continued)



Sandstone, dark-brown, medium-grained to very coarse grained, thick-bedded; trough crossbed sets 20–40 cm thick; scattered rounded pebbles 1–5 cm in diameter

Sandstone, dark-brown, medium-grained; mostly covered; horizontally massive horizontal bedding; conglomeratic zones with rounded pebbles 1–5 cm in diameter; more conglomeratic upward

Conglomerate, dark- to yellowish-brown, horizontally bedded; sandy matrix; pebbles 1–4 cm in diameter

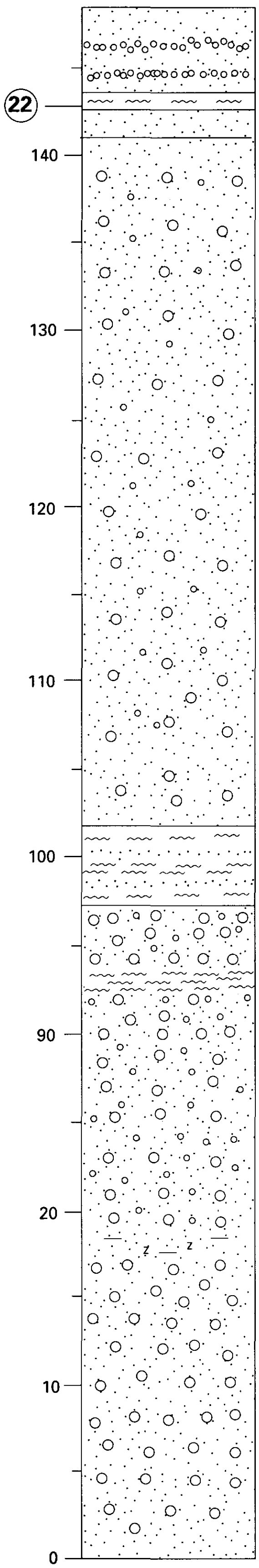
Sandstone, yellow to brown, coarse-grained, conglomeratic, thick-bedded; partly covered; scattered, rounded, green to gray volcanic pebbles; medium-grained sandstone lenses in bottom 1 m; yellow to brown, medium-grained sandstone near top

Sandstone, light-green to gray, clayey; fines upward to siltstone and silty claystone

Conglomerate, yellow to brown, sandy; rounded, scattered pebbles

Conglomerate, light-brown to gray; abundant rounded pebbles 3–5 cm in diameter; maximum particle size 15 cm; top layer of yellow to brown, oxidized sandstone

Section 8. Upper part of the West Foreland Formation. 12.5 km west of toe of Capps Glacier. NW1/4 sec. 22, T. 14 N., R. 15 W., Seward Meridian



Sandstone, light-grayish-brown, fine- to coarse-grained, soft, poorly sorted; a few thin conglomerate beds

Mudstone, grayish-brown, crumbly, blocky; dark-gray coating on fractures

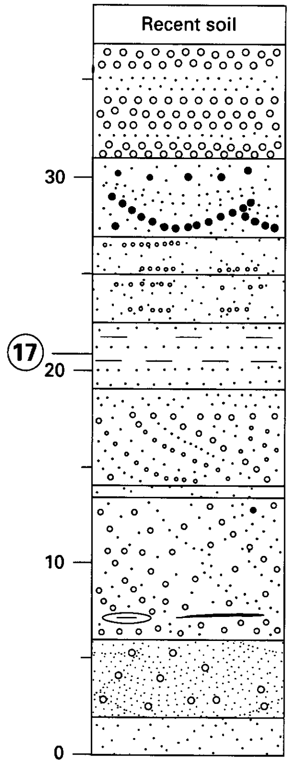
Sandstone, grayish-brown, fairly soft, crumbly

Conglomerate, gray to grayish-brown, very sandy, soft

Mudstone, light-grayish-brown, brittle, sandy at intervals; conchoidal fracture with dark-gray coating on surfaces; scarce carbonized plant fragments

Conglomerate, light- to medium-gray, sandy, soft, massive; maximum clast size 20 cm; a few thin beds of grayish-brown hard sandstone containing volcanic pebbles, plant fragments, and interbedded gray mudstone

Section 9. West Foreland Formation. Along the Chuitna River 8.0 km northwest of its confluence with Chuit Creek. SE¼ sec. 19, T. 13 N., R. 13 W., Seward Meridian



Conglomerate, light-brown, horizontally bedded; granules and pebbles, maximum clast size of 2 m; very coarse grained interbedded sandstone

Sandstone and conglomerate, light-brown; pebbles 1–2 cm in diameter in bedding planes; troughs with low -angle foresets

Sandstone and conglomerate, light-brown; same as below but coarser; pebbles to cobbles

Sandstone, light-brown, coarse-grained to very coarse grained, conglomeratic; some low-angle foresets; some pebble-bearing horizontal beds

Sandstone, brown; interbedded with light-gray claystone

Conglomerate and sandstone, reddish-brown (oxidized), coarse-grained to very coarse grained; scattered granules and cobbles and lenses with low-angle crossbeds

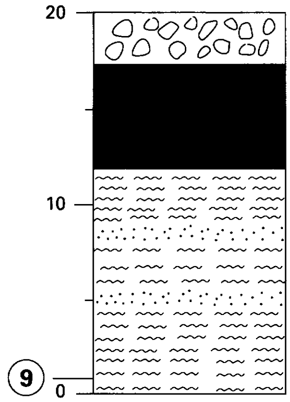
Sandstone, grayish-brown, fine-grained; partly covered

Conglomerate, brown; yellowish-brown oxidized zones; granules to pebbles; coarse sand matrix; a few coaly lenses; crossbeds; clay lenses

Conglomerate and sandstone, light-brown, medium- to coarse-grained; low-angle foreset crossbeds and trough crossbeds

Sandstone, medium- to coarse-grained, friable; scattered pebbles; partly covered

Section 10. Tyonek Formation and Pleistocene glacial till. Along Coal Creek 5 km south of Coal Creek Lake. SE1/4 sec. 26, T. 16 N., R. 13 W., Seward Meridian

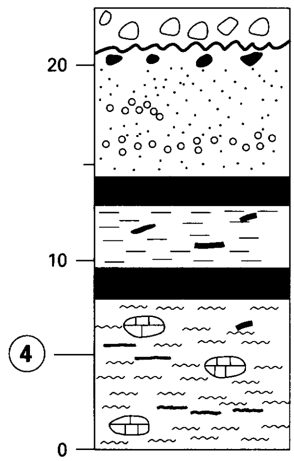


Conglomerate, reddish-brown (Pleistocene glacial till)

Coal, black, flaky, silty; light colored on weathered surfaces

Mudstone, gray to brown, micaceous; a few beds of medium-gray to grayish-brown sandstone

Section 11. Tyonek Formation and Pleistocene glacial till. Along Coal Creek 3 km north of Beluga Lake. SW1/4 sec. 31, T. 16 N., R. 12 W., Seward Meridian



Conglomerate, reddish-brown; Pleistocene glacial till; boulders as much as 1 m in diameter

Sandstone, light-grayish-brown, medium- to coarse-grained; reddish-brown at base; varicolored grains; th irregular beds have oxidized tops and layers of carbonaceous particles; interbedded conglomerate at various horizons; coal fragments at top, rounded coal pebbles at base; some layers contain pebbles and cobbles as much as 10 cm in diameter

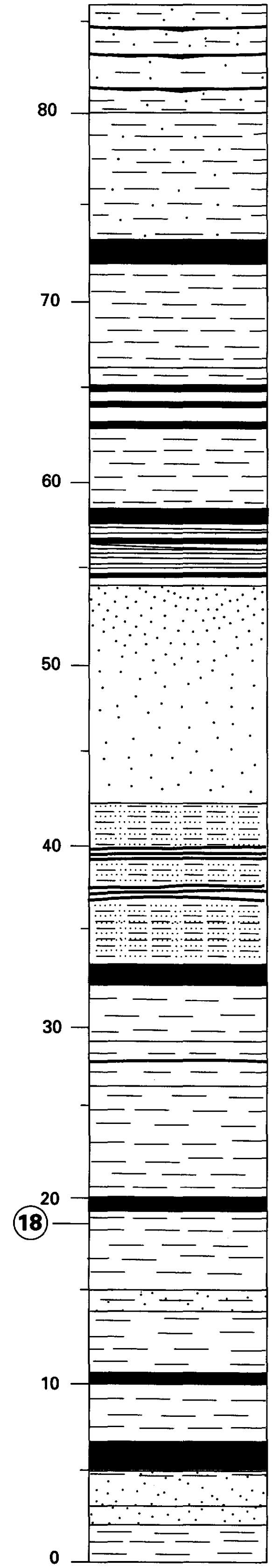
Coal, black, flaky

Clay, gray, soft; oxidized reddish-brown at base; carbonaceous fragments

Coal, black, flaky

Mudstone, medium-gray; blocky fracture; brown on weathered surfaces; carbonized wood in thin layers at intervals; traces of mica; calcareous concretions 0.15 by 0.5 m

Section 12. Tyonek Formation on the south side and near the toe of Capps Glacier. SW1/4, sec. 10, T. 14 N., R. 14 W., Seward Meridian



Claystone, gray; interbedded with shaly coal beds about 30.0–40.0 cm thick

Claystone, gray, sandy

Coal, gray, shaly; 0.5–1.5 m thick

Claystone, gray; partly covered

Claystone, light-gray; thin coal beds about 1 m apart at top

Shale, gray, interbedded with shaly coal; coal beds about 1 m thick separated by shale beds 1–2 m thick; uppermost coal bed contains less shale

Sandstone, brown; deposited in channels cut into underlying beds; channel sandstone is generally massive and has slight horizontal color banding

Siltstone and fine-grained sandstone, light-brown; siltstone and sandstone beds 1.0–1.5 m thick separated by shale beds 10–20 cm thick that form small escarpments

Coal, black, shaly

Claystone, light- to dark-gray, crumbly, shaly; darker layers are coaly

Claystone and crumbly shale, light-gray; grades upward to shaly coal beds 10–20 cm thick separated by claystone beds 30–40 cm thick

Coal, black, shaly, crumbly, lenticular

Claystone, light-gray; darker zones; partly covered

Sandstone, light-gray, medium-grained; clayey upward

Claystone, light- to bluish-gray, poorly bedded; mostly covered

Coal, black, shaly, interbedded with claystone; pinches out

Claystone, light-gray, crumbly; reddish-brown color bands; light and dark (carbonaceous) laminations

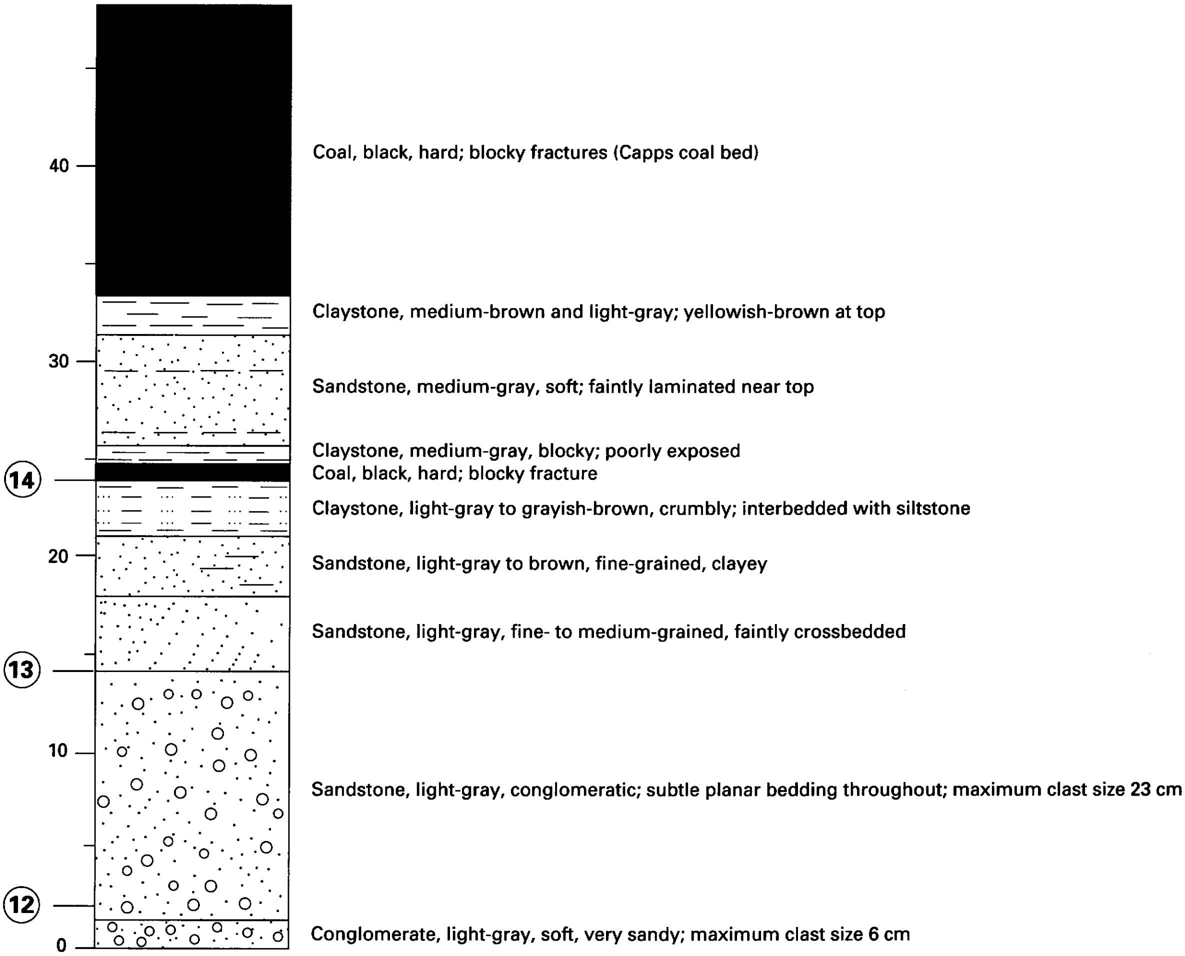
Coal, black to grayish-brown, shaly; grades upward to clayey shale

Sandstone, light-gray, medium-grained; interbedded with gray claystone at

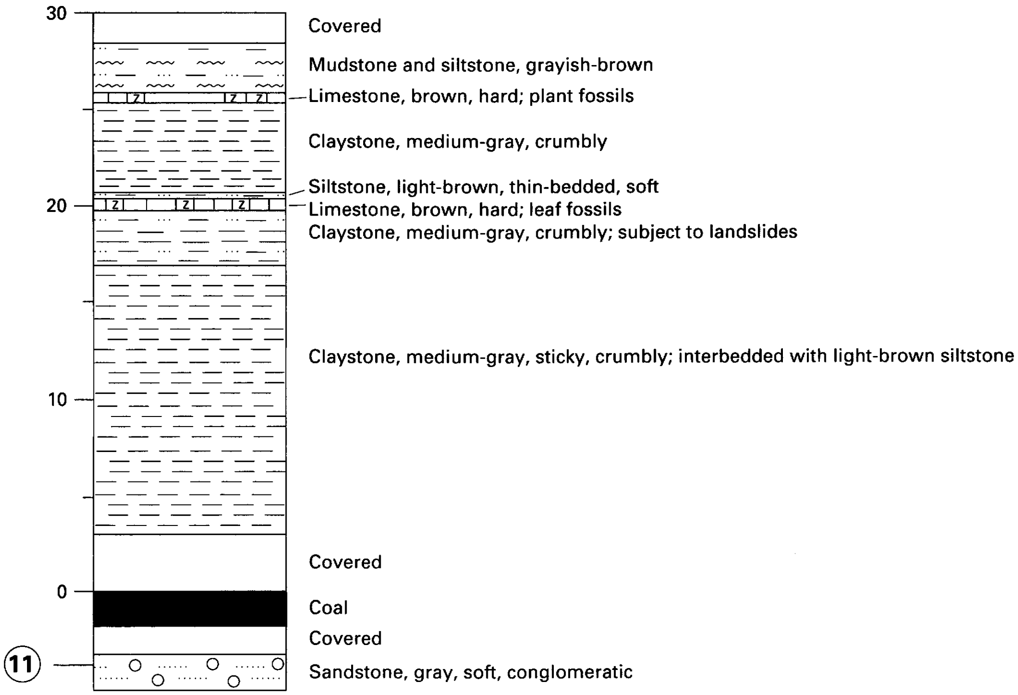
Sandstone, light-gray to brown, fine-grained; shaly and coaly at top

Claystone, gray to brown, very poorly bedded, crumbly, shaly; coaly at top

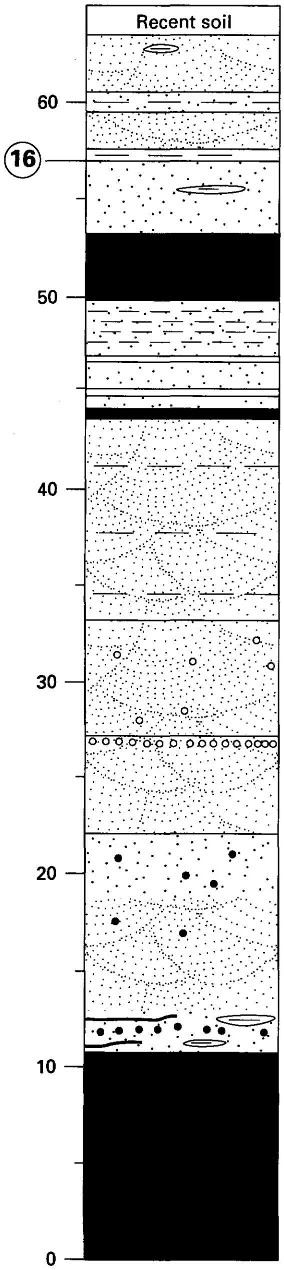
Section 13. Lower part of the Tyonek Formation. On Capps Creek, 3 miles south of the toe of Capps Glacier. SW1/4 sec. 24, R. 14 W., T. 14 N., Seward Meridian



Section 14. Tyonek Formation. On Chuitna River, 5 km northwest of entrance of Chuit Creek. NW1/4 sec. 28, T. 13 N., R. 13 W., Seward Meridian



Section 15. Upper part of Tyonek Formation. Along Chuit Creek at its junction with Chuitna River. SW1/4 sec. 1, T. 12 N., R. 13 W., Seward Meridian



Sandstone, light-brown to buff, medium-grained, well-sorted; crossbeds and iron-stained lenses

Claystone, grayish-brown, crumbly; interbedded with fine-grained sandstone

Sandstone, orange-red, fine-grained, well-sorted, very friable

Claystone, dark-reddish-brown, carbonaceous, horizontally bedded

Sandstone, light-brown, fine- to medium-grained; iron-stained zones; some clay matrix and clay lenses

Coal and coaly shale, fibrous; woody texture

Sandstone, reddish-brown, iron-stained, medium- to fine-grained; interbedded with bluish-gray shale

Coal to coaly shale, limonite-hematite-stained

Sandstone, light-gray, fine- to medium-grained; finer at top; partly covered; interbedded with a few bluish-gray claystone beds 10.0 cm thick

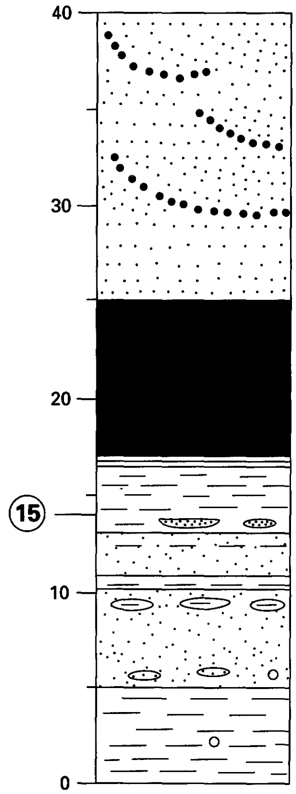
Sandstone, gray; scattered, rounded granules to pebbles, tabular-planar crossbeds

Sandstone, gray, medium-grained; thin beds of coarse-grained to very coarse grained sand; crossbeds and pebbles in sand matrix at the top

Sandstone, light-brown to buff; limonite-hematite stains along some contacts between beds; tabular crossbeds, curved laminations of coarse-grained to very coarse grained sand, coal seams, and lenses of iron-stained clay

Coal, black, shaly, crumbly, friable, fibrous; weathers into ledges (Chuitna coal bed)

Section 16. Upper part of the Tyonek Formation. Along the Chuitna River 18.0 km upstream from its mouth. NE1/4 sec. 8, T. 12 N., R. 12 W., Seward Meridian



Sandstone, light- to reddish-brown, very friable, well-sorted, medium-grained, crossbedded; well-developed horizontal planar beds 0.5–1.0 m thick with coal layers and rounded pebbles along contacts between beds; crossbeds have tangential bases

Coal, black, very shaly, flaky; fibrous wood, wood fragments, and horizontal laminations
Chuitna coal bed

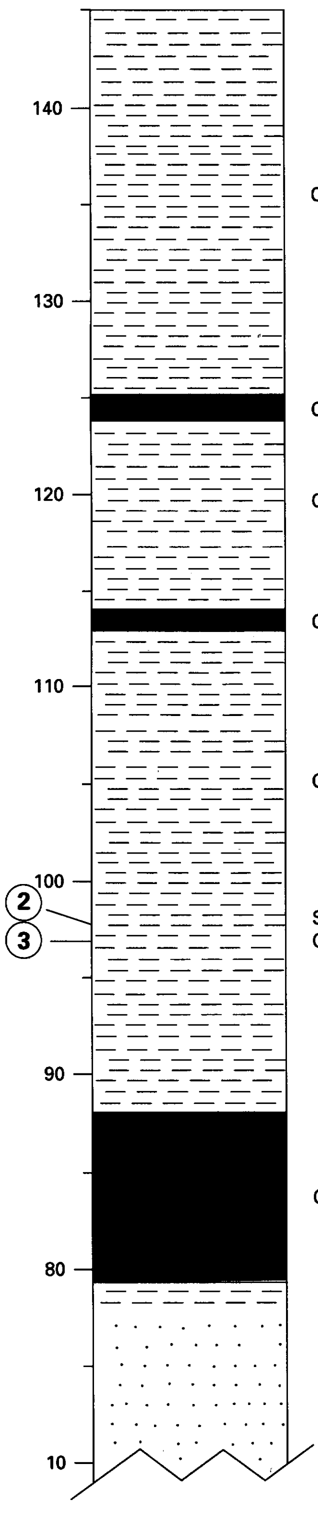
Claystone, light-greenish-gray, irregularly bedded; interbedded with sandstone lenses; shaly at top

Sandstone, light-brown, fine- to medium-grained; reddish brown staining; a few clay layers 13 cm thick Claystone, light-gray; beds 12 cm thick; medium-grained sandstone lenses

Sandstone, light- to reddish-brown, fine- to medium-grained; scattered pebbles at base, lenses of pebbles, and beds and lenses of clay

Claystone, medium-gray, sandy; scattered igneous pebbles and some coal clasts

Section 17. Beluga Formation. On the south bank of the Beluga River 4.0 km southeast of Felt Lake. NW1/4 sec. 10, T. 13 N., R. 11 W., Seward Meridian



Claystone, medium- to dark-gray, crumbly; partly covered

Coal, shaly, crumbly; poorly exposed

Claystone, medium- to dark-gray, poorly bedded, crumbly; partly covered

Coal, black, shaly, very crumbly; partly covered

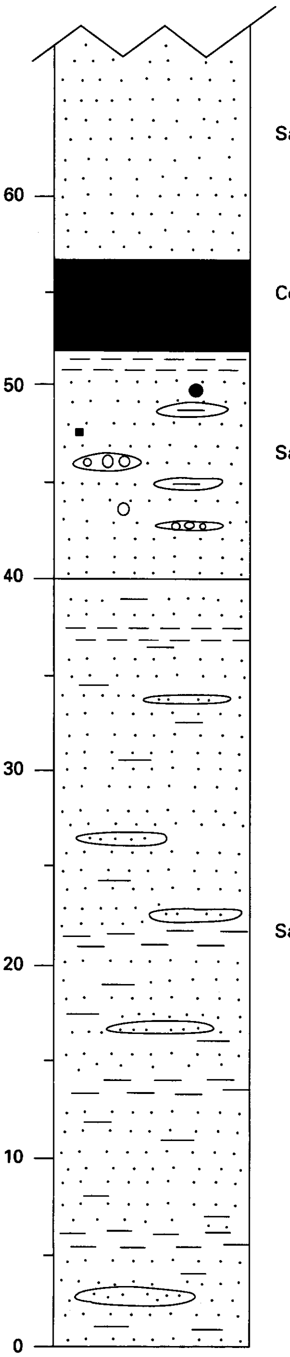
Claystone, medium- to dark-gray, poorly bedded, crumbly; partly covered

Siltstone, dark-gray, calcareous, platy, carbonaceous; horizontal laminations

Claystone, medium- to bluish-gray, poorly bedded; partly covered

Coal, very shaly; partly blocky and partly crumbly; few blocks thicker than 10 cm but some as thick as 20 cm near top

Section 17 (continued)



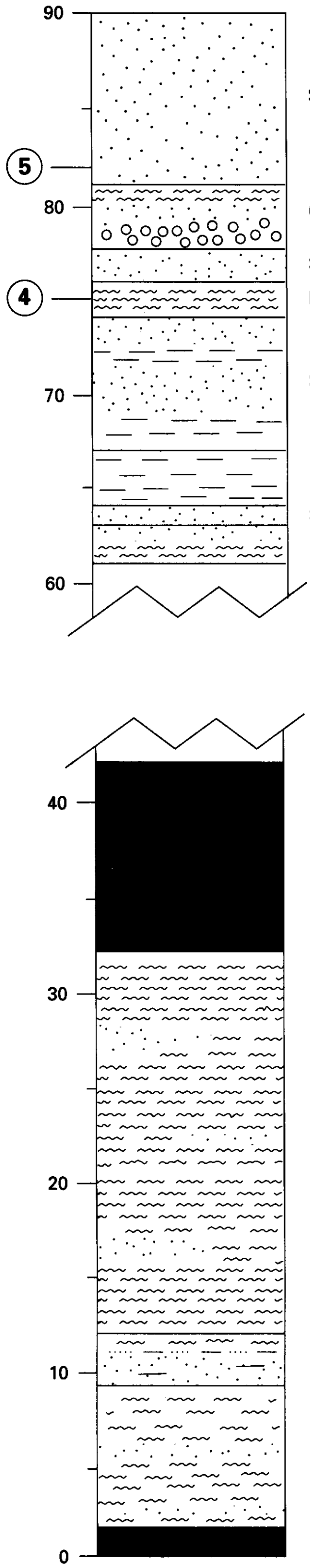
Sandstone, light-gray, friable, crumbly; medium gray on fresh surfaces; partly covered; scattered, rounded granules and pebbles; locally cemented with medium- to fine-grained calcite; good horizontal laminations about 1–3 cm apart

Coal; bottom 2 m shaly, top blocky; a few crumbly beds

Sandstone, light-gray, medium grained; scattered pebbles and lenses 5–10 cm thick of granule conglomerate and claystone that has red to brown oxidized laminations; weathers into mostly covered pinnacles

Sandstone, light-gray, medium-grained; clay matrix; lenses of medium-grained sandstone; hard beds with brown rim 20 cm 1.0 m thick; weathers into vertical spires of badlandlike topography

Section 18. Beluga Formation. On Beluga River 13.5 km northwest of Beluga. NE1/4 sec. 14, T. 13 N., R. 11 W., Seward Meridian



Sandstone, gray and brown, medium- to coarse-grained, crossbedded; crossbed sets 15 cm thick and faint large-scale crossbeds

Conglomerate, gray and brown, soft, sandy; maximum grain size 3 cm; clast upward to mudstone and sandstone

Sandstone, light-gray, fine-grained, soft

Mudstone, medium-gray, dense, soft, crumbly

Sandstone, light-gray and brown, fine-grained, crossbedded; interbeds and clasts of reddish-brown clay

Mudstone, medium-grayish-brown, laminated

Sandstone, grayish-brown, fine-grained, soft

Mudstone, medium-grayish-brown, laminated; grades upward to fine-grained sandstone

Covered; reddish-brown cindery material from burning coal

Coal; some woody fragments; partly covered

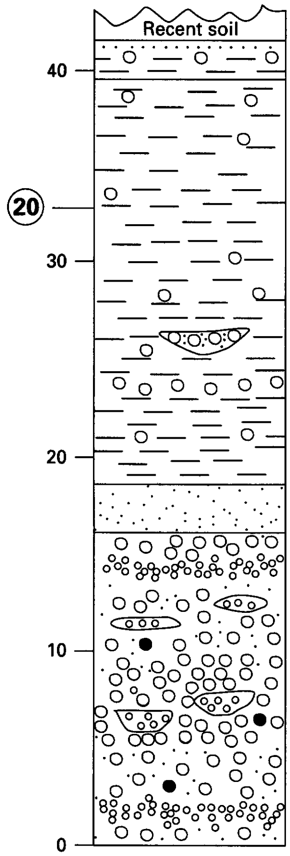
Mudstone, medium-grayish-brown, soft, crumbly; laminated or thin bedded at intervals; grades to fine-grained sandstone in places

Sandstone, medium-grayish-brown, soft, fine-grained, clayey; grades upward to siltstone and mudstone

Mudstone, medium-grayish-brown, silty, carbonaceous, faintly thin bedded to laminated; interbedded with soft fine-grained grayish-brown sandstone

Coal, black, hard, flaky; wood

Section 19. Beluga Formation on the north bank of the Beluga River at the confluence with Coffee Creek. SW¼ sec. T. 13 N., 7, R. 10 W., Seward Meridian



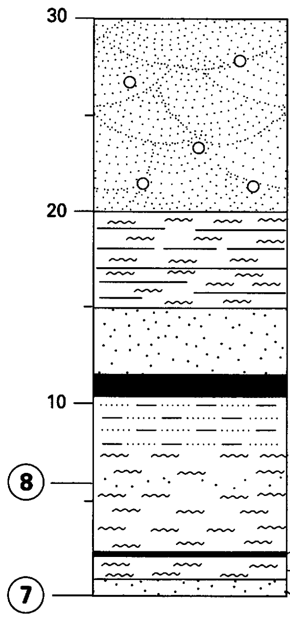
Claystone, brown to yellowish-brown, sandy; coal clasts, scattered pebbles, and granules; grades upward to sandstone

Claystone, dark-gray, conglomeratic, sandy; brown zones; vague horizontal bedding; granule filled channel

Sandstone, light- to medium-brown, medium-grained, very friable, oxidized

Conglomerate, light-gray to light-brown, laminated; pebbles 1–4 cm in diameter; granules 0.5–0.7 cm in diameter abundant; medium- to fine-grained matrix; beds 0.5–5.0 m thick; interbedded medium-grained sandstone lenses with pebble and granule laminations; clay galls and wood molds in clay and sandstone lenses; low-angle foresets; a few filled channels have low-angle foresets

Section 20. Beluga Formation. Along the Chuitna River 13.0 km upstream from its mouth. NE¼ sec. 22, T. 12 N., R. 11 W., Seward Meridian



Sandstone, brown, oxidized, fairly well sorted, crossbedded; some pebbles and small-scale contorted beds

Mudstone, light-brown; laminated with thin coal beds; poorly exposed

Sandstone, light-brown to gray; carbonaceous fragments and clayey coal beds at various horizons

Coal, black, flaky

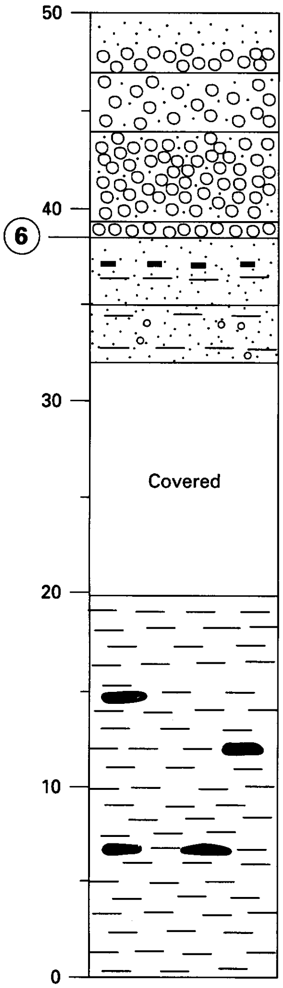
Mudstone, gray, laminated; thicker layers are oxidized brown on surface and drape over logs in coal below; grades upward to thin-bedded siltstone at top

Coal; fossil tree bark and partially carbonized wood

Mudstone, grayish-brown, dense, fairly hard; carbonized and partly carbonized wood fragments; some dark brown streaks

Sandstone, grayish-brown, coarse-grained, poorly sorted, thinly to irregularly bedded; oxidized horizons and varicolored grains

Section 21. Beluga Formation. On the south bank of the Chuitna River 8.0 km upstream from its mouth. SW1/4 sec. 20, T. 12 N., R. 11 W., Seward Meridian



Conglomerate, gray to brown; grain-supported, sandy matrix is more sandy upward; pebbles to cobbles, maximum clast size 2.0 cm

Conglomerate, gray to brown, sandy; interbedded with thin sandstone layers

Conglomerate, gray to brown, sandy; granules to pebbles, maximum clast size 1–3 cm; interbedded with medium-grained sandstone beds 10 cm thick; scattered igneous clasts as large as 10 cm

Conglomerate, gray to brown, sandy; granules to pebbles; grain-supported coarse-grained to very coarse grained sand matrix; coal seam 2 m thick

Sandstone, light-brown to brown; fines upward from fine-grained to very fine grained; oxidized reddish-brown lenses, bluish-gray clay beds, reddish-brown coaly laminations, and coal clasts

Sandstone, brown, fine- to medium-grained; sandstone beds 10–30 cm thick interbedded with bluish-gray clay beds 10 cm thick; igneous pebbles; zones of reddish-brown, oxidized pebbly sandstone

Claystone, light- to bluish-gray, shaly; irregular horizontal laminations; pods of coal 10–20 cm thick and 1–2 m wide; partly covered

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