STATE OF ALASKA

DEPARTMENT OF NATURAL RESOURCES

DIVISION OF GEOLOGICAL & GEOPHYSICAL SURVEYS

Tony Knowles, *Governor*

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Report of Investigations 98-12

GEOLOGY OF THE SLEETMUTE C-7, C-8, D-7, AND D-8 QUADRANGLES, HORN MOUNTAINS, SOUTHWESTERN ALASKA

by

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(in envelope)

GEOLOGY OF THE SLEETMUTE C-7, C-8, D-7, AND D-8 QUADRANGLES, HORN MOUNTAINS, SOUTHWESTERN ALASKA

by

T.K. Bundtzen,[1] E.E. Harris,[2] M.L. Miller,[3] P.W. Layer,[4] and G.M. Laird[5]

ABSTRACT

The Sleetmute C-7, C-8, D-7, and D-8 quadrangles cover a 2,089 km^2 area in the lower Kuskokwim River basin of southwestern Alaska. The area is characterized by accordant rounded ridges, averaging about 500 m in elevation; the rugged Horn Mountains, which reach a maximum 1,072 m above sea level; and broad, sediment-filled lowlands in the Kuskokwim, Holokuk, and Kolmakof River valleys that average about 100 m in elevation.

The study area is sparsely populated; only three permanent residents reside there today (1998). Land ownership is nearly equally divided among state, Native, and federal lands. Small, private cabin parcels occur at several sites along the Kuskokwim River and at the New York Creek placer gold and Kolmakof mercury mines.

Geologic units range in age from early Late Cretaceous to Holocene. The Kuskokwim Group consists of marine turbidites and shallow marine to nonmarine fluvial deposits that formed in a post-accretionary successor basin along what was then the southern margin of Alaska. The Kuskokwim Group, which is roughly estimated to be 2,200 m thick in the study area, contains Turonian to Santonian fossil assemblages (early Late to middle Late Cretaceous).

Intruding and overlying the Kuskokwim Group are: (1) the meta-aluminous Late Cretaceous to early Tertiary Iditarod Volcanics; (2) the meta-aluminous to slightly peraluminous Horn Mountains volcanic-plutonic complex; and (3) peraluminous granite porphyry dikes, sills, and small plutons Our geochemical and radiometric age data suggests that all igneous rocks are related to a 70 Ma, north-vergent, shallow-dipping subduction zone that was accompanied by an extensional, wrench-fault tectonic event.

Unconsolidated, late Tertiary to Holocene deposits blanket about 65 percent of the study area. Although much of the area has remained unglaciated, four Pleistocene glaciations and associated outwash deposits form a distinct radial pattern around the glacially carved Horn Mountains upland. Thermoluminescence data (from volcanic ash) and radiocarbon dating (from peat) suggest Illinoian (140,000 years B.P.) and Late Wisconsin (13,600 years B.P.) ages for the Bifurcation Creek and Tolstoi Lake glaciations, respectively, in the study area.

Bedrock units have been subjected to an early (Latest Cretaceous?) open to subisoclinal folding event and a later (early to middle Tertiary?) open folding event that structurally compressed the terrane. Subsequently, northeast-trending high-angle faults of unknown magnitude displaced both sedimentary and volcanic units and may have served as structural conduits for metallic mineralization.

Principal mineral deposits include: (1) mesothermal, boron-enriched, base precious metal mineralization hosted in high-level cupolas and hornfels of the Horn Mountains volcanic-plutonic complex; (2) mercury antimony (gold) lodes in peraluminous granite porphyry and altered mafic dikes; and (3) heavy mineral gold placers. Lode mineralization at the previously productive Kolmakof mercury and New York Creek gold deposits, which rank among the earliest known mineral discoveries in Alaska, probably formed in epithermal conditions. Known metallic mineralization conforms to mineral deposit models proposed by Bundtzen and Miller (1997) for many metallic mineral deposits found throughout the Kuskokwim mineral belt.

INTRODUCTION AND GEOGRAPHY

During the 1990, 1991, and 1992 field seasons, four 1:63,360-scale quadrangles were geologically mapped in the Sleetmute Quadrangle of southwestern Alaska (fig. 1). The 2,089 km^2 (816 mi^2) area consists of broad lowlands, which are filled with unconsolidated sediments, interspersed with rounded ridgelines and small mountain massifs. Relief ranges from 85 m (280 ft) along the Kuskokwim River to 1,072 m (3,515 ft) atop an unnamed peak in the Horn Mountains. Most of the streams and rivers in the study area empty into the Kuskokwim River, which flows through the southern part of the map area and is Alaska's second largest river drainage. In the northwestern part of the study area, the Iditarod River flows northeastward through the Sleetmute D-8 Quadrangle, and

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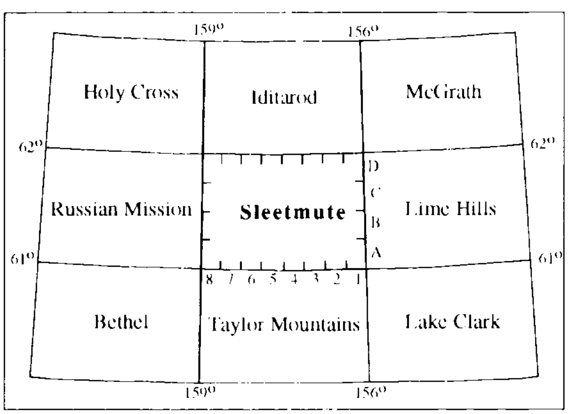
EXPLANATION

Geologic units

- Undifferentiated alluvial, colluvial, glacial, and eolian deposits (late Tertiary to Holocene).
- Intrusives peraluminous granite and small plutons of mafic and intermediate composition (Late Cretaceous and early Tertiary).
- Horn Moutains pluton granodiorite, and lesser amounts of quartz monzodiorite, quartz diorite, and granite (Late Cretaceous and early Tertiary).
- Hornfels (Late Cretaceous and early Tertiary).
- Horn Mountain Volcanic Field composition ranging from basaltic andesite to rhyolite (Late Cretaceous and early Tertiary).
- Iditarod Volcanics basalt, basaltic andesite, andesite, volcanic breccia, dacite tuff and sandstone (Late Cretaceous and early Tertiary).
- Kuskokwim Group marine turbidites and subordinate shallow water to nonmarine deposits (Cretaceous).

Symbols

- High angle fault dashed where concealed
- Anticline
- Syncline
- Overturned anticline
- Overturned syncline
- Mine or prospect locality (see table 7 and sheet 1)
- Settlement



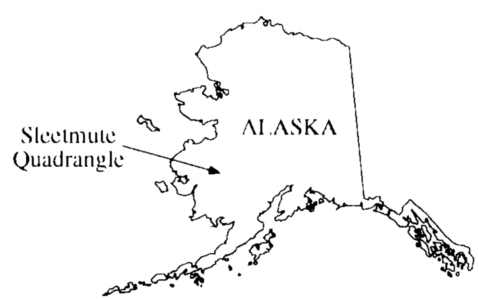
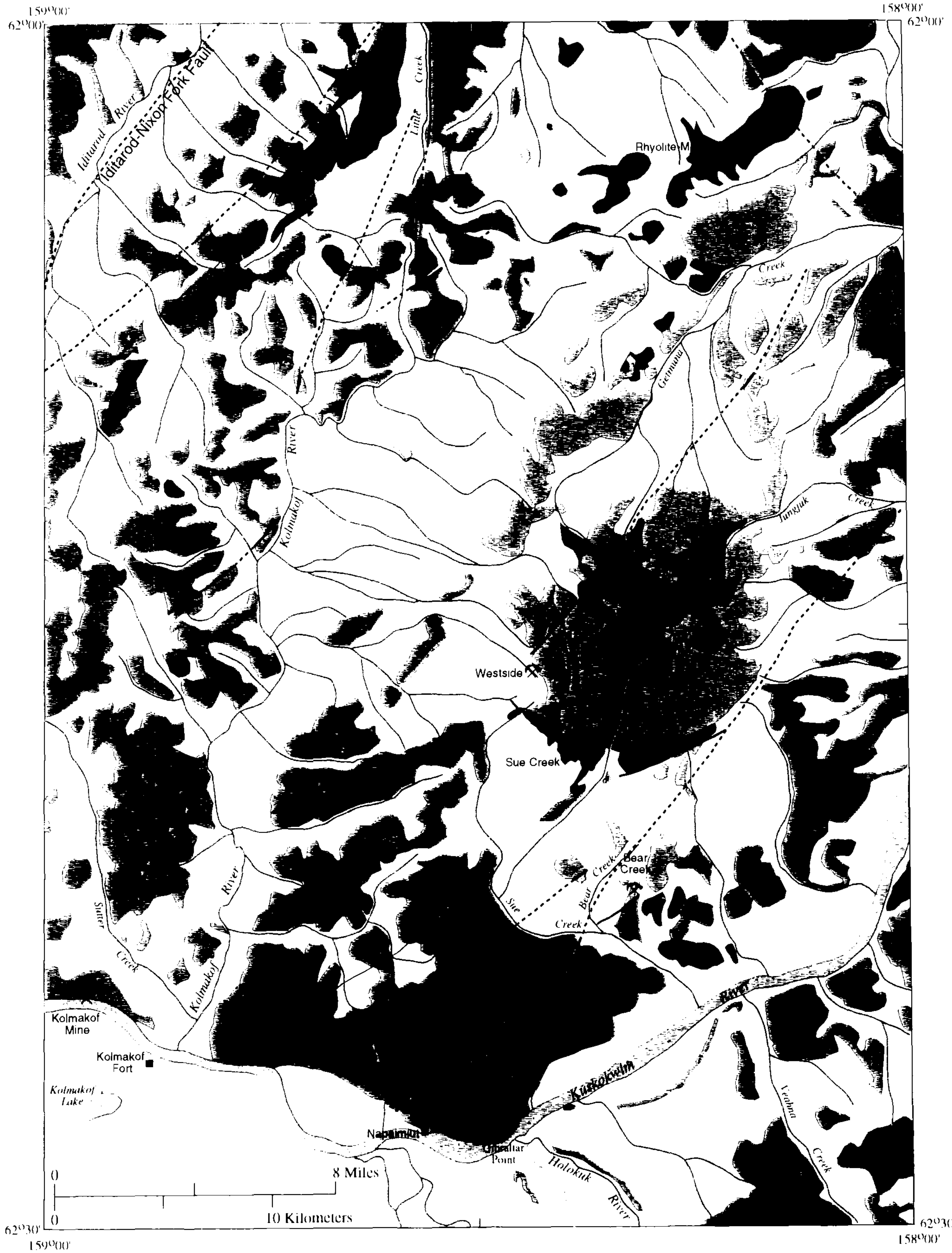


Figure 1. *Index map showing generalized geology, prospect localities, and location of the Sleetmute C-7, C-8, D-7, and D-8 quadrangles, southwestern Alaska.*



159°00'
62°00'
158°00'
62°00'
Iditarod River
Iditarod-Nixon Fork Fault
Little Creek
Rhyolite M
Creek
Getmuna
Kolmakof River
Junjuk Creek
Westside
Sue Creek
Bear Creek
Bear Creek
Sue Creek
Sutter Creek
River
Kolmakof
River
Kolmakof Mine
Kolmakof Fort
Kolmakof Lake
Kuskokwim
Napaimiut
Gibraltar Point
Holokuk River
Veahna Creek
0
8 Miles
0
10 Kilometers
62°30'
159°00'
62°30'
158°00'

eventually empties into the Innoko River and Yukon River drainage basins. Although much of the study area is unglaciated, the rugged Horn Mountains and adjacent lowlands experienced at least four separate Pleistocene glaciations.

The region is sparsely populated. Presently, three people reside at the old village of Napaimiut on the north shore of the Kuskokwim River (June McAtee, written commun., 1998). From 1990 to 1992, Morris and Mary Hofseth (both now deceased) lived in a cabin at the mouth of the Holokuk River. Seasonal residents have worked the Kolmakof mercury and New York Creek placer mines in previous years. The Kuskokwim River villages of Aniak and Crooked Creek both just outside the map area serve as the main logistical/supply centers for the study area.

Most of the fieldwork was conducted from several small spike camps in various locations within the study area, and with helicopter support in remote areas west and south of the Kolmakof and Iditarod rivers.

This detailed investigation is designed to interface with an ongoing U.S. Geological Survey (USGS) project begun in the late 1980s (Miller and others, 1989) that summarizes the geology and resource potential of the Sleetmute Quadrangle.

The results presented in this report consist of: (1) a summary text; (2) paleocurrent data (table 1); (3) major oxide and trace-element analyses of igneous rocks (table 2, in pocket; table 5); (4) $^{40}Ar/^{39}Ar$ and $^{40}K/^{40}Ar$ isotopic age determinations (tables 3 and 4); (5) $^{14}C/^{13}C$ age determinations (table 6); (6) geochemical determinations of mineralized zones (table 7, in pocket); and (7) a 1:63,360-scale geologic map (sheet 1, in pocket) accompanied by complete map unit descriptions (in text, p. 31-38).

GEOLOGIC UNITS

Geologic units in the study area are subdivided into four rock assemblages—all post-accretionary as defined by Plafker and Berg (1994): (1) Cretaceous flysch; (2) Upper Cretaceous mafic to felsic volcanic rocks; (3) Upper Cretaceous and lower Tertiary(?) intermediate to felsic plutonic rocks; and (4) widespread unconsolidated lithologies that range in age from late Tertiary through Quaternary. During discussion of these geologic units, the reader is referred to the geologic map (sheet 1) and explanation for more complete descriptions.

KUSKOKWIM GROUP

The major sedimentary rock units exposed in the study area belong to the marine turbidites and subordinate shallow water to nonmarine deposits of the Kuskokwim Group, which was first defined by Cady and others (1955). Regionally, the Kuskokwim Group consists of variable amounts of sandstone, shale, siltstone, and conglomerate that was deposited in a post-accretionary successor basin (Decker, 1984; Miller and Bundtzen, 1994).

The Kuskokwim Group has been subdivided into nine lithologic units (Ksq, Ksc, Kss, Kslt, Ksh, Kssf, Kssq, Kssp, Kus; sheet 1) that we interpret as turbidite fan, foreslope, shallow-marine, and possibly shoreline or nonmarine deposits formed in a marine regressive succession. The deepest water facies generally occur in the central part of the study area, and consist of limey sandstone and shale (Kslt), lithic sandstone and shale (Kss), coarse-grained sandstone and pebble conglomerate (Ksc), coarse-grained proximal turbiditic sandstone (Kssp), shale and siltstone (Ksh), and undifferentiated clastic rocks (Kus). These units exhibit graded Bouma facies Ta-e, flutes, shale ripups, and locally channel breccias that probably formed in a turbidite fan system. Different lithologic units have sand:shale ratios that range from 1:3 to 10:1, and exhibit variable sedimentary structures, both of which probably reflect different turbidite fan environments.

Nearly all of the sandstones from the deeper water facies contain metamorphic clasts, but many are also notably enriched in chert, meta(?) granitic, limestone, and volcanic lithic fragments suggesting variable source terranes (Miller and Bundtzen, 1994). The limestone may have been derived from the nearby Farewell terrane, whereas the distinctive chert fragments are probably derived from the Innoko terrane (Decker and others, 1994), which underlies the Kuskokwim Group in the Iditarod D-1 Quadrangle north of the study area (Bundtzen and Laird, 1983). Metamorphosed granitic clasts may be derived from the Lower Proterozoic Idono Complex, which crops out 70 km northeast of the study area (Miller and others, 1991).

Both upsection and to the northwest, Kuskokwim Group lithologies become progressively more quartz-rich toward the shoreline of the Kuskokwim Group basin (Miller and Bundtzen, 1994). Mapped units are clean, quartzose, sublithic sandstone and siliceous shale (Ksq) and finer-grained sublithic sandstone and shale (Kssq) that exhibit cross-stratified sands, finely laminated shales, local leaf-rich beds, rare bone coal, and coquina composed of brackish water brachiopods. Field relationships suggest that both the Kssq and Ksq represent shoreline sequences that successively overlap the deeper water deposits previously described.

An unusual unit (Kssf) composed of poorly consolidated, quartzite sandstone, shale, slump breccia, and bleached volcanic tuff(?) crops out in the Holokuk River canyon near the southeastern corner of the map area. The presence of bone coal, coupled with the lack of high-energy flow regime indicators and the siliceous composition of sediments, suggest that the Kssf unit formed in either shallow marine or nonmarine conditions. However, deep-water turbidite deposits (Kssp) apparently overlie (?) the shallow-water deposits of the Kssf unit (sheet 1). Hence we remain unsure of the specific facies relationships between these contrasting deep- and shallow-water deposits. In the absence of precise faunal collections and apparent interbedded nature between Kssf and the Ksh and Ksq units, we regard the Kssf unit as a part of the Kuskokwim Group, although it might be younger.

Limited paleocurrent data (table 1) from the Kuskokwim Group within the study area suggest easterly to southeasterly directions of sediment transport presumably from a shoreline somewhere to the west. This data is consistent with paleocurrent information and interpretations presented by Miller and Bundtzen (1994) from the Kuskokwim Group in the Iditarod Quadrangle to the north.

Cady and others (1955) originally reported that the Kuskokwim Group, based on measurements in the study area, was at least 12,000 m thick. Because of the presence of isoclinal folds, recumbent folds, and complicated fault history, we are unsure of a true thickness of the sedimentary section. Bundtzen and others (1992) and Miller and Bundtzen (1994) provide thickness estimates of 2,000 to 5,000 m for equivalent rocks elsewhere.

Table 1. *Paleocurrent data from Cretaceous Kuskokwim Group sedimentary rocks, Sleetmute C-7, C-8, D-7, and D-8 quadrangles, Alaska*

Map no.	Field no.	Paleocurrent Azimuth[a]	Azimuth mean	Flow regime and lithology
1	92BT100	128° 120° 150°	133°	Lower (cross beds in Kssq unit)
2	91BT27	170° 168° 149° 162°	162°	Upper (flute casts in Kssf unit)
3	91BT83	90° 110° 96°	99°	Upper (flute casts in Kus unit)
4	92BT89	72° 91° 60° 52° 84° 90°	75°	Upper and Lower Imbricate orientation of (*Inoceramus* shells and on flutes in Kssp unit)
5	91BT80	81° 84°	83°	Upper (flutes in Kssf Unit)
6	91BT81	148° 128° 104°	127°	Upper (flutes and load casts in Kssf unit)

[a]Corrected for tilt.

Regionally, the Kuskokwim Group contains Cenomanian to Early Santonian (early Late and middle Late Cretaceous) pelecypods (Box and Elder, 1992; Decker and others, 1994; Miller and Bundtzen, 1994). A death assemblage of *Inoceramus athabaskensis* and *I. nahwisi* from sand-silt layers in the Kssp unit at the base of Gibraltar Point (Cady and others, 1955) are Turonian or of early Late Cretaceous age.

IDITAROD VOLCANICS

Basalt, basaltic andesite, andesite, volcanic breccia, and dacite tuff and sandstone of the Iditarod Volcanics, as defined by Miller and Bundtzen (1988), conformably overlie the Kuskokwim Group in the northwest part of the map area. Three units were subdivided during our study: (1) agglomerate, chert, tuff, and sandstone (Kaci); (2) altered dacite tuffs, flows and sandstone (Kvti); and (3) basaltic andesite flows (TKvmi). The total thickness for the Iditarod Volcanics in the study area is estimated at 150 m. This compares to a thickness of about 500 m for the DeCourcy Mountain section and 600 m in the Beaver Mountain section, which are the type areas for the Iditarod Volcanics north of the study area (Miller and Bundtzen, 1988).

Ubiquitous alteration prevented any detailed analysis of the geochemical characteristics of the Iditarod Volcanics in the study area. In the DeCourcy Mountain area immediately to the northeast, the presence of columnar jointing, lahar deposits, and air-fall sequences clearly indicates a subaerial depositional environment for the Iditarod Volcanics (Miller and Bundtzen, 1988). Map distribution and contact relationships within the study area (sheet 1) offer some of the best evidence yet reported that the Iditarod Volcanics conformably overlie shallow water to nonmarine facies (Ksq, Kssq) of the Kuskokwim Group. The Iditarod Volcanics are exposed in the axis of a syncline that can be mapped for more than 40 km of strike length. Within this fold structure, interbeds of quartzose sands identical to the Kuskokwim Group (Kssq unit description) appear as interbeds within basal volcanic units of the Iditarod Volcanics (Kvti unit description).

The youngest faunal collections from the Kuskokwim Group in the study area and the nearby Iditarod

Quadrangle (Cady and others, 1955; Miller and Bundtzen, 1994) yield Coniacian (88–84 Ma) pelecypods; isotopic ages from the base of the Iditarod Volcanics range from 77 to 76 Ma (Miller and Bundtzen, 1988). However, the Kuskokwim Group does contain Santonian (81–76 Ma) pelecypod collections about 75 km southeast of the study area (Box and Elder, 1992); hence there may be only a minimal age break between the two rock successions. Miller and Bundtzen (1988) reported that the upper portion of the Iditarod Volcanics ranges in age from 62 to 58 Ma. We have no age control for any units of the Iditarod Volcanics in the study area.

HORN MOUNTAINS VOLCANIC FIELD

A 700-m-thick volcanic succession ranging in composition from basaltic andesite to rhyolite covers a 285 km^2 (178 mi^2), circular region centered on the Horn Mountains in the east-central part of the map area (sheet 1). This volcanic succession is herein referred to as the Horn Mountains Volcanic Field (HMVF) after rugged volcanic exposures in the Horn Mountains.

The 12 mappable units of the HMVF are subdivided into four informally named volcanic complexes (sheet 1; fig. 2).

Getmuna Caldera Complex

The base of the HMVF consists of coarse-grained vitric tuff (TKgrt), welded(?) vitric tuff (TKat), and potassium-enriched, andesite and latite tuffs (TKdt) that form a 170-m-thick section, which is best exposed on lower Getmuna Creek about 10 km north of the Horn Mountains. The presence of extensive, coarse-grained vitroclastic textures, welded(?) shards, explosive air-fall tuffs, and pyroclastic deposits in all units suggest that the Getmuna caldera complex represents the initial development of a volcanic caldera shortly after the exhumation of the Kuskokwim Group. The very coarse grained nature of vitric tuffs in the TKgrt unit might suggest formation proximal to a vent system.

Jungjuk Mafic Flow Complex

Overlying the pyroclastic tuff-dominated section of the Getmuna caldera complex is a 125-m-thick section of at least four individual basaltic andesite flows (TKvm), one flow unit of vitreous andesite (TKvv), two or three flow units of geode-rich basaltic andesite and agglomerate (TKgvm), and two flow units of porphyritic basaltic andesite and high potassium andesite (TKpvm). The Tkvm basaltic andesite flows are similar to mafic flows in the Iditarod Volcanics, but differ chiefly in degree of alteration, and contrasting stratigraphic positions.

The Jungjuk mafic flow complex is best exposed on a north-trending ridge north of upper Jungjuk Creek (sheet 1). The generally dark colored, massive, columnar-jointed flows of the Jungjuk mafic flow complex contrast with the lighter colored, friable, pyroclastic tuffs of the underlying Getmuna caldera complex. The appearance of the mafic flows marks a transition from explosive volcanic phases of the Getmuna caldera complex to a mafic and intermediate, flow-dominated, volcanic cycle.

Sue Creek Intermediate Tuff and Flow Sequence

The Jungjuk mafic flow complex rapidly grades upward into a 350-m-thick section of intermediate tuffs and flows, which consist of: (1) highly porphyritic andesite flows and tuff (TKvip); (2) latite and potassic andesite flows (TKvi); (3) nonporphyritic andesite flows (TKa); and (4) an interbedded latite to andesite flow and tuff section (Tkvit). The Sue Creek intermediate tuff and flow sequence is best exposed along rugged ridges northwest of Sue Creek, where it forms a nearly continuous, well-exposed section. The sequence is folded into a broad north-trending syncline. The Sue Creek intermediate flow-tuff sequence comprises more than 45 percent of the entire HMVF section. The appearance of air-fall tuffs and the transition to more intermediate compositions midway through the volcanic succession illustrates the general trend toward more siliceous compositions and air-fall dominance through time in the HMVF.

Kolmakof Air-Fall Tuff

The interbedded flows and tuffs of the HMVF are capped by a distinctive, 45-m-thick section of bleached, light gray to white, fine-grained air-fall tuffs of both intermediate and felsic composition (TKft). The Kolmakof air-fall tuff is best exposed in the axes of two synclines in the southeast and western Horn Mountains (sheet 1). The fine-grained air-fall sequences are interrupted by thin trachyte flows, which are the youngest flow units recognized in the HMVF. Hence, the Kolmakof air-fall tuff apparently represents the final, preserved phases of volcanic activity in the HMVF.

The circular ring structure exhibited by the aerial distribution of the HMVF, coupled with the recognition of local faulted contacts between volcanic and sedimentary rocks led Cady and others (1955) to suggest that the HMVF was a collapsed caldera active during latest Cretaceous time.

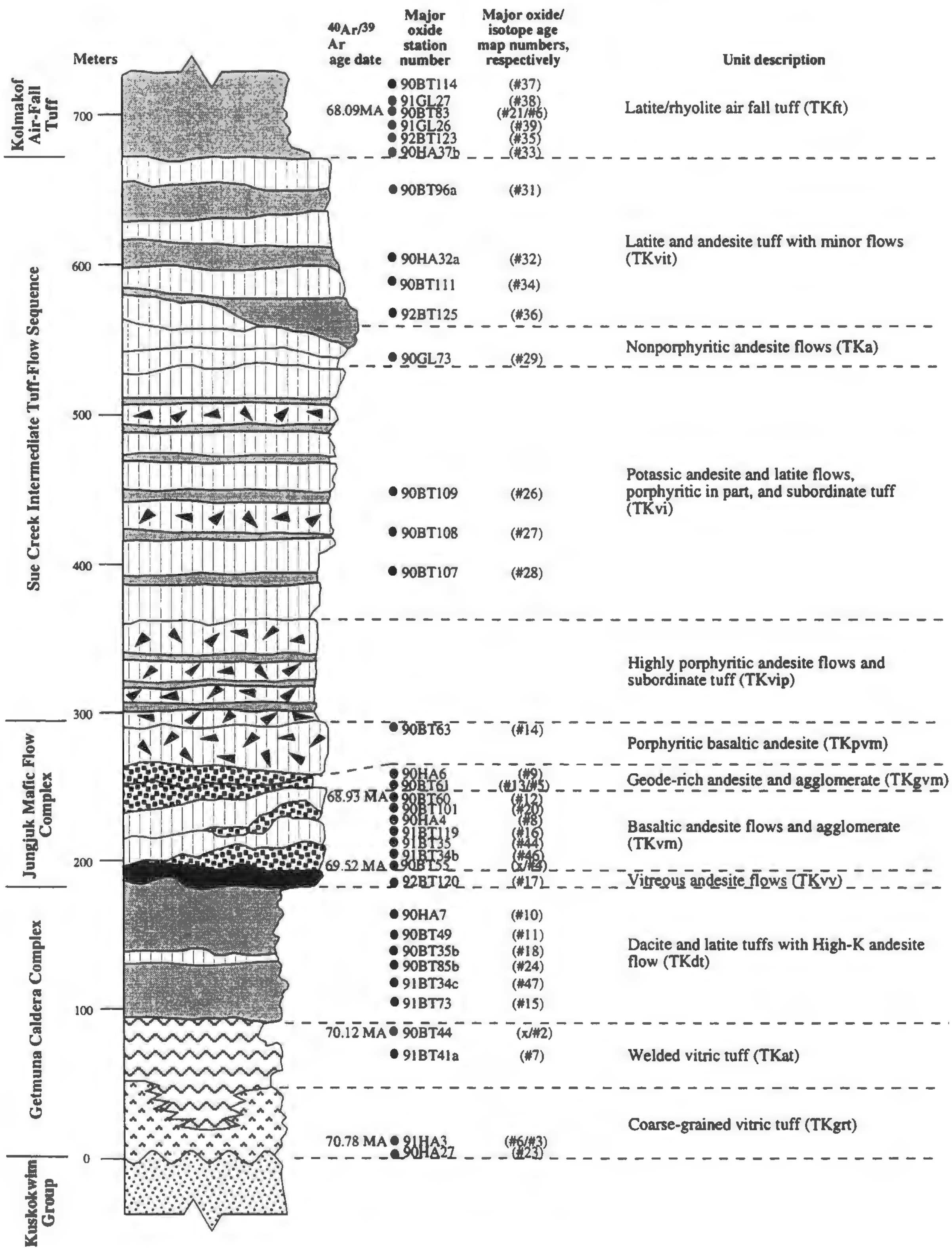


Figure 2. *Composite stratigraphic section of the Horn Mountains Volcanic Field (HMVF), Sleetmute Quadrangle, Alaska, showing stratigraphic positions of selected major oxide analyses (table 2) and radiometric age determinations (table 3). See sheet 1 for map number localities.*

INTRUSIVE ROCKS AND HORNFELS

Seven intrusive units and hornfels were subdivided during our work (sheet 1; table 2, in pocket). Granodiorite, minor granite, and rare quartz syenite (TKsy) and granodiorite porphyry, quartz syenite, and granite porphyry (TKsyp) comprise two mappable phases of the Horn Mountains pluton, which underlies and intrudes the Horn Mountains Volcanic Field. Porphyritic and equigranular phases of the Horn Mountains pluton contain altered biotite and clinopyroxene; hornblende is only rarely present. In addition, primary minerals in both mappable units (TKsy, TKsyp) are commonly altered to secondary minerals. Primary(?) tourmaline occurs in several localities of the TKsyp phase; Hietanen and Erd (1978) and Bundtzen and Laird (1991) both reported primary ferroaxinite grains in the groundmass of samples from the Russian Mountains pluton about 40 km west of the Horn Mountains. Hence, both plutons apparently have boron incorporated into their respective magmas. Compositional plots on a QAPF diagram (fig. 3) after Streckeisen and LeMaitre (1979) indicate that granodiorite and lesser amounts of quartz monzodiorite, quartz diorite, and granite predominate in the Horn Mountains pluton.

A 1-km-wide zone of biotite hornfels (TKhf) conspicuously rims the south flanks of the Horn Mountains pluton. Thermal effects of the pluton were also noted in adjacent volcanic rocks of the HMVF; however, they are not depicted as hornfels on the geologic map (sheet 1).

Small plutons of mafic and intermediate composition intrude the older layered rocks north and northwest of the Horn Mountains and in the southeast part of the map area (sheet 1). They consist of small diopside-rich, quartz monzodiorite to diabase intrusions (TKgd) near the head of Little Creek and east of the Holokuk River near Veahna Creek, and a clinopyroxene-rich gabbro to diorite plug (TKgb) just north of the Kuskokwim River and east of Sue Creek. Both of these intrusions plot in the quartz diorite field of a QAPF diagram (fig. 3). Small hornfels aureoles (TKhf) surrounding both intrusions suggest that the igneous bodies persist for some distance laterally and at depth.

Peraluminous granite and alaskite porphyry sills, stocks, and dikes (TKgp, TKgr) intrude the Kuskokwim Group throughout the study area. These bodies occur in three elongated, northeast-trending belts that intrude the Kuskokwim Group flysch. The largest granite porphyry complex, centered on Juninggulra Mountain, is 17 km long, 4 km wide, and trends northeastward to Donlin Creek (Miller and Bundtzen, 1994). Another pluton forms prominent outcrops on Aghaluk Mountain near the southeast corner of the map area. Small bodies intrude the Kuskokwim Group flysch at VABM Sue and along the

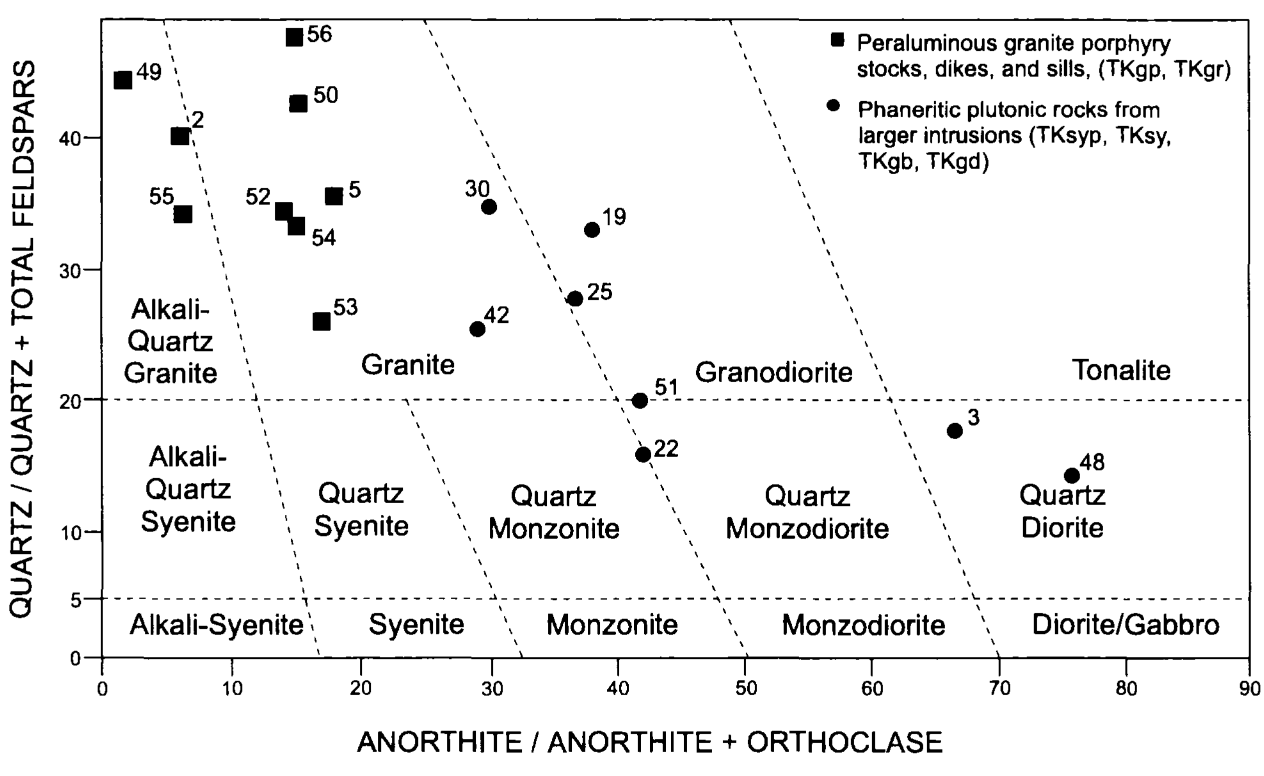


Figure 3. *Normative QAPF diagram, after Streckeisen and LeMaitre (1979), of 17 plutonic rocks from the Horn Mountains area, Sleetmute Quadrangle, Alaska. Symbols are keyed to map numbers on sheet 1 and refer to analyses in table 2.*

Kuskokwim River (sheet 1). Garnet phenocrysts have been found in all of the major peraluminous granite bodies (TKgp, TKgr), and all representative samples plot in the QAPF fields of granite and alkali quartz granite (table 2; fig. 3). Unlike the phaneritic intrusions in the study area (TKgb, TKgd, TKsy, TKsyp), the peraluminous intrusions rarely produce pronounced hornfels or recrystallization of host rocks. An exception is a small fault-bounded wedge of hornfels (TKhf) adjacent to a TKgp intrusion on the flanks of Aghaluk Mountain.

Isolated masses of hornfels (TKhf) ranging in size from 1 to 4 km^2 were mapped in various locations throughout the study area. Despite the lack of intrusive rock exposures, these thermally altered areas probably indicate that intrusive rocks occur at shallow depths beneath and adjacent to the TKhf hornfels masses.

Geochronology of Late Cretaceous–early Tertiary Igneous Rocks

Eight $^{40}Ar/^{39}Ar$ and one $^{40}K/^{40}Ar$ age determinations have been made on Late Cretaceous and early Tertiary igneous rocks in the study area (tables 3, 4; sheet 1). Five mineral and four whole rock analyses were obtained. All samples were analyzed in the UAF Geochronology Laboratory (see Solie and Layer, 1993, for description of analytical methods used). All ages were calculated using the constants of Steiger and Jaeger (1977) (table 4) and for the $^{40}Ar/^{39}Ar$ ages, the standard MMhb-1 with an age of 513.9 Ma

Table 3. *$^{40}Ar/^{39}Ar$ age determinations from selected igneous rocks in the Sleetmute C-7, C-8, D-7, and D-8 quadrangles, Alaska*[a] *(Localities shown with octagon on sheet 1.)*

Map no.	**1**	**1**	**2**	**3**
Sample no.	**90BT40**	**90BT40**	**90BT44**	**90HA3**
Rock type	**Granite Porphyry (TKgp)**	**Granite Porphyry (TKgp)**	**Vitric Tuff (TKat)**	**Coarse Vitric Tuff (TKgrt)**
Mineral dated	biotite	whole rock	biotite	biotite
Sample weight (g)	0.0703	0.2725	0.0777	0.0607
Number of fractions	9	9	9	10
Integrated age and 1s error (Ma)	69.46 ± 032	68.92 ± 0.26	69.37 ± 0.31	70.33 ± 0.57
K_2O(weight %)	7.4	4.3	7.0	7.0
CaO (weight %)	0.1	1.1	0.2	0.2
Plateau (p) or isochron (i) age and 1s error (Ma)	69.6 ± 0.3 (p)	68.7 ± 0.3 (p)	70.1 ± 0.3 (p)	70.8 ± 0.6 (p)
Initial $^{40}Ar/^{36}Ar$ and 1s error for isochrons	6	6	5	6
Map no.	**4**	**5**	**6**	**8**
Sample no.	**90BT55**	**90BT61**	**90BT83**	**90BT70**
Rock type	**Basaltic Andesite (TKvm)**	**Basaltic Andesite (TKgvm)**	**Andesite Tuff (TKft)**	**Granodiorite Porphyry (TKsyp)**
Mineral dated	whole rock	whole rock	whole rock	biotite
Sample weight (g)	0.2107	0.2264	0.2026	0.0656
Number of fractions	10	10	10	10
Integrated age and 1s error (Ma)	71.16 ± 0.35	70.89 ± 0.36	70.01 ± 0.35	68.79 ± 0.64
K_2O(weight %)	2.4	2.0	2.3	3.6
CaO (weight %)	5.3	5.2	4.5	3.6
Plateau (p) or isochron (i) age and 1s error (Ma)	69.5 ± 1.0 (i)	68.9 ± 0.5 (i)	68.1 ± 0.8 (i)	69.0 ± 0.6 (p)
Initial $^{40}Ar/^{36}Ar$ and 1s error for isochrons	307 ± 4	330 ± 7	372 ± 12	8

[a]Analyses by Dr. Paul Layer, 1991, DGGS-UAF Cooperative Geochronology Laboratory, Fairbanks, Alaska. Samples run against standards of Steiger and Jager (1977).

(Sampson and Alexander, 1987; Lanphere and others, 1990) was used to calculate the irradiation parameter.

Five stratigraphically consistent $^{40}Ar/^{39}Ar$ isotopic ages were determined from the span of the Horn Mountains Volcanic Field (sheet 1; table 3). About 2.7 +/-1.0 (1s) Ma separates the oldest, stratigraphically lowest volcanic unit (TKgrt, 70.8 Ma) from the youngest, stratigraphically highest unit (TKft, 68.1 Ma) of the HMVF. At a 95 percent confidence level, the minimum time for the duration of volcanism could be as short as 700,000 years and as long as 4.7 million years. We note that the effect of thermal overprinting from the Horn Mountains pluton may have reset the ages of the dated volcanic samples. However, we found no mineralogical evidence for thermal alteration in any of the analyzed samples. The 68.1 to 70.8 Ma age range from the HMVF compares favorably to an average age of 68.3 Ma from volcanic samples in volcanic-plutonic complexes of the Kuskokwim mineral belt (Bundtzen and Miller, 1997).

Three $^{40}Ar/^{39}Ar$ and one $^{40}K/^{40}Ar$ isotopic ages are available from plutonic rocks in the study area (tables 3, 4). A single radiometric age of 69.0 Ma was obtained from a TKsyp phase of the Horn Mountains pluton. This compares to a 67.7 Ma average age from 42 plutons in volcanic-plutonic complexes in the Kuskokwim mineral belt (Bundtzen and Miller, 1997).

Biotite and whole-rock $^{40}Ar/^{39}Ar$ ages of 69.6 and 68.7 Ma, respectively, were obtained from a granite porphyry sample on the south flank of Juninggulra Mountain (sheet 1; table 3). Bundtzen and Miller (1997) reported three $^{40}K/^{40}Ar$ ages from different portions of the Donlin dike swarm: (1) 65.3 Ma whole-rock minimum age; (2) 70.9 Ma from white mica; and (3) 69.5 Ma from biotite. The Donlin dike swarm, which contains plutonic rocks of felsic and intermediate composition, is on strike with the Juninggulra granite porphyry complex to the northeast. A $^{40}K/^{40}Ar$ biotite age of 72.0 Ma was obtained from a granite porphyry sill along the south flank of the Kuskokwim River near the southeastern map border (table 4; sheet 1). Overall the granite porphyry radiometric ages in the study area compare well with an average age of 67.5 Ma from 23 peraluminous granite porphyry complexes throughout the Kuskokwim mineral belt.

Table 4. *$^{40}K/^{40}Ar$ determination from granite peraluminous porphyry sill, Sleetmute C-7 Quadrangle, Alaska[a] (Locality shown with octagon on sheet 1.)*

Map no.	12
Sample no.	87MDT25
Rock type	granite porphyry(TKgr)
Mineral dated	biotite
Sample weight (g)	0.1144
K_2O (weight %)	8.822
^{40}Ar (10^{-11} mol/g)	93.2541
^{40}Ar(%)	49.73
$^{40}Ar/^{40}K \times 10^{-3}$	4.2667
Age (ma)[b]	71.98 ± 2.16

[a]Analyses by Robin Cottrell and Donald L. Turner, 1988, DGGS-UAF Cooperative Geochronology Laboratory, Fairbanks, Alaska.
[b]Constants used in age calculations

$\lambda_e = 0.581 \times 10\text{-}10\ yr^{-1}$

$\lambda_b = 4.962 \times 10\text{-}10\ yr^{-1}$

$^{40}K/K_{total} = 1.167 \times 10^{-4}$ mol/mol

Petrogenesis of Late Cretaceous–early Tertiary Igneous Rocks

Although the volcanic and plutonic rocks of Late Cretaceous and early Tertiary age in the study area exhibit textural and geochemical variances, most are probably genetically related and share a common origin. The Horn Mountains Volcanic Field (HMVF) (SiO_2=54.00–75.00 percent) flanks and overlies a granodiorite to granite pluton (SiO_2=64.25–67.70 percent). The Getmuna caldera complex and Jungjuk mafic flow complex are slightly older than the pluton; however, the Kolmakof air-fall tuff—the highest stratigraphically dated part of the HMVF—is slightly younger than the nearby pluton. Hence both volcanic and plutonic rocks probably constitute a comagmatic volcanic-plutonic complex of the Kuskokwim Mountains type (Bundtzen and Miller, 1997).

When plotted on a K_2O-SiO_2 compositional diagram of McBirney (1984), samples from the HMVF range from basalt to rhyolite (fig. 4). Welded and vitric tuffs from the Getmuna caldera complex (TKgrt, TKat, TKdt; fig. 2, table 2) plot in the rhyolite field. Most samples from the Jungjuk mafic and intermediate flow complex (TKvv, TKvm, TKgvm; fig. 2) plot in the basalt and andesite fields, whereas many intermediate volcanics from the Sue Creek flow-tuff complex and Kolmakof air-fall tuff (TKvi, TKa, TKvit, TKft; fig. 2) plot in the fields of high-K andesite, latite, and uncommonly, banakite (fig. 4). These intermediate volcanics exhibit potassium-enriched geochemistry similar to that reported in the nearby Russian Mountains (Bundtzen and Laird, 1991) and elsewhere in the Kuskokwim mineral belt (Miller and Bundtzen, 1994; Moll-Stalcup, 1994; Bergman and others, 1987).

A plot of chondrite-normalized rare earth element (REE) concentrations of volcanic and plutonic rocks from the study area (fig. 5; table 5) show trends typical of igneous rocks formed in upper continental crust (Rollinson, 1993, p. 142–144). A weak europium (Eu) anomaly is expressed in only three samples; the remaining seven have no Eu depletion. The samples are enriched in light REE elements and depleted in heavy REE elements. Moll-Stalcup (1994), Szumigala (1995), and Bundtzen and others

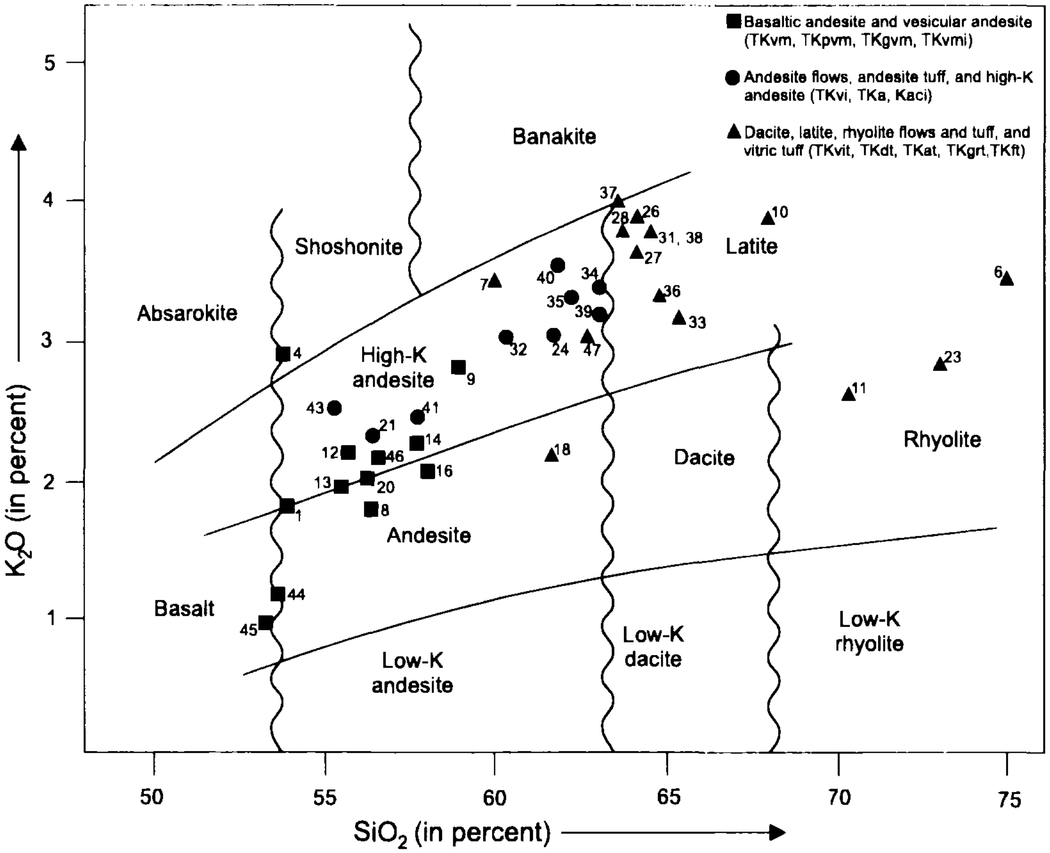


Figure 4. *Plot of selected volcanic rocks from the Horn Mountains Volcanic Field and the Iditarod volcanics on K_2O-SiO_2 compositional diagram as advocated by McBirney (1984). Symbols are keyed to map numbers on sheet 1 and refer to analyses in table 2.*

(1992) have reported similar data from volcanic and plutonic rocks elsewhere in the Kuskokwim mineral belt.

The alumina content of volcanic and plutonic rocks in the study area is graphically illustrated on a molecular alumina/calcium+sodium+potassium (A/CNK) versus SiO_2 diagram (fig. 6). According to Keith (1991a), this diagram not only illustrates alumina content, but also removes the effects of subtle spilitic, phyllic, argillic, and sericitic alteration, which can be widespread in volcanic and plutonic rocks. Ten (or 17 percent) of the volcanic and plutonic samples from the study area plot in altered fields while 47 (or 83 percent) of the samples fall in the unaltered field (fig. 6). The majority of samples from the HMVF and Iditarod Volcanics are metaluminous to weakly peraluminous. Phaneritic plutonic rocks (8 samples) are both metaluminous and peraluminous; however, if altered samples are removed, then five of six phaneritic, plutonic samples plot in the metaluminous field. All samples from the granite porphyry suite are weakly to strongly peraluminous; in fact, they all fall within the field of world-wide peraluminous granites (Keith, 1991b).

Interpretation of the tectonic setting for emplacement of Late Cretaceous–early Tertiary igneous rocks in the study area is attempted using various trace-element diagrams as advocated by Pearce and others (1984), Pearce and Norry (1979), and Pearce (1983). Many, though not all, andesite and basaltic andesite samples from the HMVF and Iditarod Volcanics that are plotted on Zr/Y-Zr logarithmic diagrams (figs. 7a, 7b) fall within 'continental arc' and 'within-plate' fields (Pearce and Norry, 1979; Pearce, 1983). This implies that the HMVF and Iditarod Volcanics probably formed well back from an ancestral continental margin subduction zone and probably in an in-board position.

Granitic rocks from the study area that are plotted on logarithmic Y-Nb (fig. 8) and Rb/Y+Nb (fig. 9) diagrams yield a somewhat more complicated picture. In the former diagram, the plutonic rocks fall within a combined field of both 'volcanic arc' and 'syn-collisional' granites. In the latter diagram, plutonic rocks fall mainly within the combined fields of 'volcanic arc' and 'syn-collisional' granites. In both diagrams, one sample of the Horn Mountains pluton (map no. 42, table 2) falls in the 'within-plate' field.

Overall, we believe that the major oxide and trace-element data show that the Late Cretaceous–early Tertiary rocks of the study area and others in the Kuskokwim mineral melt (KMB) formed as the result of continental margin

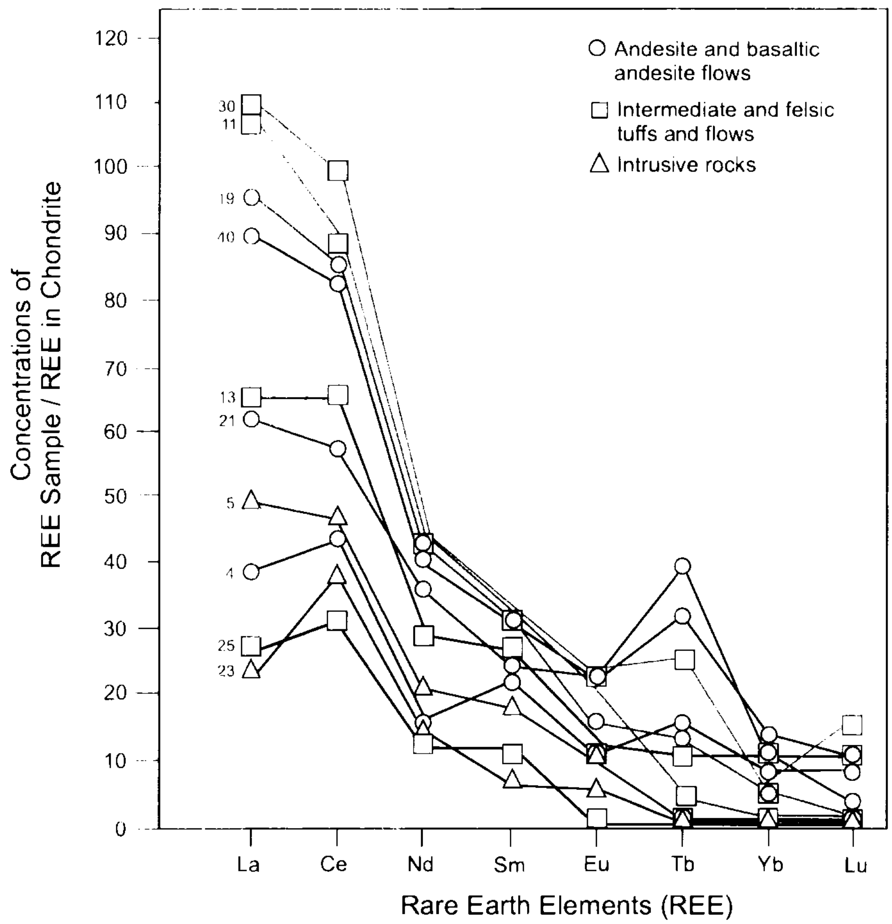


Figure 5. *Plot of chondrite-normalized rare-earth element (REE) concentrations (spider diagram) of volcanic and plutonic rocks from the Horn Mountains volcanic-plutonic complex, Horn Mountains area, Sleetmute Quadrangle, Alaska. Chondrite values from Taylor and McLennan (1985). Symbols are keyed to map numbers on sheet 1 and refer to analyses in tables 2 and 5.*

subduction—and probably in a back arc, extensional-related position considerably inboard from the subduction zone (Miller and Bundtzen, 1994; Bundtzen and Miller, 1997). The strong 'within-plate' signature of the HMVF and Iditarod Volcanics (fig. 7a), coupled with volcanic arc signatures from the granitic rocks of the study area (figs. 8, 9), lend evidence to this interpretation. Initial strontium ratios reported by Bundtzen and Miller (1997) indicate that volcanic and metaluminous plutonic rocks of the Kuskokwim mineral belt were likely derived from the mantle with some degree of crustal contamination. In contrast, the peraluminous granite porphyry suite (TKgr and TKgp in study area) may be a product of crustal melting perhaps generated by high heat flow from the volcanic-plutonic complexes (i.e., the Horn Mountains complex). The strong syn-collisional and volcanic arc granite signatures exhibited by the peraluminous granite porphyry suite of the study area (fig. 8) would also be consistent with this latter interpretation.

Moll-Stalcup and Arth (1991) believed that comagmatic, volcanic, and plutonic rocks in the Blackburn Hills, which constitute another Kuskokwim mineral belt volcanic-plutonic complex, are an example of continental arc magmatism produced from mixed subduction sources. The Blackburn Hills Sr Nd data plots in fields defined by magmatic arc rocks extensively studied in the Chilean

Table 5. *Rare Earth Element (REE) and U and Th determinations[a] from selected igneous rocks in Sleetmute C-7, C-8, D-7, and D-8 quadrangles, Alaska (all values in ppm)*

Map no.	**4**	**5**	**11**	**13**	**19**
Field no.	**90GL31**	**90BT40**	**90BT49**	**90BT61**	**90BT81**
Rock type	**Basaltic Andesite (TKvm)**	**Granite Porphyry (TKgp)**	**Latite (TKdt)**	**Basaltic Andesite (TKgvm)**	**Granodiorite (TKsy)**
Ce	40.2	44.0	86.0	62.0	82.0
Eu	1.0	1.0	2.0	1.0	1.5
La	14.0	18.0	39.0	24.0	35.0
Lu	0.3	ND	0.1	0.4	0.2
Nd	10.0	15.0	30.0	20.0	30.0
Sm	4.4	4.5	6.5	5.8	6.4
Tb	0.9	ND	0.2	0.7	0.8
Th	2.0	8.0	10.0	6.0	11.0
U	1.0	3.0	2.0	3.0	3.0
Yb	2.1	ND	0.8	2.6	1.3

Map no.	**21**	**23**	**25**	**30**	**40**
Field no.	**90BT83**	**90HA27**	**90BT121**	**90BT93**	**90BT115**
Rocky type	**Latite Tuff (TKft)**	**Vitric Lithic Tuff (TKgrt)**	**Granodiorite Porphyry (TKsyp)**	**Granodiorite (TKsy)**	**Andesite (TKvit)**
Ce	56.0	36.0	30.0	94.0	80.0
Eu	2.0	0.5	ND	2.0	2.0
La	23.0	15.0	9.0	40.0	32.0
Lu	0.4	ND	0.1	0.6	0.1
Nd	25.0	10.0	10.0	30.0	30.0
Sm	5.3	2.3	2.4	6.3	6.5
Tb	2.3	ND	ND	1.5	2.0
Th	8.0	4.0	4.0	12.0	10.0
U	3.0	2.0	ND	2.0	4.0
Yb	3.0	0.1	0.8	1.6	2.9

[a]Analyses by W.G. Armanin, Chemex Labs Ltd., Sparks, Nevada, using induced nuclear activation techniques.

Andes. These magmatic arc signatures are consistent with previously postulated magmatic arc signatures proposed for the KMB by Bundtzen and Miller (1997).

Major oxide data from 13 intrusive samples in the study area were plotted on an alkalinity versus ferric/ferrous oxide ratio diagram (fig. 10) as advocated by Leveille and others (1988). Plutonic oxidation state is determined by the whole-rock Fe_2O_3/FeO ratio, which is an approximation of oxygen fugacity. Leveille and others (1988) argued that magnetite-rich magmas result in a decrease in gold concentration in residual liquids during magmatic differentiation. Hence, gold concentrations are favored in reduced or 'Ilmenite series' (I type) granitic rocks. Figure 10 shows that the phaneritic plutonic rocks from the study area fall in the gold-favorable (reduced) field; however, samples from the peraluminous granite porphyry suite plot in the gold-unfavorable (oxidized) field. This latter suite includes samples from the Juninggulra Mountain area, which is a southwest extension of the gold-bearing Donlin Creek dike swarm (Bundtzen and Miller, 1997). Leveille and others (1988) determined that whole-rock analyses from gold-bearing, base-metal porphyry systems did not always plot in the gold-favorable (reduced) field; they concluded that pervasive, sometimes subtle alteration effects generated during formation of porphyry systems results in secondary oxidation effects in an originally reduced magma series. This may be the case for predicting gold favorability in the peraluminous granite porphyry suite in the study area.

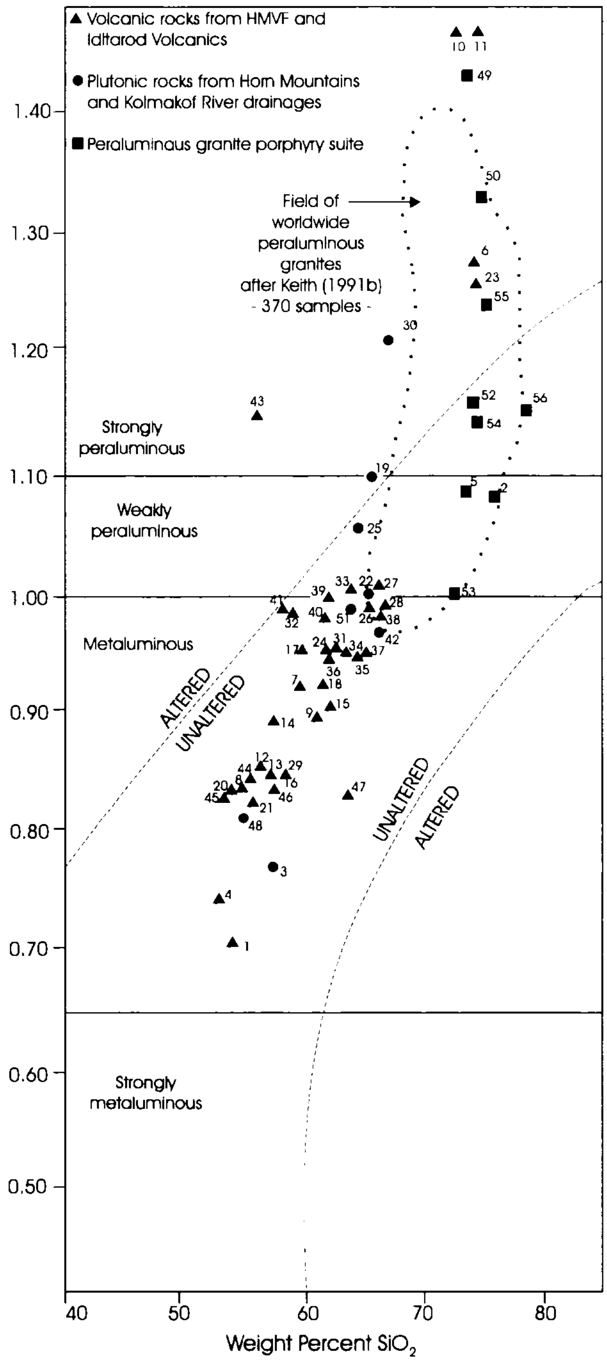
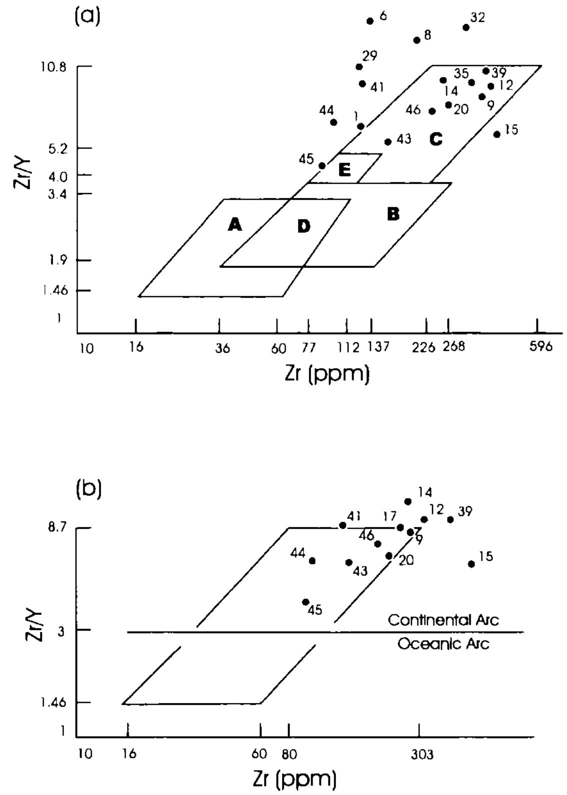


Figure 6. *Molecular $Al_2O_3/CaO+Na_2O+K_2O$ (A/CNK ratio) versus SiO_2 variation diagram for plutonic and volcanic rocks in the Horn Mountains area, Sleetmute Quadrangle, Alaska. Fields of alumina content and alteration are those advocated by Keith (1991a). Symbols are keyed to map numbers on sheet 1 and refer to analyses in table 2.*



Figures 7a, 7b. *Plots of selected andesite and basaltic andesite samples from Horn Mountains volcanic-plutonic complex and Iditarod Volcanics on Zr/Y–Zr logarithmic variation diagrams; (a) Fields of tectonic settings shown as: A–Volcanic arc; B–Mid ocean ridge basalts (MORB); C–Within plate; D–MORB and volcanic arc; and E–MORB and within plate (Pearce and Norry, 1979). (b) Fields of continental and oceanic volcanics as determined by Pearce and Norry (1979) and Pearce (1983). Plots are keyed to map numbers on sheet 1 and refer to analyses in table 2.*

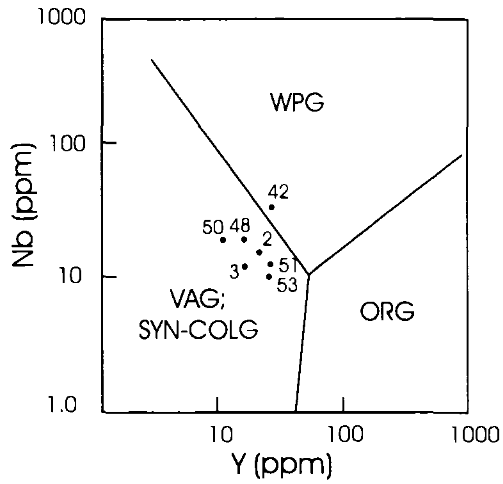


Figure 8. *Plot of selected granitic rocks from the Horn Mountains area, Sleetmute Quadrangle, Alaska, on logarithmic Y–Nb diagram after Pearce and others (1984) showing fields of volcanic arc granites (VAG), syn-collisional granites (SYN-COLG), oceanic ridge granites (ORG), and within-plate granites (WPG). Symbols are keyed to map numbers on sheet 1 and refer to analyses in table 2.*

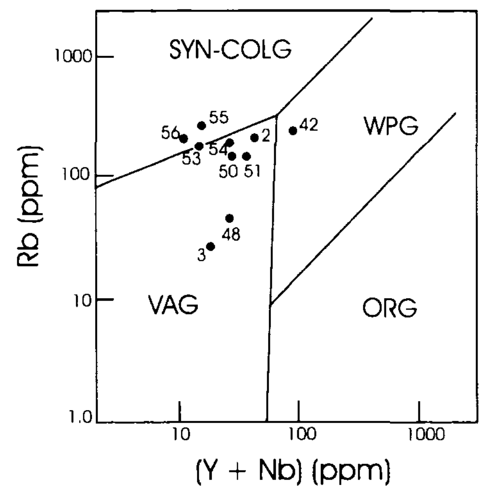


Figure 9. *Plot of granitic rocks from the Horn Mountains area, Sleetmute Quadrangle, Alaska, on logarithmic Rb–(Y+Nb) diagram after Pearce and others (1984) showing fields of volcanic arc granites (VAG), syn-collisional granites (SYN-COLG), oceanic ridge granites (ORG), and within-plate granites (WPG). Symbols are keyed to map numbers on sheet 1 and refer to analyses in table 2.*

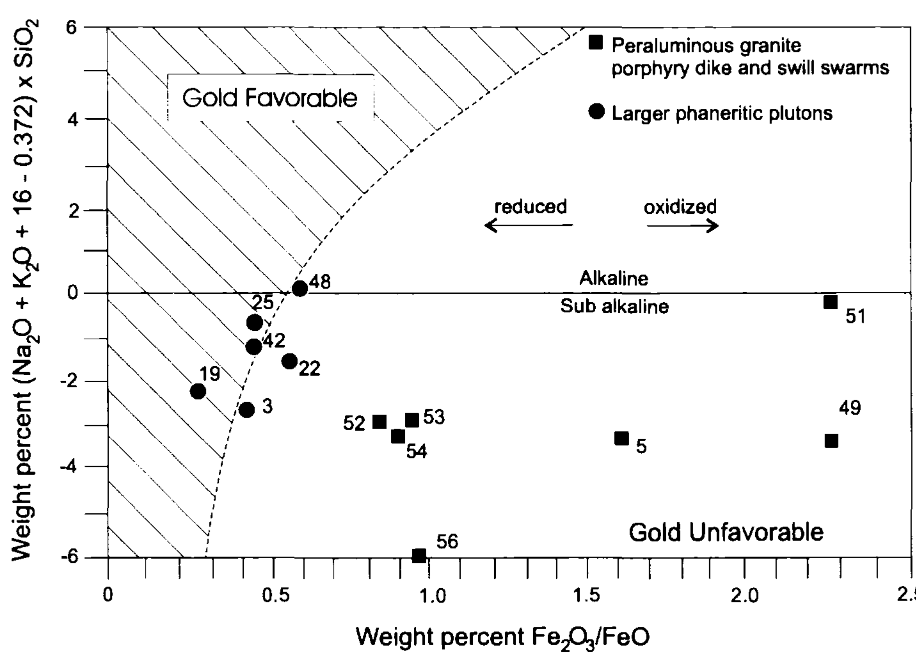


Figure 10. *Plot of gold favorability utilizing alkalinity versus ferric/ferrous oxide ratio, as advocated by Leveille and others (1988), from 13 plutonic samples in the Horn Mountains area, Sleetmute Quadrangle, Alaska. Symbols are keyed to map numbers on sheet 1 and refer to analyses in table 2.*

UNCONSOLIDATED DEPOSITS

A wide variety of unconsolidated deposits ranging in age from late Tertiary to Holocene cover about 55 percent of the map area. We have subdivided these into 24 alluvial, glacial, colluvial, and eluvial units (sheet 1).

Glaciogenic Deposits

Glacial till (Qgt_{1-4}), rock glacier (Qrg), and associated glacial outwash (Qor, Qof, Qog) form areally extensive and locally thickened unconsolidated deposits in the region. The glacial till is mainly confined to river valleys and cirques in the immediate vicinity of the Horn Mountains, the point of origin of the glaciers that produced these deposits. At least four (4) ages of glacial deposits can be inferred, and are graphically represented on figure 11.

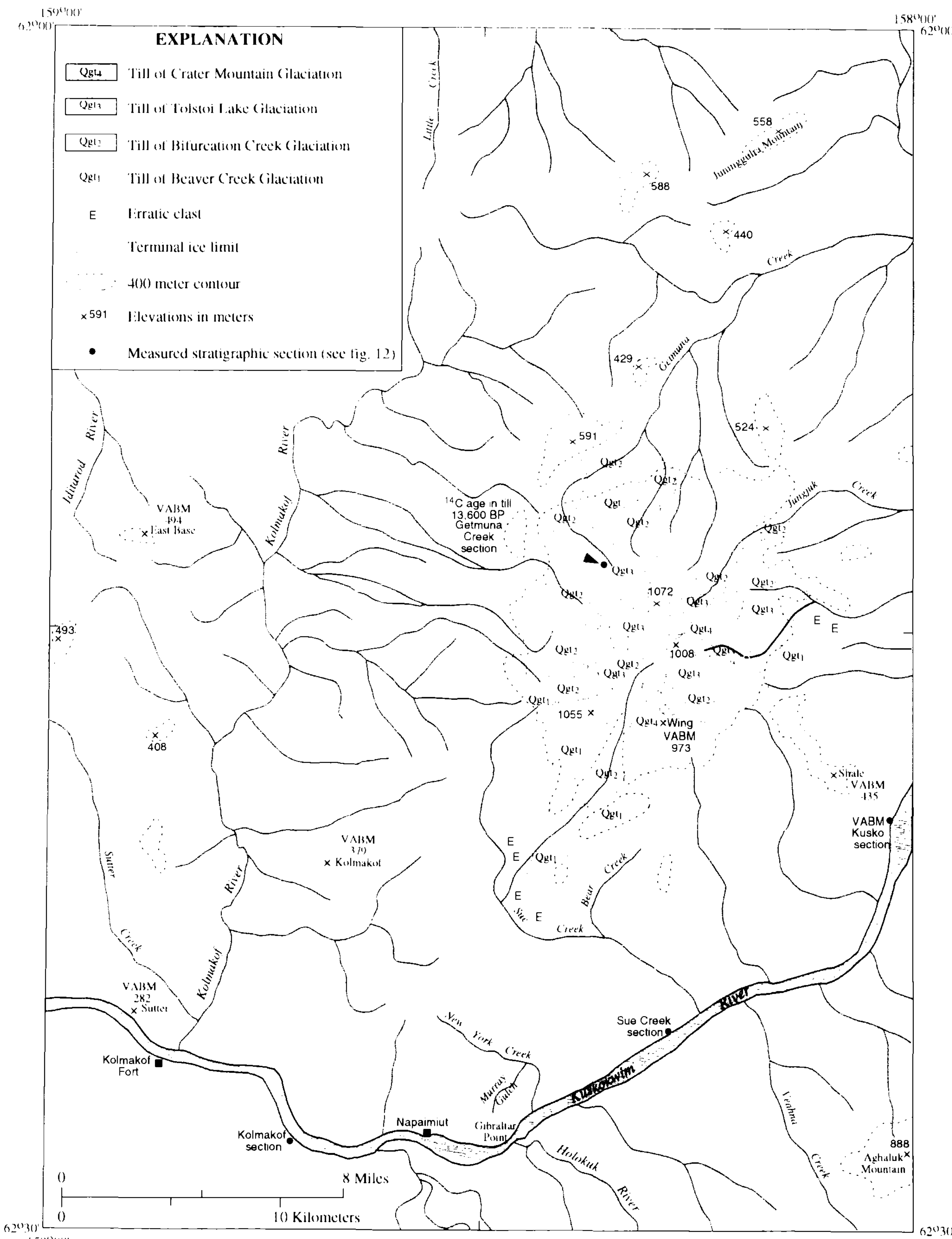
The oldest till (Qgt_1) consists of isolated patches of diamicton on planated summits outboard from the Horn Mountains at about 420 m elevation (fig. 11; sheet 1). Isolated plutonic erratics on these surfaces are probably relict from completely eroded Qgt_1 till deposits. Erosion and dissection of unit Qgt_1 has completely removed morphological characteristics of a former morainal topography. Judging from the widespread, fan-like distribution of Qgt_1 deposits, the Horn Mountains may have supported a small 275 km^2 ice cap when the Qgt_1 glaciers were active. The Qgt_1 till is probably equivalent to the pre-Wisconsin—probably pre-Illinoian—Beaver Creek Glaciation in the northern Iditarod Quadrangle (Kline and Bundtzen, 1986) or the Oskawalik Creek glacial interval in the Chuilnuk and Kiokluk Mountains of the south-central Sleetmute Quadrangle about 65 km southeast of the study area (Waythomas, 1990).

The next oldest till (Qgt_2) consists of at least two ages of dissected, terminal, and recessional moraines in most valleys radially draining the Horn Mountains (fig. 11; sheet 1). Trunk glaciers traveled down Getmuna and Whitewing creeks a maximum of about 16 and 13 km, respectively, and 4 to 8 km in other drainages, most notably Jungjuk Creek, and small, unnamed, eastern tributaries of the Kolmakof River. During this glacial event, about 20 cirques throughout the Horn Mountains were occupied by ice. During the Qgt_2 glacial interval, valley aspect did not influence the extent of glaciation, and major trunk glaciers radiated from the Horn Mountains in all directions. Qgt_2 till is very similar to deposits of the Bifurcation Creek Glaciation in the Beaver Mountains of the northern Iditarod Quadrangle (Kline and Bundtzen, 1986), and the Chuilnuk Glacial interval in the Chuilnuk and Kiokluk Mountains southeast of the study area (Waythomas, 1990). Kline and Bundtzen (1986) considered Bifurcation Creek deposits to be of early Wisconsin age; whereas Waythomas (1990) believed the Chuilnuk Glacial Interval might be pre-Wisconsin in age, citing a lack of glacial-related, eolian sedimentation of Early Wisconsin age in the adjacent Holitna lowland.

Younger Qgt_3 deposits formed in sharply defined, steeply fronted terminal and recessional moraines of at least three ages in the Horn Mountains. Although Qgt_3 deposits occur in most Horn Mountains valleys, well-developed valley glaciation is expressed only in Getmuna Creek, where trunk glaciers advanced down-valley a maximum of about 5 km. During the Qgt_3 glacial interval, ice occupied 14 north-oriented cirques, but was essentially absent in south-oriented cirques and valley fills (fig. 11; sheet 1). Important radiometric age control was obtained during our investigations that help refine the age of Qgt_3 drift (figs. 11, 12; table 6). A radiocarbon age of 13,600 years B.P. was obtained from a thin peat layer at about 2.0 m depth in till on Getmuna Creek near the youngest Qgt_3 morainal advance. This age is almost identical to radiocarbon dates obtained from the Bootlegger Cove Clay, which was laid down during the Woronzofian transgression at the same time of the deposition of the Elmendorf drift near Anchorage, Alaska (Schmoll and others, 1972). Such data strengthens the Late Wisconsin age estimates for other similar drift units in the Kuskokwim Mountains—notably those of the Tolstoi Lake Glaciation in the northern Iditarod Quadrangle (Kline and Bundtzen, 1986) and the Buckstock Glacial Interval in the Kiokluk and Chuilnuk Mountains southeast of the study area (Waythomas, 1990).

The youngest glaciation in the study area (Qgt_4) appears as three small, high-level cirques at about 700 m elevation, about 90 m above the average elevation of the older Qgt_3 and Qgt_2 cirque basins. The Qgt_4 deposits are fresh and not dissected, but no radiometric age control is available. Kline and Bundtzen (1986) suggested that similar cirque development in the Beaver Mountains occurred during the early(?) Holocene Crater Mountain Glaciation, citing active rock glacier development and a single radiocarbon age of 7,660 years B.P. (Beta no. 11,889) in peat-bearing sandy diamicton and fluvial sand found directly downstream from a cirque of Crater Mountain age. Waythomas (1990) described two additional glacial events in the Chuilnuk and Kiokluk Mountains southeast of the Horn Mountains. He believed that many cirque basins upvalley from Buckstock-age moraines were reactivated during early Holocene time. In addition, a double-crested, high-level cirque in the Kiokluk Mountains, referred to as the Kiokluk Peak advance, may have formed during a late Holocene climatic cooling, which has been documented in cirques throughout Alaska (Calkin, 1988).

Figure 11 (right). *Map showing extent of Quaternary glacial advances and locations of measured sections in Horn Mountains area, Sleetmute Quadrangle, Alaska. Glacial nomenclature after Kline and Bundtzen (1986).*


EXPLANATION
Qgt4 Till of Crater Mountain Glaciation
Qgt3 Till of Tolstoi Lake Glaciation
Qgt2 Till of Bifurcation Creek Glaciation
Qgt1 Till of Beaver Creek Glaciation
E Erratic clast
Terminal ice limit
400 meter contour
×591 Elevations in meters
● Measured stratigraphic section (see fig. 12)
159°00'
62°00'
158°00'
62°00'
62°30'
159°00'
62°30'
158°00'
Little Creek
558
Junnggultz Mountain
588
440
Creek
429
Getmuna
591
524
Iditarod River
Kolmakof River
VABM 494 East Base
14C age in till 13,600 BP Getmuna Creek section
Junjuk
Creek
1072
1008
1055
Wing VABM 973
493
408
Shale VABM 435
VABM Kusko section
Sutter
Creek
River
VABM 379 Kolmakof
Bear Creek
Sue Creek
VABM 282 Sutter
Kolmakof
Kolmakof Fort
Kolmakof section
New York Creek
Murray Gulch
Napaimiut
Gibraltar Point
Sue Creek section
Kuskokwim River
Holokuk River
Veahna Creek
888 Aghaluk Mountain
0 8 Miles
0 10 Kilometers

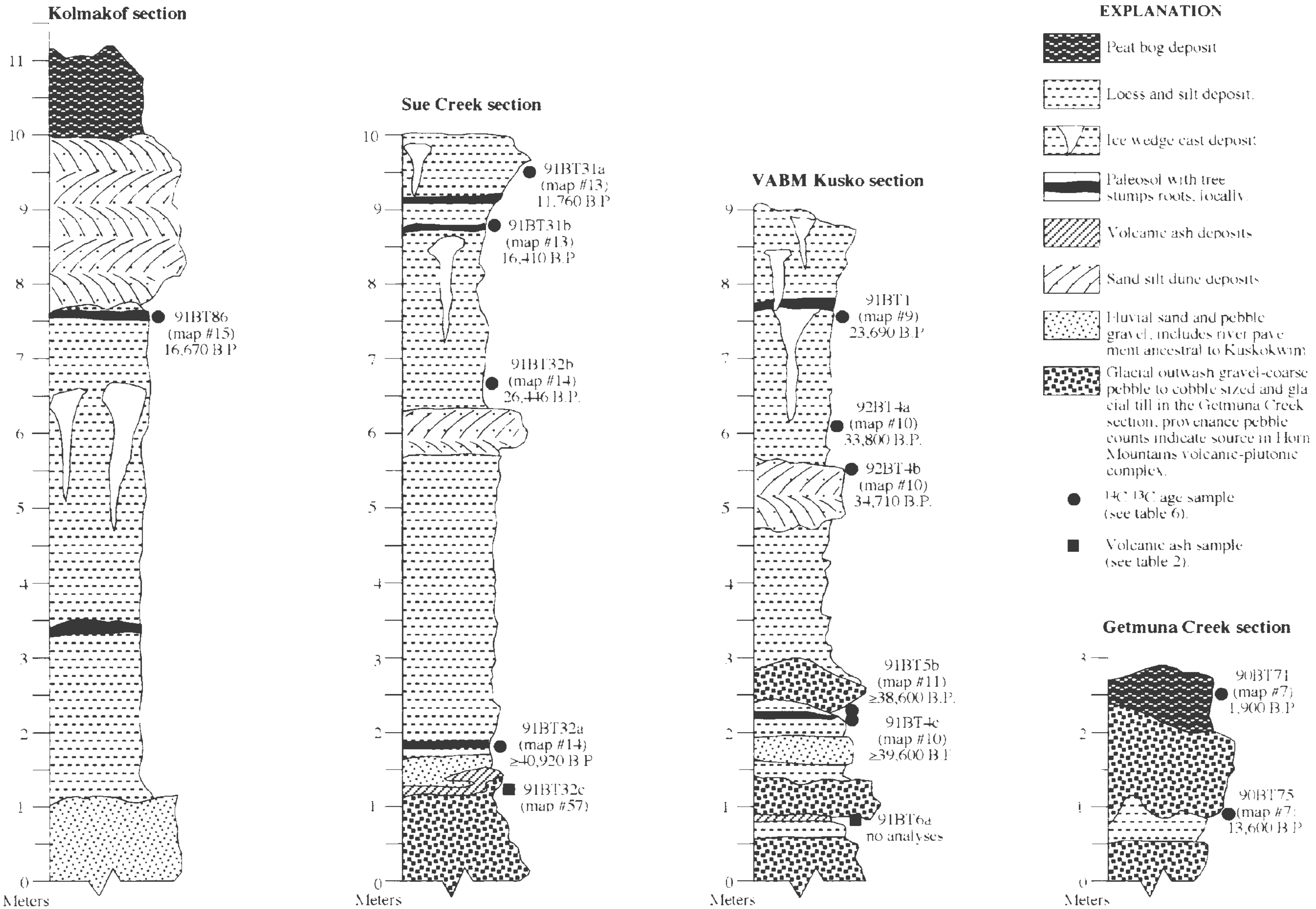


Figure 12. *Stratigraphic sections of Quaternary deposits in the Horn Mountains area, Sleetmute Quadrangle, Alaska. See figure 11 for locations of measured sections, table 6 for sample descriptions, and sheet 1 for sample localities.*

Table 6. *^{14}C /^{13}C analytical determinations from measured sections of Quaternary units in Sleetmute C-7, C-8, D-7, and D-8 quadrangles, Alaska[a] (see fig. 12 for measured sections) (Localities shown with octagons on sheet 1.)*

Map no.	Field no.	Laboratory no.	^{14}C age (years B.P. ± 15)	$^{13}C/^{12}C$	^{13}C adjusted age	Sample description and location
7	90BT71	Beta 40059	1,900 ± 41 B.P.	NA	NA	Palsa on till of Tolstoi Lake age on upper Getmuna Creek at 655 m (2,150 ft) elevation; sample taken from 0.5 m depth on top of blue, varved, lacustrine deposit (Getmuna Creek section, fig. 12).
7	90BT75	Beta 40060	13,600 ± 293 B.P.	NA	NA	From organic peat layer in till of Tolstoi Lake age in upper Getmuna Creek at 655 m (2,150 ft) elevation; sample taken 1.5 m below 90BT71 (Unit Qgt_3) (Getmuna Creek section, fig. 12).
9	91BT1	Beta 47634	23,690 ± 510 B.P.	-26.9	23,660 ± 510 B.P.	From organic loess 1.5 m below surface on top Jungjuk Creek outwash fan. All samples from along west bank of Kuskokwim River in NE corner of Sleetmute C-7 Quadrangle (VABM Kusko section, fig. 12).
10	92BT4a	Beta 47635	33,800 ± 2,000 B.P.	-26.6	33,770 ± 2,000 B.P.	From peat layer 3 m below surface (VABM Kusko section, fig. 12).
	92BT4b	Beta 47636	34,710 ± 1,240 B.P.	-28.5	34,650 ± 1,240 B.P.	From top of thin outwash 0.5 m below 91BT4a (VABM Kusko section, fig. 12).
	91BT4c	Beta 47367	≥39,600 B.P.	-27.2	NA	From peat layer below outwash (VABM Kusko section, fig. 12).
11	91BT5b	Beta 47638	≥38,600 B.P.	-27.2	NA	From bluish clay layer in outwash gravel 0.5 km downstream from 91BT4a-c site (VABM Kusko section, fig. 12).
13	91BT31a	Beta 47639	11,760 ± 70 B.P.	-26.8	11,730 ± 70 B.P.	From forest layer 0.5 m below loess cap, about 5 km below mouth of Sue Creek, Kuskokwim River (Sue Creek section, fig. 12).
	91BT31b	Beta 47640	16,410 ± 150 BP	-26.9	16,380 ± 150 B.P.	From peat layer .75 m below 91BT31a, (Sue Creek section, fig. 12).
14	91BT32a	Beta 47641	≥40,920 B.P.	-28.3	NA	From organic silt horizon 0.3 m above outwash gravel 8 m below modern forest layer (Sue Creek section, fig. 12).
	91BT32b	Beta 47642	26,446 ± 530 B.P.	-27.6	26,400 ± 530 B.P.	From organic peat 3 m below modern forest layer; site is 0.5 km downstream from 91BT31 sample site (Sue Creek section, fig. 12).
15	91BT86	Beta 47643	16,670 ± 360 B.P.	-27.2	16,640 ± 360 B.P.	From organic silt layer directly underneath sandy eolian dune complex; about 6 km downriver from Napaimiut (Kolmakof section, fig. 12).

[a]Analytical work by Beta Analytic Inc. Coral Gables Florida, 33124; dates are reported as RCYBP (radiocarbon years before 1950 AD). Half-life of radiocarbon is 5,568 years; accuracy of results are one standard deviation. Adjusted ages are normalized to -25 per mil carbon-13.

Outwash deposits (Qof, Qor, Qog) of several morphological variations radially formed around the Horn Mountains during each successive glaciation. These include outwash fan and outwash gravel deposits of several ages—subdivisions are not shown due to our inability to differentiate them in the field. No measurable sections of the Qof or Qog deposits exist in the study area, except for their appearance as thin, distal gravels in bluffs along the Kuskokwim River. Both Qog and Qof deposits consist of clasts derived mainly from the Horn Mountains volcanic-plutonic complex. Relative thickness estimates were difficult to determine, due to lack of exposure. In stream cuts of the uppermost Kolmakof River west of Horn Mountains, outwash fan deposits (Qof) range from 10 to 25 m thick.

Most of the outwash fan deposits (Qof) probably formed during the formation of Qgt_2 and Qgt_1 deposits, which implies a pre-Wisconsin age. The outwash gravels are believed to be younger in that they occur near the base levels of modern stream valleys, and are probably related to Qgt_3 and perhaps Qgt_4 glaciations. However, an important exception occurs northwest of Getmuna Creek, where outwash gravel apparently 'jumped' a low stream divide into the upper Kolmakof River drainage (sheet 1); these Qog deposits must be ancestral to Wisconsin stream development and may be middle or early Pleistocene in age.

Volcanic ash was found below about 6.5 to 7.5 m of Wisconsin loess and sand near Sue Creek and downstream from the abandoned village of Oskawalik in the Sleetmute C-6 Quadrangle (sheet 1; fig. 12). The ash consists of light gray, very fine grained, moderately sorted glass shards, pumice, feldspar, biotite, hornblende (?), and either zircon or anatase. The ash layer thins and thickens from 6 to 45 cm within or immediately above buried glacial outwash (Qof) thought to be related to Qgt_2 drift derived from the Horn Mountains. The pumice fragments are typically stretched and elongated; lithic grains from the interbedded outwash may have contaminated the ash layer at the Sue Creek and Oskawalik localities. Although our attempts at radiometrically dating these ash deposits with $^{40}Ar/^{39}Ar$ technology proved to be unsuccessful, both ash sections were found below peat layers that yielded infinite radiocarbon ages of >39,600 years B.P. and >40,920 years B.P., respectively (fig. 12; table 6).

A major oxide analysis of the volcanic ash (map no. 57; table 2) was compared to several Quaternary ash deposits of southwestern Alaska—including the Lethre tephra-bearing sections that are widespread in the Katmai area (Pinney and Begét, 1991). The major oxide and other trace-element concentrations of ash in the study area (no. 57; table 2) resemble those of the Old Crow Tephra, which was found in stream cuts of the Kulukbuk Hills and Holitna lowland 65 km east of the study area (Waythomas, 1990; Waythomas and others, 1994). The most recent age estimate of the Old Crow Tephra, based on fission-track and thermoluminescence methods, is 140,000 $\pm$ 10,000 years B.P. (Westgate, 1988; Westgate and others, 1990), or of Illinoian age.

If volcanic ash and unit correlations prove to be true, our data and that of Waythomas and others (1994) suggest an Illinoian age for outwash fan deposits (Qof) related to Qgt_2 glaciation in the study area. This may require a revision of the age of the Bifurcation Creek Glaciation (Qgt_2), which was originally defined and mapped in the Beaver Mountains as an Early Wisconsin glacial interval by Bundtzen, (1980) and Kline and Bundtzen (1986). Obviously, more stratigraphic and age-dating work should be initiated on the ash-bearing sections and both Qgt_2, and Qof deposits in the study area to further corroborate or refute this hypothesis.

Eolian Deposits

Eolian sand and loess (Qe, Qer) form a thin veneer on older Quaternary units of the study area (sheet 1; fig. 12). Dated sections near Sue Creek and the eastern limit of the map area indicate that a sand-rich eolian event occurred at about 34,710 years B.P., perhaps related to the onset of Late Wisconsin glaciation (first Qgt_3 stade) in the study area (fig. 12; table 6).

A younger eolian sand buildup (radiocarbon age of 16,670 yrs B.P.) occurred in the Kolmakof section (fig. 12); this may correlate with a latest Wisconsin glacial event observed—either was the youngest dated (13,600 years B.P.) Qgt_3 glacial stade on Getmuna Creek in the study area, or was blown in from the areally extensive Aniak River valley outwash fan immediately west of the study area (Cady and others, 1955). No mineralogical identifications or wind measurements were collected from any of the loess or sand deposits in the study area. The development of ice wedge casts (fig. 12) between the dated peat layers (34,710 and 16,670 years B.P.) in the Kolmakof section are probably related to the cool climatic conditions that existed in late Wisconsin time.

Colluvial and Alluvial Deposits

Alluvial deposits of several ages (QTat, Qat, Qaf, Qas, Qag, Qa) reflect stream dissection and deposition during Quaternary time. No absolute or paleontological age control is available; age estimates are based on geomorphological characteristics. The oldest terrace alluvium (QTat) at the head of the Iditarod River formed prior to stream capture by present Suter Creek drainage, and may be as old as early Pleistocene. These deposits infill an underfit stream valley, and may actually be outwash formed by meltwater streams originating from the oldest glacial intervals documented in the Russian Mountains (Bundtzen and Laird, 1991); however, we did not examine any exposures of these QTat gravels. Hence they are simply mapped as ancestral terrace alluvium.

Progressively younger alluvial terrace and alluvial fan deposits (Qat, Qaf) probably formed in middle and late Pleistocene time. Much modern stream alluvium (Qa, Qas, Qag) is actively forming today. Silt and peat (Qsp) accumulated in bogs and water-saturated zones within poorly drained upland sites and floodplains of major river systems.

Colluvial deposits (Qca, Qc, Qct, Qt, Qctf) formed as the result of recent dissection of the bedrock terrane, coupled with influx of eolian sedimentation and reworking of older Quaternary units. Based on limited radiocarbon age control (table 6), most colluvial units range in age from Wisconsin to Holocene.

Holokuk Gravel

Semi-consolidated, slightly tilted, and oxidized, fluvial gravels cover a 35 km^2 area in the southeastern part of the study area. We have adopted the informal name 'Holokuk gravel' to describe these deposits, after the Holokuk River drainage, where the best exposures are found. These gravels are geomorphologically expressed in a high-level gravel terrace about 35 to 65 m above the modern floodplain of the Holokuk River. Based on several paleocurrent determinations (imbricate pebble measurements), gravel clasts of dominantly igneous origin are likely derived from igneous complexes in the Chuilnuk Mountains about 60 km south of the study area (described by Decker and others, 1995). The Holokuk gravel is inclined as much as 5 degrees locally, and forms a badlands-type of erosional topography on the dissected peneplain south of the Kuskokwim River. Lacking paleontological or isotopic data, we are uncertain of the age of the Holokuk gravel; its relative antiquity compared to younger, unconsolidated units and morphological character suggest the Holokuk gravel was deposited in high-energy stream environment during Late Tertiary or Early Pleistocene time.

STRUCTURAL GEOLOGY

The layered rocks in the study area have been deformed by two ages of folding, and high-angle, normal to reverse faults. The earliest fold event deformed the Kuskokwim Group into upright to overturned isoclinal folds (see cross sections, sheet 1). Cady and others (1955) and Decker and Hoare (1982) measured section in the Kuskokwim Group of the study area under the assumption of homoclinal to open fold styles. Bundtzen and others (1989) mapped large-scale, overturned folds with amplitudes of up to 4 km and with vergence to the southeast in the Sleetmute C-7 Quadrangle. Bundtzen and others (1992) suggested that the Kuskokwim Group southeast of the Iditarod–Nixon Fork fault underwent significantly more deformation than rocks northwest of this major northeast-trending, transcurrent fault; the fault may have acted as a structural buttress for southeast to northwest compressional stress. After the Latest Cretaceous isoclinal fold event, a younger—probably mid-Tertiary compression refolded the Kuskokwim Group and Late Cretaceous–early Tertiary igneous rocks into broad, open, north-vergent, open folds (see cross sections, sheet 1).

Northeast-trending, high-angle faults ranging from N30E to N70E orientations cut bedrock units in the study area. They roughly parallel the Iditarod–Nixon Fork fault (exposed in the northwest corner of the map area), that juxtaposes shoreline deposits (Ksq) against turbidite facies (Kslt, Ksc) of the Kuskokwim Group. The youngest high-angle faults trend N20W to N35W, and cut older structures and all bedrock units.

Cady and others (1955) first noted that the circular volcanic field in the Horn Mountains (our HMVF) probably represented a collapsed caldera feature in fault contact with the Kuskokwim Group. We concur with this interpretation; however, in the absence of good contact relationships, the HMVF is not shown in fault contact with host flysch deposits on sheet 1. Perhaps future airborne geophysical investigations could better define the nature of this contact.

A regional air photo lineament trends about N10W to N15W from Veahna Creek near Aghaluk Mountain at the southern boundary of the map area, along the western edge of the Horn Mountains, and finally into the headwaters of Little Creek at the northern edge of the map area. We found no evidence of a structural discontinuity at any location along this feature; however, we note that the Veahna–Little Creek lineament parallels the Aniak–Thompson Fault, a regional, left-lateral tear fault exposed north of Aniak about 45 km west of the study area.

ECONOMIC GEOLOGY

Gold–polymetallic and mercury–antimony resources were investigated in the Horn Mountains, at Juninggulra Mountain, and at the Kolmakof mercury mine and New York Creek placer gold deposits. The area has seen modest mineral resource production. The Rhyolite and Kolmakof mercury (stibnite) deposits were explored and developed and modest amounts of mercury were produced from both deposits (Maloney, 1962; Smith and Maddren, 1915). The New York Creek gold placers were developed around 1910 and have intermittently produced gold since then. Total New York Creek production, from 1910 to 1937, was at least 48 kg (1,543 oz) gold; an unknown amount of production has taken place to the present day. The mineral deposits of the study area conform to several mineral deposit models present in the Kuskokwim mineral belt as defined by Bundtzen and Miller (1997). During the following discussions, the reader is referred to sheet 1 and table 7 (in pocket).

GOLD AND POLYMETALLIC PROSPECTS IN HORN MOUNTAINS

The Getmuna Creek prospect (map nos. 23, 24; table 7; fig. 1) consists of one or two thin (5 to 10 cm thick) quartz–arsenopyrite gold veins that trend about N20E discontinuously for several hundred meters. Poor exposure prevented an accurate estimate of the size and grade of the Getmuna Creek auriferous veins, and existing evidence suggests the prospect is small and of limited extent. Samples from the Getmuna Creek prospect contain up to 14.5 ppm (0.43 oz/ton) gold, 29.2 ppm (0.86 oz/ton) silver, 165 ppm bismuth, and anomalous arsenic, copper, lead, antimony, and mercury.

Tourmaline-enriched, base metal–silver occurrences are found in high-level portions of the Horn Mountains pluton. At the Jungjuk Creek, Greisen, and Saddle occurrences (map nos. 15, 20, 28, respectively; table 7; fig. 1), N25W-trending tourmaline breccias and veins cut granodiorite porphyry either below roof pendants of andesite and latite tuff or within the pendants themselves. Values of up to 2,302 ppm lead, 18.9 ppm (0.56 oz/ton) silver, 1,179 ppm zinc, 924 ppm arsenic, and 321 ppm antimony were obtained from the three mineral occurrences (table 7).

The Sue Creek prospect (fig. 13; map no. 39; table 7; fig. 1) consists of a distinctive zone of tourmaline-ferricrete flooding in hornfels adjacent to granodiorite porphyry of the Horn Mountains pluton, just west of Sue Creek canyon. The mineralization, which covers an irregularly shaped 75 m by 65 m area, consistently yields weak polymetallic mineralization (i.e., maximum values of 570 ppm zinc, 140 ppb gold, 788 ppm arsenic, 337 ppm antimony, 102 ppm tungsten, 33 ppm tin). Although all samples contain sub-economic grades, the apparent size and extent of the mineralized zone may indicate a larger, possibly more promising deposit at depth.

The Jungjuk, Greisen, and Saddle occurrences and the Sue Creek prospect are morphologically and geochemically similar to the boron-enriched silver–tin–polymetallic deposit type as defined by Bundtzen and Miller (1997), and other precious and base metal prospects (Szumigala, 1995; 1996) in the Kuskokwim mineral belt.

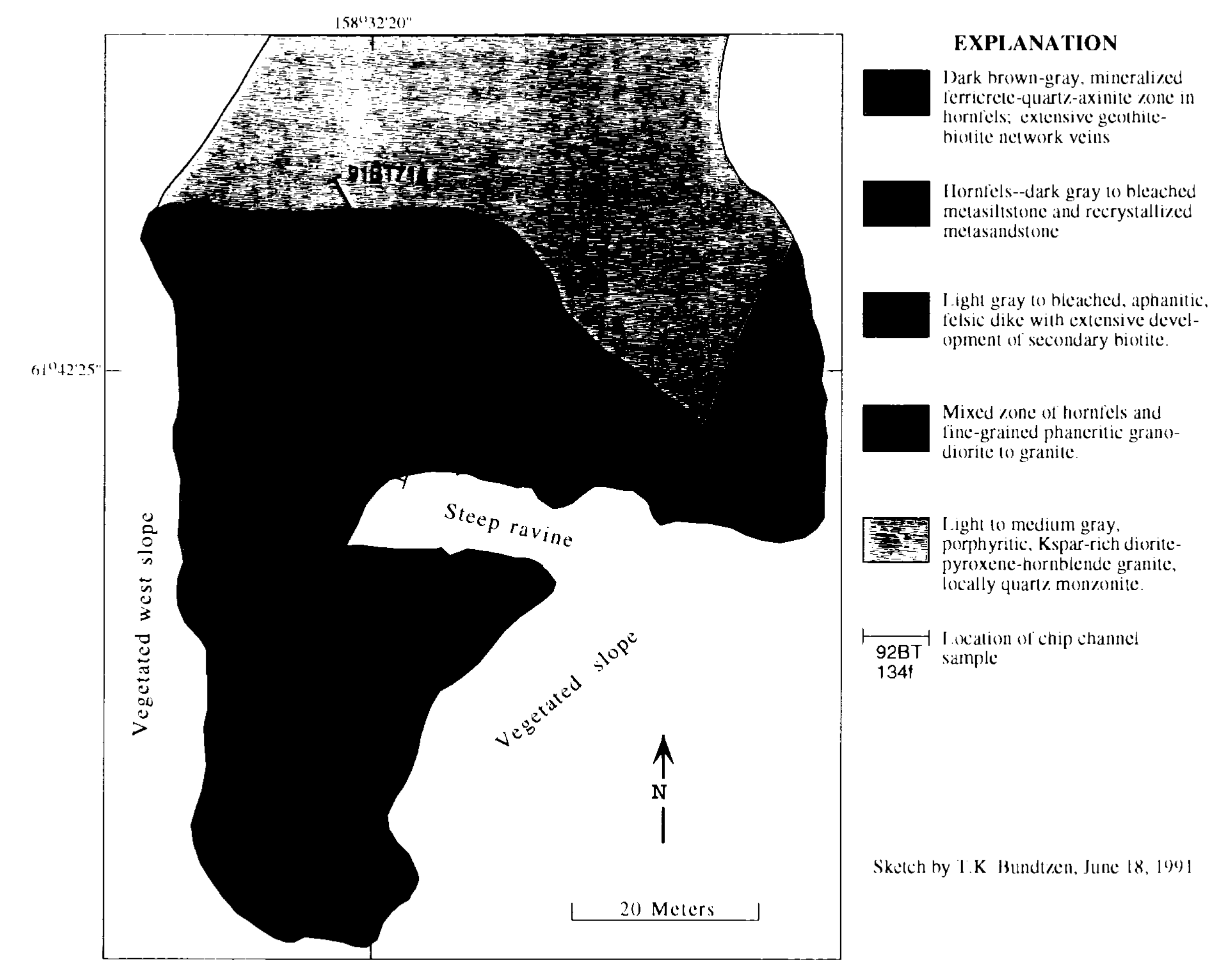


Figure 13. *Geologic sketch of Sue Creek Sb-As-Zn (W-Sn) prospect, Sleetmute C-7 Quadrangle, Alaska (map #39, sheet 1, and table 7). Modified from Bundtzen and Miller (1997).*

EPITHERMAL MERCURY (ANTIMONY–GOLD) DEPOSITS

Kolmakof Mercury Mine

Lode mercury deposits that contain elevated anomalous gold and tellurium values are associated with altered mafic dikes at the Kolmakof Mine (fig. 14; map no. 53; sheet 1; table 7; fig 1). According to Spurr (1900), the Kolmakof mercury (antimony) deposit was discovered by Russian explorers in 1838, making it one of Alaska's earliest mineral discoveries. In 1881, prospector George King ascended the Kuskokwim River and explored the Kolmakof cinnabar (stibnite) deposit (Brown, 1983). Shortly thereafter, Alaska Commercial Company agent Reinhold Separe mined and shipped several tons of high-grade mercury ore from Kolmakof to a refiner in California. However, the ore was worth only $11/ton, and the mining effort was an economic failure. Later, Edward Lind, another trader at Kolmakof, also mined the deposit but failed to turn a profit. In 1901, prospector Duncan McDonnell found high-grade ore at Kolmakof that was said to be worth $341/ton in mercury; however, his 'Milwaukee Mining Company' never initiated mine development (Brown, 1983).

In 1908, Gordon Bettles explored the deposit with an adit and mined and produced mercury from high-grade cinnabar zones on a small scale (M. Hofseth, oral commun., 1991). Bettles and previous workers sunk several winzes on the property—one to about 24 m deep (Jasper, 1955). Later William Holoday opened up the first pit operation at Kolmakof and built a small retort and mill sometime prior to 1940. After World War II, Dean Rhehart constructed a gravity-feed mill, and processed about 136 tonnes of selected cinnabar ore. The property was held by Willie Rabideau from about 1950 to 1953. The U.S. Bureau of Mines examined and sampled the deposit in 1944 (Webber and others, 1947); in 1958 (Maloney, 1962); and in 1970 (Merrill and Maloney, 1974). Jasper (1955) visited the property during a stripping program initiated in 1954 by Western Alaska Mining Company. His extensive sampling program indicated assay results ranging from 0.38 to 19.20 percent mercury over channel sample widths ranging from 56 to 130 cm. No other metals were analyzed during Jasper's investigation.

The last production occurred during 1969–1970, spurred in part by high prices during the Vietnam War, when the Rhehart-Holoday partnership mined and shipped cinnabar concentrations that were processed in a 10 tonne/day mill. In addition this partnership conducted an exploratory program at the Kolmakof mine from 1969-72 (Fackler, 1972). Total production from the Kolmakof mine is estimated to be no more than 8,618 kg (250 flasks) of mercury (M. Hofseth, oral commun., 1991). In 1991, the small gravity-fed mill built by Rhehart, in a state of disrepair, still existed 200 m east of the deposits. Most of the past mine activities took place in a small, open pit above a prominent bluff along the north side of the Kuskokwim River (fig. 14).

Mineralization at the Kolmakof mine consists of narrow stringers of cinnabar, arsenopyrite, and trace stibnite in silica–carbonate-altered breccia zones and fractures of altered mafic dikes that intrude the Kuskokwim Group flysch. The sand:shale ratio of the sedimentary host rocks averages about 5:1 at the mine site and individual sandstone beds appear to be about 9 m thick. The altered mafic dikes (sills) strike about N45E and dip 40 to 60 degrees NW. The cinnabar appeared to be in fractures adjacent to the sandstone-dike contacts and at small offsets of the dikes, very similar to the structural controls observed at the Red Devil Mine near Sleetmute. One problem encountered during mine development at Kolmakof was the lack of horizontal and vertical continuity of individual ore chutes (Jasper, 1955).

Chalcedonic adularia zones overprint the main cinnabar-bearing zones; precious metals with assays of up to 10 grams/tonne (0.32 oz/ton) gold and 45 grams/tonne (1.45 oz/ton) silver have been found in isolated samples. Quartz–carbonate veins in bleached sandstone along the beach 75 m east of the main mine workings contain 27 to 66 ppm tellurium and 24 to 54 ppm molybdenum. Del-34 sulfur (0/00) isotopic analyses of -3.9, -4.7, and -1.7 from cinnabar at the Kolmakof mine probably indicates the sulfur was derived from magmatic sources (Bundtzen and Miller, 1997; Gray and others, 1997). The molybdenum tellurium anomalies, coupled with the conspicuous alteration bleaching in host rocks, might indicate additional mineralization exists at the Kolmakof mine.

Rhyolite Mercury (Antimony) Prospect

The Rhyolite mercury prospect is hosted in a large peraluminous granite porphyry sill (TKgp) on the southern flank of Juninggulra Mountain. A few small stringers of cinnabar were discovered in granite porphyry in 1953, and by 1956, local prospectors Robert Lyman and Joe Stuver conducted bulldozer trenching and panning. In 1959, the U.S. Bureau of Mines systematically investigated the prospect with more bulldozer trenching and sampling (Maloney, 1962). These trenches were nearly completely overgrown during our visits in 1990 and 1991. The principal mercury mineral (metacinnabar) is apparently confined to small, N60 to 80E trending, stringers and lenses in silica–carbonate-altered zones in the Juninggulra Mountain granite porphyry sill. Stibnite float near the old airstrip yielded nearly 66.3 percent antimony (Maloney, 1962); however, most other samples yielded only mercury anomalies. Our meager sampling (map nos. 2, 3; table 7; fig. 1) of metacinnabar–quartz–carbonate veining at the Rhyolite mercury prospect contained anomalous zinc (574 ppm), arsenic (136 ppm), antimony (279 ppm), silver (0.8 ppm),

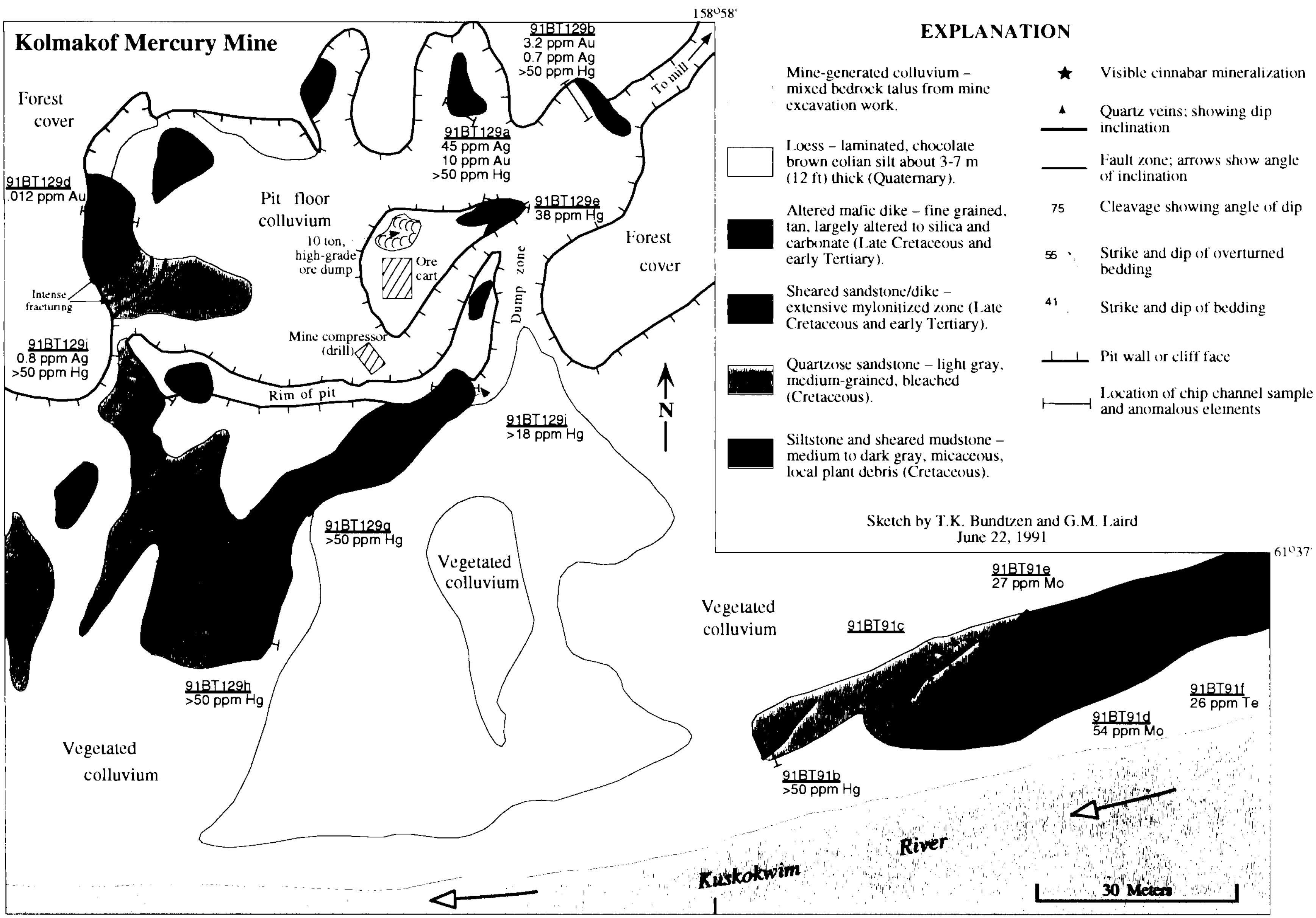


Figure 14. *Geologic sketch and mineral zones of the Kolmakof mercury mine, Sleetmute C-8 Quadrangle, Alaska (map #53, sheet 1, and table 7). Modified from Bundtzen and Miller (1997).*

and tin (21 ppm). Although our investigations did not indicate gold values, the Juninggulra Mountain granite porphyry sill complex trends northeasterly into the Donlin Creek peraluminous granite porphyry dike sill–pluton complex, which is currently being explored by Placer Dome Exploration. In addition, the anomalous metallic suite observed in our samples is similar to that found in the peraluminous granite porphyry hosted gold polymetallic deposit type described by Bundtzen and Miller (1997) and found throughout the Kuskokwim mineral belt. Gray and others (1997) reported that the Rhyolite prospect yielded a $^{40}Ar/^{39}Ar$ age from sericite of >70.9 Ma, within the age range for mineralization of this type throughout the Kuskokwim mineral belt.

Bear Creek Epithermal Gold Mineralization

A single sample from a chalcedonically altered zone in a mafic flow of the Jungjuk mafic flow complex east of Bear Creek and along the southern Horn Mountains upland (map no. 47; table 7; fig. 1) yielded 880 ppb gold. The chalcedonic alteration appears for a distance of up to several hundred meters away from the sampled area. Further work is suggested on this anomaly.

PLACER DEPOSITS

New York Creek (Murray Gulch)

Small placer deposits have been exploited intermittently since 1910 at Murray Gulch, tributary to New York Creek, about 6 km northeast of Napaimiut (sheet 1; nos. 63, 64, table 7; fig. 1). In 1914, George A. Fredericks, a trader at Georgetown, reported that a blind Native American shaman told him that in 1844 nearly 4 years before the 1848 placer gold discovery on the Kenai Peninsula by the Russian mining engineer Peter Doroshin (Brown, 1983; Berry, 1973) Russian explorers had located paying quantities of placer gold on both New York Creek in the study area and on Black River, upstream from Sleetmute.

In 1910, prospectors Nick Miljevic, A. Perledo, and J. Bittewith discovered coarse placer gold about 6 km (4 mi) above the mouth of New York Creek. Hydraulic mining was initiated in 1915, and by the 1920s and 1930s, several tributaries including Murray Gulch and Mary Creek had been mined on a small scale (Brown, 1983). Intermittent (probably incomplete) production records for nine reporting years of mine activity from 1914 through 1937 amounts to 47.98 kg (1,542.8 oz) gold and 7.1 kg (230.0 oz) silver from 29,472 m^3 (38,545 yd^3) of pay (table 8). During the early years gold was exploited chiefly by trenches and short shafts and drifts in frozen ground (Maddren, 1915). In 1937, Brink Mining Company recovered 11.8 kg (380 oz) of gold from a small mechanized placer mine on Murray Gulch; this was the largest recorded single-season production for New York Creek (M. Hofseth, oral commun., 1991).

The Murray Gulch mine was inactive in 1990 and 1991; however, judging from conditions at the site, some mine activity probably occurred in the 1980s (fig. 15). According to M. Hofseth (oral commun., 1991), past operators Brink Mining Company and W. Dobnick shipped cinnabar-rich gold concentrates for offsite processing. Principal heavy minerals identified in concentrates during our work included gold, silver, cinnabar, radioactive monazite, and arsenopyrite. Smith (1941) reported that gold fineness from the New York Creek drainage ranged from 825 to 840 and averaged about 830.

Open-cut mine activities are largely confined to a cut measuring about 500 m long and 250 m wide in Murray

Table 8. *Recorded placer gold production from the New York Creek drainage, Sleetmute C-8 Quadrangle, Alaska*[a]

Year	Operator	Location	Gold (troy oz)	Silver (troy oz)	Cubic Yards of Pay Processed
1914	J. Bittewith	New York Creek	147.0	18.9	4,000
1915	J. Bittewith	New York Creek	159.0	21.0	4,550
1917	Louis Huber	Discovery Claim	243.4	15.9	5,300
1918	Louis Huber	Marys Fork	155.0	32.0	5,749
1919	Louis Huber	New York Creek	103.9	9.3	888
1920	Louis Huber	New York Creek	123.3	14.5	900
1921	Louis Huber	Marys Fork	176.2	40.2	5,208
1922	Louis Huber	New York Creek	65.0	11.3	1,380
1937	Brink Mining Co.	Murray Gulch	370.0	66.9	10,570
Total			**1,542.8**	**230.0**	**38,545**
(metric units)			**(47.98 kg)**	**(7.1 kg)**	**(29,472 cubic meters)**

[a]Date source United States Mint Records, and Morris Hofseth, oral commun., (1991).

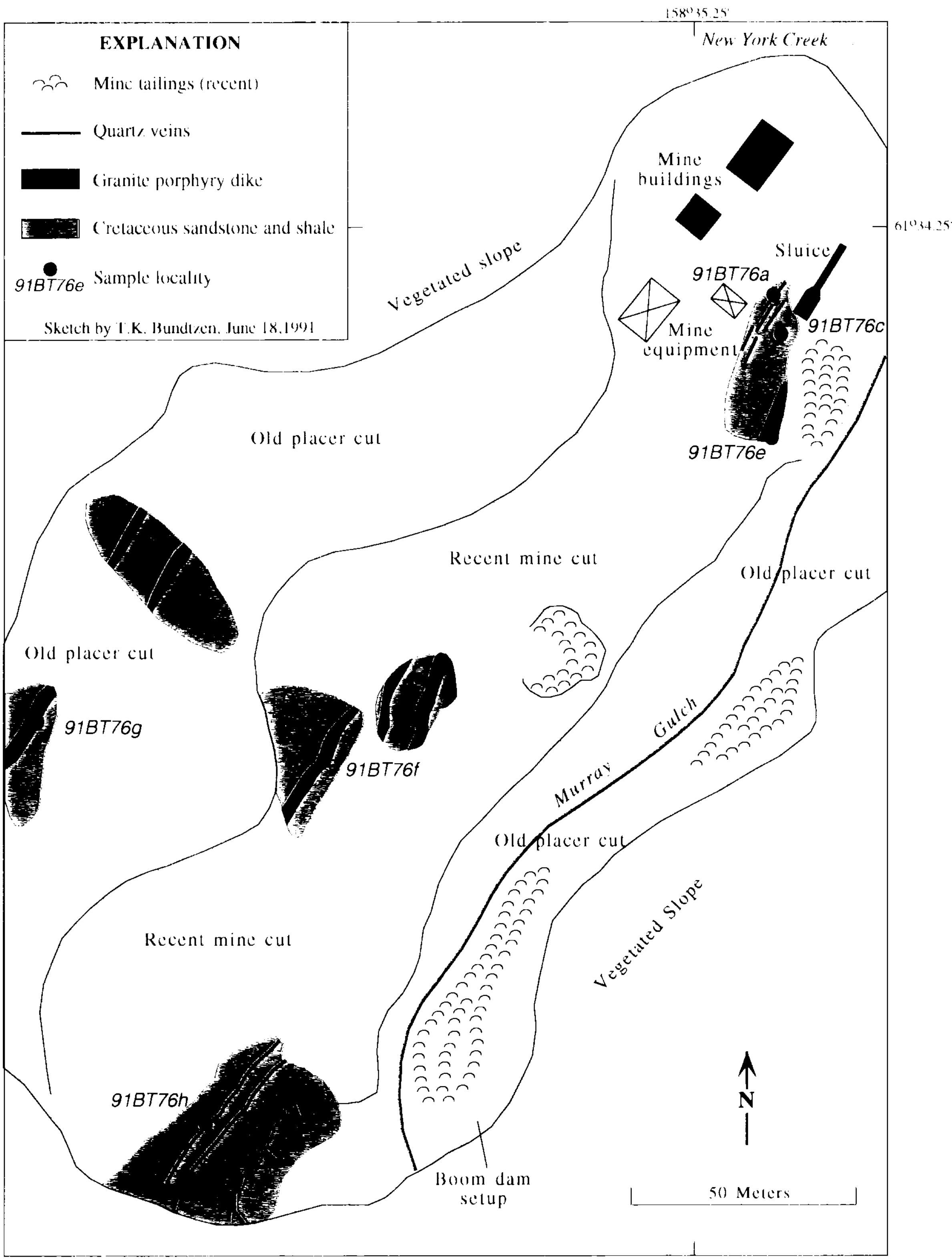


Figure 15. *Geologic sketch of Murray Gulch, New York Creek drainage, Sleetmute C-7 Quadrangle, Alaska (map #63, sheet 1, and table 7). Modified from Bundtzen and Miller (1997).*

Gulch. We observed evidence of both drilling and drifting on an ancestral left limit bench of New York Creek below the Murray Gulch opencut (fig. 15). Maddren (1915) reported that bench gravels northwest of Murray Gulch were being prospected (in 1914) at two levels: (1) a lower one 4.5 m (15 ft) above the present floodplain; and (2) a higher bench 21.3 m (70 ft) above the active floodplain.

A small but persistent swarm of peraluminous granite porphyry dikes about 4 km long and 2 km wide cuts Kuskokwim Group flysch in the immediate New York Creek mine area and on the ridge adjacent to the mine access road (sheet 1). Placer gold is always found downslope and downstream from the felsic dike swarm. The relatively low gold fineness (average 830) in New York Creek, and associated heavy minerals (native silver, arsenopyrite, cinnabar and monazite) are similar to the placer gold fineness and heavy minerals found at Donlin Creek, Julian Creek, Stuyahok–Flat Creek, and other districts where peraluminous granite porphyry hosted gold–polymetallic deposits are the apparent source of placer gold deposits (Bundtzen and Miller, 1997; Miller and others, 1996).

Little Creek

Placer gold deposits were discovered on Little Creek sometime prior to World War II, but mineral production has never been recorded (Cady and others, 1955; Miller and others, 1989). According to Spencer Lyman (oral commun., 1992), a low-grade but persistent placer gold paystreak 150 to 200 m wide and about 4 km long was found under relatively shallow overburden averaging about 5 m thick. Specific values or grades of the gold placer were not given; however, mineral development has been contemplated by various operators since the mid 1970s. Little Creek bisects the Iditarod Volcanics and Kuskokwim Group. A pluton of intermediate composition (TKgd) crops out about one mile south of the valley head of Little Creek (sheet 1). Little Creek drainage is poorly exposed, and potential gold sources are unknown.

West-Flowing Stream Drainages, Horn Mountains

Abundant scheelite ($CaWO_3$) and minor gold were discovered in stream gravels along the western side of the Horn Mountains by early 20th century prospectors (M. Hofseth, oral commun., 1990; Cady and others, 1955). Theodorakos and others (1992) and Gray and others (1994) reported maximum values of 500 ppm gold, 20 ppm silver, and 120 ppm arsenic, but no anomalous tungsten from stream gravels and stream sediment samples of this area. Bedrock underlying this area includes the Horn Mountains pluton, the HMVF, and intrusive-volcanic contact zones.

GEOCHEMISTRY AND PROSPECTING GUIDES

Theodorakos and others (1992) and Gray and others (1994) presented geochemical data and described favorable areas for metallic mineral resources in the Horn Mountains area—in fact their sample program exclusively covers the Sleetmute C-7, C-8, D-7, and D-8 quadrangles, the boundaries of this investigation. Included in their sample set are 138 stream sediment, and 137 heavy mineral pan concentrate samples. Combined with data from bedrock sites collected during this study (table 7; sheet 1), a useful geochemical sample survey is available for the study area that can help predict mineral potential and determine background metal concentrations in the northwest corner of the 1:250,000-scale Sleetmute Quadrangle.

Predictably, most of the mineralized areas previously described are reflected by anomalous elements in stream-sediment and pan-concentrate samples. Of significance are persistent boron–gold–silver–arsenic–tungsten–antimony–lead–bismuth anomalies in stream-sediment and pan-concentrate samples from the Horn Mountains. Megascopic gold, scheelite, and barite were panned by Theodorakos and others (1992) from stream gravels of the Horn Mountains. In addition, large areas of mercury–zinc–tellurium–tungsten anomalies are found in western tributaries of the Kolmakof River (see area 5 of Gray and others, 1994). A large concentration of cinnabar found in samples near VABM Kolmakof is coincident with a hornfels zone in the Kuskokwim Group, which may suggest the existence of a buried mineralized intrusion.

Several anomalous areas reported by Gray and others (1994) do not contain known favorable geology or known mineral occurrences. In particular a large 40 km^2 area centered on VABM Shale contains anomalous tin, tungsten, barium, gold, and lead. This and other anomalous areas deserve diligent prospecting in the future.

The broad, curvilinear belt of mercury, tellurium, arsenic, and related anomalies surrounding the Horn Mountains upland (Theodorakos and others, 1992; this study) might be the manifestation of epithermal mineralization deposited in structurally favorable zones rimming the Horn Mountains Volcanic Field (HMVF) and Horn Mountains pluton. The Horn Mountains volcanic caldera and plutonic complex is geochemically similar to the geologic setting of the Emperor gold mine in the Tavua goldfield of Figi, South Pacific (Ibbotson, 1967) and other gold–silver–tellurium caldera-hosted, vein deposits (Cox and Bagley, 1986). Gold–silver–tellurium–mercury mineralization at the Emperor mine occurs in curvilinear structures surrounding the rim of a collapsed caldera of Tertiary age.

INDUSTRIAL MINERALS

No past production of industrial minerals is known from the study area. Bundtzen and others (1989) discussed the availability of sand and gravel and riprap in the study area, and presented laboratory data that characterizes the suitability of several bedrock sites for riprap armor applications.

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DESCRIPTION OF MAP UNITS

UNCONSOLIDATED DEPOSITS

Alluvial Deposits

Qa SANDY FLOOD-PLAIN ALLUVIUM—Unconsolidated, well stratified, gray to slightly tan weathered, fine to coarse grained, pebble-rich sand, silty sand, and silt deposited by modern streams in Holocene stream valleys. Some coarser-grained alluvium found in Holokuk River drainage. Finer-grained alluvium dominant in Iditarod and Kolmakof rivers and tributaries. Edges of unit commonly covered by sphagnum moss and thickets of willow (*Salix sp.*), alder (*Almus sp.*), and cottonwood (*Populus balsamifera*). Unit generally thawed due to thermal upgrading (thaw bulb) of active streams. Unit ranges in thickness from 3 to 10 m, based on depth to bedrock in Horn Mountains and along Holokuk River.

Qag COARSE-GRAINED, GRAVEL-RICH ALLUVIUM—Unconsolidated, moderately to well stratified silt, medium to coarse grained, pebbly sand, and gravel deposited by modern streams in Horn Mountains and as upper ends of point bars and side bars along Kuskokwim River. Gravel-rich deposits in Horn Mountains consist of clasts of volcanic and plutonic rocks to 0.5 m in diameter. Deposits in nonglaciated lowlands and along Kuskokwim River contain clasts of sedimentary, metamorphic, and igneous rocks derived from local sources and from as far away as the Alaska Range. Only deposits in active channel of Kuskokwim River shown on sheet 1. Deposits range from 1 to 20 m thick; thickest sections based on dredging point bars near Aniak west of study area. Unit typically thawed.

Qas FLOOD-PLAIN ALLUVIUM INCLUDING EXTENSIVE OVERBANK DEPOSITS—Alluvium composed of interbedded, dark brown to gray, organic rich, fine grained, micaceous sand to silty sand ranging from 1 to 10 m thick that commonly overlies sandy flood plain alluvium. Overbank deposits represent flood cycles consisting of aggradational successions of rhythmically bedded silt. Each layer ranges from 0.2 to 0.5 m thick and is usually capped by vegetation mattes. Unit forms broad, interchannel areas on the Kuskokwim River flood plain. Unit is commonly thawed due to proximity to thaw bulb of Kuskokwim River.

Qsp SILT AND PEAT—Poorly stratified, black to brown, organic-rich, alluvial, lacustrine, or bog silt and peat. In Getmuna Creek and the upper Kolmakof River drainage, unit contains multiply stacked palsencomposed of well stratified peat layers 2 cm to 3 m thick interwoven with parallel ice lenses. Bog silt and peat generally mantled with tussocks, grasses, sedges, and sphagnum in low wetlands, and lichen and sedges in alpine settings. Carbon-14 age determinations range from 1,900 years BP to more than 39,600 years BP for peat development in study area (table 6); most areally extensive and thickest (up to 5 m) deposits found in Iditarod and Kolmakof River drainages. Unit is typically frozen.

Qaf ALLUVIAL FAN DEPOSITS—Generally poorly sorted, partially stratified sand and coarse-grained gravel deposits occurring as fans or cones where second and third order streams enter fourth to sixth order trunk drainages. Restricted to mature, unglaciated terrain; can be transitional to Qca fan units of Horn Mountains. Inferred to be pre-late Wisconsin in age; typically frozen.

Qat YOUTHFUL TERRACE ALLUVIUM—Moderately to well sorted, gray to light tan weathered, well stratified sand and gravel weakly cemented by iron oxides. Unit is 3 to 12 m thick above active river flood plains and probably includes stripped strath terraces in Kolmakof and Iditarod River drainages. Surfaces are usually covered with climax vegetation, dissected by Holocene streams, and mantled by eolian silt. No isotopic age control is available, but unit may be equivalent to middle Pleistocene deposits in interior Alaska (Péwé, 1975), in the Beaver Mountains (Kline and Bundtzen, 1986), and in the Iditarod mining district (Bundtzen and others, 1992).

QTat OLDER TERRACE ALLUVIUM—Moderately to well sorted, well stratified sand and gravel, extensively cemented by iron oxides to a significantly greater degree than Qat deposits. Unit is 10 to 20 m above active flood plains of present stream drainages, and probably includes strath terraces largely stripped of sediments. Unit is ubiquitously covered by climax vegetation, which overlies eolian silt and ice-rich, poorly drained soils. Like many Quaternary deposits, absolute age control is not available, and conventional thinking would place the age of ancestral terrace alluvium as exclusively Quaternary in age. However, older terrace alluvium may be as old as late Tertiary, based on radiometric age dating of similar deposits in the Fairhaven district of the Seward Peninsula (Hopkins and others, 1971) and in the Livengood district north of Fairbanks (Karl and others, 1988). This unit in headwaters of Iditarod River is probably ancestral outwash from Russian Mountains now captured by Suter Creek drainage. A similar stream capture north of Jungjuk Creek isolated high level QTat deposits. In study area unit averages 5 m thick, based on exposures in Iditarod River.

Ts HOLOKUK GRAVEL—High-level gravel terrace exposed along lower Holokuk River valley; consists of slightly consolidated, well sorted, iron oxide coated, coarse-grained pebble sandstone and pebble to cobble-rich gravels. Clasts composed of igneous rocks (granitic and volcanic) probably derived from mountainous region south of study area. Source also indicated by northerly dominated imbricate pebble orientations in three localities. Gravel may be inclined as much as 5 degrees; forms classic badlands erosional pattern. Age is not known, but gravel is situated nearly 100 m above Holokuk River flood plain, and iron-rich alteration is similar to other late Tertiary fluvial deposits in interior Alaska (Kirschner, 1994).

Colluvial Deposits

Qca COLLUVIAL–ALLUVIAL FAN DEPOSITS—Poorly to moderately sorted silt, sand, gravel, and diamicton, the last of which is primarily of glacial origin. Commonly forms alternating stratified and unstratified zones and lenses in gullies and steep, intermittent or ephemeral, tributary streams. Colluvial–alluvial fans most active during spring runoff.

Qctf FAN AND TERRACE DEPOSITS—Composite unit containing poorly sorted, partially stratified silt, sand, gravel, and colluvium that form broad, coalescing colluvial–alluvial fans and buried ancestral terrace deposits. May include alluvial aprons near stream cuts. Maximum thickness of 20 m near Aghaluk Mountain and north of Getmuna Creek. North facing exposures are generally frozen.

Qc UNDIFFERENTIATED COLLUVIAL DEPOSITS—Mixed alluvial, eolian, and colluvial deposits that include bedrock-derived talus at toes of hillslopes and alluvium near stream cuts. Can be transitional to Qctf unit. Locally ranges from 2 to 5 m thick. Generally frozen.

Qt TALUS CONES—Angular fragments of frost-riven bedrock talus transported downslope by gravity and deposited as aprons or fans at toes of slopes. Distal zones of talus cones or aprons may grade into protalus ramparts and rock glaciers.

Qct COARSE COLLUVIUM—Unsorted, coarse-grained talus and mixed regolith along steep slopes in Horn Mountains. Can be transitional to talus cones.

Glacial and Related Deposits

Qrg ROCK GLACIER DEPOSITS—Tongue-shaped masses of unsorted, angular, frost-shattered boulders and cobbles locally reaching 2 m in diameter. Most rock glaciers in study area are believed to be inactive; however, some uncommon valley wall and longitudinal rock glaciers and protalus ramparts in Whitewing Valley may be active.

Qor REWORKED OUTWASH—Well sorted, unconsolidated, well stratified sand and gravel reworked from Qog and Qof deposits. Commonly discontinuous and found in intermittent stream drainages. Estimated 1 to 3 m thick. Typically thawed.

Qog OUTWASH GRAVEL—Poorly consolidated, well stratified sand and gravel deposited distally from glacial sources in the Horn Mountains. May include patches of Pleistocene till. Unit could range in age from Early to Late Pleistocene, but most of unit depicted in Getmuna and Sue Creek drainages is probably late Wisconsin in age. Unit ranges from 1 to 5 m thick. Some coarse, boulder-rich gravels present in Jungjuk Creek area.

Qof OUTWASH FAN DEPOSITS—Poorly consolidated, moderately well stratified sand and gravel deposited as several large fans radially distributed around Horn Mountains massif. Sediments are derived from meltwater from ice-marginal features proximal to Pleistocene glaciers of several ages in the Horn Mountains. Most Qof deposits in study area probably formed during pre-Wisconsin and early Wisconsin time and predate Qog deposits, which partially recycled outwash fan deposits. Qof deposits east of Sue Creek are ancestral to modern stream dissection and may be of Early Pleistocene age. Volcanic ash interbedded with and overlying outwash gravel in Kuskokwim River cuts (see text) tentatively correlated with Old Crow Tephra of Illinoian age. Unit reaches 15 m in thickness as measured on stream cuts on west side of Horn Mountains.

Glaciations

Till—Unsorted to poorly sorted diamicton composed of clay, silt, sand, gravel, and boulders deposited by glacial ice. Divided into four subunits that correspond to glacial chronology delineated in Kuskokwim Mountains by Bundtzen (1980), Kline and Bundtzen (1986), Waythomas (1990), and Bundtzen and Laird (1991). From youngest to oldest, they are as follows:

Qgt_4 CRATER MOUNTAIN GLACIATION—Largely unmodified till of early Holocene age; confined to northerly cirques;

Qgt_3 TOLSTOI LAKE GLACIATION—Till of late Wisconsin age, mainly consisting of undissected moraines in northerly valleys and cirques in south-facing valleys; carbon-14 age of 13,600 years BP determined on Getmuna Creek (table 6);

Qgt_2 BIFURCATION CREEK GLACIATION—Till of early Wisconsin or Illinoian age; consists of dissected moraine and modified land forms in all valleys of Horn Mountains;

Qgt_1 BEAVER CREEK GLACIATION—Till of pre-Wisconsin age; highly modified diamicton on planated summit levels beyond limits of Horn Mountains and erratic boulder trains; morainal morphology destroyed by erosion.

Eolian Deposits

Qer REWORKED LOESS DEPOSITS—Loess and fine-grained sand reworked by water in gullies and along lower slopes in southern part of study area downslope from Qe deposits.

Qe LOESS—Moderately well stratified, gray to tan weathered, highly micaceous eolian silt and minor fine-grained sand. Forms extensive deposits blanketing lowlands and broad ridges south of Kuskokwim River west of Napaimiut, and thin discontinuous sheets on hills east of Kolmakof River. Minor loess deposited southeast of Horn Mountains. Carbon-14 age determination from extensive loess blanket near Napaimiut is 16,640 years BP; other loess deposits upstream from Holokuk River mouth range from 11,760 to 26,446 years BP, or late Wisconsin in age (table 6). Bulk of loess probably deposited by winds blowing off the Aniak outwash fan west of the study area; some loess may have been derived from glacial outwash trains radiating from Horn Mountains massif.

Placer Tailings

Qht PLACER MINE TAILINGS—Irregular, stacked piles of water-washed gravel and in-place bedrock slabs confined to New York Creek drainage. Originally stream alluvium and slope colluvium artificially processed to recover placer gold and other heavy minerals.

INTRUSIVE ROCKS AND HORNFELS

TKsy GRANODIORITE, GRANITE, AND QUARTZ SYENITE—Light gray to greenish gray (altered), fine to medium grained, equigranular to hypidiomorphic, orthoclase-rich, biotite-bearing granodiorite, locally granite, and uncommonly quartz syenite. In a few thin sections original clinopyroxene (about 2 percent maximum of groundmass) altered to magnetite, chlorite, and leucoxene. Modal quartz averages 25 to 28 percent of groundmass and average plagioclase composition determined to be An27–An29 or oligoclase–andesine (Carlsbad–albite twinning method). Average differentiation index (DI) is 75.9 (table 2); color index (CI) is about 8–10. High-level portions of quartz syenite in Jungjuk Creek drainage impregnated with tourmaline probably related to intrusion of late hydrothermal breccias. Resistant and forms core of Horn Mountains massif.

TKsyp GRANODIORITE PORPHYRY, QUARTZ SYENITE, AND MINOR GRANITE—Brownish gray, greenish altered, fine grained to porphyro-aphanitic, tourmaline-bearing, biotite, muscovite granodiorite porphyry, locally quartz syenite and granite, and rarely quartz monzonite. Averages about 22 percent quartz or about 5 percent less than TKsy unit—the other phase of Horn Mountains pluton. Average differentiation index (DI) is 71.6 (table 2) and average normative plagioclase composition is An33 or andesine. Color index (CI) is 10 to 12. Original clinopyroxene (up to 4 percent of groundmass) is altered to magnetite and chlorite. In some thin sections, tourmaline (dravite) grains are replaced by plagioclase and biotite, which may suggest primary igneous crystallization of tourmaline—similar to paragenesis of ferroaxinite in Russian Mountains pluton west of study area (Hietanen and Erd, 1978; Bundtzen and Laird, 1991). Resistant, and with TKsy unit, forms Horn Mountains massif. $^{40}Ar/^{39}Ar$ age on biotite of 69.0 Ma (table 4).

TKgp PERALUMINOUS GRANITE PORPHYRY AND ALKALI QUARTZ GRANITE—Light gray to distinctly tan weathered, usually bleached, aphanitic to porphyro-aphanitic, locally garnet bearing, biotite, muscovite granite porphyry, locally alaskite. Generally restricted to large dike swarms, and linear hypabyssal bodies. Largest is Juninggulra Mountain complex, which is 12 km long and 4 km wide. Unlike TKsy and TKsyp units, TKgp does not produce hornfels aureole in enclosing Kuskokwim Group flysch. Always contains normative corundum (table 2) and frequently modal garnet, and is peraluminous. Average differentiation index is 91.46, and average plagioclase composition (An11) is albite–oligoclase (table 2). Color index is 5 or less. $^{40}Ar/^{39}Ar$ age of 69.6 and 68.7 Ma from Juninggulra Mountain complex (table 4) Forms moderately resistant hillslopes covered with distinct tan rubble.

TKgr GRANITE—Light gray, tan weathered, fine to medium grained, equigranular to hypidiomorphic, biotite, muscovite granite; probably a coarser grained version of TKgp unit on Aghaluk Mountain. Average differentiation index is 92.20 (table 2), and plagioclase (An9) is albite. Color index (CI) is 5 to 8. $^{40}K/^{40}Ar$ age of 72.0 Ma from small pluton north of Aghaluk Mountain. Forms resistant core of Aghaluk Mountain.

TKgd QUARTZ MONZODIORITE AND DIABASE—Medium gray to olive tan, aphanitic to fine grained, diopside, biotite quartz monzodiorite and diabase. Restricted to small plutons northwest of Getmuna and Little Creeks and large dike swarm north of Aghaluk Mountain. Peculiar to these rocks are interlocking diopside and plagioclase in hyalophitic or ophitic textures. Differentiation index ranges from 46.22 to 72.04 and average normative plagioclase composition (An48) is andesine (table 2). Color index is 25 to 35. Moderately resistant.

TKgb GABBRO-DIORITE AND QUARTZ DIORITE—Dark gray, fine-grained phaneritic, equigranular, clinopyroxene-rich biotite bearing gabbro-diorite and quartz diorite; restricted to a small plug south of Horn Mountains. Contains abundant euhedral labradorite phenocrysts (An53) near contact zones.

TKd,
TKdi DIKES AND DIKE SWARMS—Intermediate (TKdi) and undifferentiated (TKd) dikes and dike swarms, all of which are extensively altered to secondary minerals. In New York Creek area, Tkd dikes are mainly altered granite porphyry; in much of remaining area TKd dikes were mafic or picritic in composition, now altered to silica, carbonate, chlorite, and magnetite. Dikes rarely more than 4 m wide and 1 km in length.

TKhf HORNFELS—Brown to gray, massive to locally porphyroblastic, chlorite, biotite, tourmaline, axinite hornfels. Dark massive varieties difficult to distinguish from fine-grained volcanic rocks. Hornfels unit forms 1 km, wide, southern boundary zone of Horn Mountains massif, and peculiar, isolated knobs in three localities within Kolmakof River drainage. The latter localities probably indicate intrusions at depth. Volcanics in Horn Mountains are also thermally altered by the intrusive rocks, but not shown as hornfels on sheet 1. Protolith of most hornfels localities on sheet 1 is probably Kuskokwim Group clastic rocks.

VOLCANIC AND SEDIMENTARY ROCKS

Horn Mountains Volcanic Field

(this study)

Kolmakof Air-Fall Tuff

TKft RHYOLITE AND LATITE TUFF—Light greenish gray to nearly white, very fine grained to fine grained, platey, crystal lithic, air-fall tuff. Occurs as distinct graded sequences where each layer is 10 to 20 cm thick; interrupted by two thin augite-bearing trachyte flows. Normative plagioclase (An34) is andesine; average differentiation index (DI) is 68.62 (table 2). Unit is estimated to be 45 m thick south of Getmuna Creek. $^{40}Ar/^{39}Ar$ age of 68.1 Ma determined for Tkft unit, which represents stratigraphically highest volcanic lithology in Horn Mountains volcanic field. Forms nonresistant talus slopes.

Sue Creek Intermediate Tuff-Flow Sequence

TKvit LATITE AND POTASSIC ANDESITE TUFFS AND FLOWS—Medium green-gray, very fine grained, locally porphyritic, biotite-rich latite and high-potassium andesite flows and subordinate amounts of light greenish gray platey weathered crystal lithic tuff, and rare tuffaceous sandstone. Plagioclase grains are oligoclase–andesine (AN32) in composition, and differentiation index (DI) is 70.94 (table 2). Estimated to be 40 m thick west of Whitewing Creek. Forms resistant ridgelines and hillslopes.

TKa NONPORPHYRITIC ANDESITE FLOWS—Dark greenish gray, nonporphyritic, augite-bearing andesite flows interpreted as laterally equivalent to TKvit unit. Average normative plagioclase composition (An41) is andesine; average differentiation index (DI) is 56.41 (table 2). Estimated to consist of two flow units totaling 20 m in thickness; forms resistant hillslopes and ridges.

TKvi LATITE AND POTASSIC ANDESITE FLOWS—Porphyritic, medium gray, fine-grained oligoclase–andesine rich, clinopyroxene, biotite, high-potassium andesite, dacite, and latite flows that show distinctive columnar joints. Nine major flows recognized west of Whitewing Creek. Individual flows range from 5 to 15 m thick; minor interbedded tuff units separate some flows. Total TKvi unit estimated to be 200 m thick, and it forms one of the dominant units in Horn Mountains volcanic field. Average differentiation index (DI) is 72.25 for flows (table 2). Forms resistant cliff faces in cirque headwalls.

TKvip HIGHLY PORPHYRITIC ANDESITE FLOWS AND SUBORDINATE TUFF—Highly porphyritic, medium gray, porphyro-aphanitic, oligoclase–andesine rich clinopyroxene-bearing andesite, and subordinate medium greenish gray air-fall tuffs. May be laterally equivalent to TKvi unit. Estimated to be 90 m thick north of Jungjuk Creek; forms resistant slopes.

Jungjuk Mafic Flow Complex

TKpvm PORPHYRITIC BASALTIC ANDESITE—Medium to dark gray, locally maroon colored, porphyritic (labradorite phenocrysts), clinopyroxene-rich (15 percent of groundmass) basaltic andesite and minor agglomerate. Labradorite phenocrysts to 2 cm in length comprise up to 30 percent of groundmass in many samples. Columnar jointed flows estimated to be about 25 m in total thickness. Forms resistant knobs north of Horn Mountains.

TKgvm GEODE-RICH BASALTIC ANDESITE AND AGGLOMERATE—Dark green-gray, locally maroon, clinopyroxene-rich basaltic andesite containing conspicuous chalcedonic, agate-grade geodes up to 20 cm in diameter; unit also contains lapilli tuff and agglomerate that has elliptical bombs and fragmental volcanic clasts up to 0.5 m in diameter. Average differentiation index is 52.68; plagioclase is andesine (table 2). $^{40}Ar/^{39}Ar$ age of 68.9 Ma determined from Tkgvm sample. Estimated to be 25 m thick. Forms semi-resistant knobs north of Horn Mountains.

TKvm **Basaltic andesite flows**—Medium to dark green-gray, maroon or sooty locally, aphanitic to fine grained, clinopyroxene-rich (15–20 percent in groundmass) basaltic andesite; locally containing labradorite–bytownite phenocrysts. Well developed columnar jointing exhibited in a series of six or seven individual flows; total unit thickness is at least 75 m. Average differentiation index (DI) is 45.44 (table 2). $^{40}Ar/^{39}Ar$ whole rock age of 69.5 Ma (table 4). Forms resistant knobs and elongated ridgelines north of Horn Mountains.

TKvv **Vitreous andesite flows**—Dark brown to dark gray, fine grained, vitreous andesite containing broken crystals of normative plagioclase (An36), pale-green pyroxene, and rounded biotite flakes in a devitrified glassy matrix. Differentiation index (DI) from one flow is 68.97 (table 2). Estimated to be 10 to 15 m thick west of upper Getmuna Creek; forms nonresistant hogbacks and rubble on rounded slopes.

Getmuna Caldera Complex

TKdt **High-potassium andesite and latite tuff**—Light to medium green-gray, ubiquitously altered, fine-grained crystal lithic tuff, vitric tuff, and minor altered andesite flows. May include minor welded tuffs near base of unit. Some latitic vitric ash composed of cellular pumice, devitrified glass, and broken fragments of plagioclase and hypersthene. Where fresh, plagioclase determined to be andesine (An31). Differentiation index (DI) from six samples is 73.30 (table 2). Estimated to be 35 to 50 m thick; forms semi-resistant slopes and hogbacks.

TKat **Welded(?) vitric tuff**—Light gray, locally hematitically stained, fine to medium grained, quartz-saturated, biotite-rich, muscovite-bearing, vitric, welded (?) tuff. Broken phenocrysts of quartz, sanidine, and sedimentary rock clasts appear to float in a matrix of devitrified glass shards, and undetermined dust in a classic vitroclastic texture. One sample yields differentiation index (DI) of 62.06 (table 2). $^{40}Ar/^{39}Ar$ ages on biotite of 70.1 Ma (table 2). The unit markedly thins to the southwest, where grain size also decreases, suggesting that the eruptive center for the welded (?) vitric tuff was north of the Horn Mountains. Estimated to be 90 thick south of Juninggulra Mountain. Generally nonresistant and forms eroded hogbacks and flat upland terrain.

TKgrt **Coarse-grained vitric tuff**—Light gray, yellowish tan weathered, flaggy, coarse grained, muscovite-bearing, biotite-rich, quartz-saturated, vitric tuffs and pyroclastic breccias, the last of which contains sedimentary clasts up to 30 cm long. Contains devitrified glass (?), and broken quartz grains in a vitroclastic texture. TKgrt represents a coarse-grained variant of the TKat unit, and possibly formed proximal to a vent system. Differentiation index (DI) of one sample is 87.18 (table 2). $^{40}Ar/^{39}Ar$ age of 70.8 Ma from TKgrt near Juninggulra Mountain. Unit thickness is estimated at 50 m. Unit is more resistant than TKat, and forms more massive outcrops.

Iditarod Volcanics

(Miller and Bundtzen, 1988)

TKvmi **Basaltic andesite**—Dark maroon to gray, fine grained, clinopyroxene, labradorite-rich basaltic andesite flows and minor agglomerate. Plagioclase grains (An51) occur in a fine-grained matrix of clinopyroxene and undetermined feldspar and opaque minerals. TKvmi unit is part of Iditarod Volcanics as described by Miller and Bundtzen, (1988; 1994), and is compositionally similar to mafic volcanic units (TKvm, TKpvm, and TKgvm) in Horn Mountains volcanic field. Unit is estimated to be 20 to 30 m thick. Forms moderately resistant hogback ridges.

Kaci **Agglomerate, chert, tuff, and sandstone**—Medium to dark green agglomerate, chert, lapilli tuff, andesite breccia, and flow rock. Where recognizable, contains minor antigorized olivine, orthopyroxene(?), and hornblende grains in altered groundmass. Two major oxide analyses indicate andesite composition with andesine–labradorite (An32 and 43) plagioclase and differentiation indices (DI) of 63.71 and 60.63, respectively (table 2). Kaci may represent initial Iditarod Volcanics eruptive activity. Thickness of unit unknown due to isolated outcrop pattern; forms very resistant knobs and isolated hogback hills.

Kvti ALTERED INTERMEDIATE TUFFS, FLOWS, AND SANDSTONE—Heterogeneous, light tan to iron red, aphanitic to fine grained, altered andesite, dacite, and lithic tuff interbedded with quartzose, sublithic sandstone near unit base. Groundmass of most volcanic samples altered to silica (tridymite), carbonate, and chlorite; pseudomorphs of clinopyroxene found in andesitic rocks. Unit estimated to be about 100 m thick. Forms nonresistant, rounded, and subdued ridge rubble. Correlated with base of Iditarod Volcanics as defined by Miller and Bundtzen (1988) and mapped near Moore Creek in central Iditarod Quadrangle by Bundtzen and others (1988), where $^{40}K/^{40}Ar$ ages range from 75 to 77 Ma.

Kuskokwim Group

(Cady and others, 1955)

Ksq QUARTZOSE SUBLITHIC SANDSTONE AND SILICEOUS SHALE—Gray to light gray, fine to coarse grained, moderately well sorted, subangular to rounded, quartz-rich sandstone, pebble conglomerate, siliceous siltstone, and shale. Sand layers lack graded sequences and contain crossbeds, coalified organic mattes, and shell coquina, all of which suggest a shallow-water shoreline environment of deposition. Regional petrographic studies indicate mixed provenance of metamorphic, sedigenic, and volcaniclastic source areas. Estimated to be at least 200 m thick in study area. Resistant as compared to all other Kuskokwim Group lithologies, and forms steep ridgeline terrain.

Ksc COARSE-GRAINED SANDSTONE AND PEBBLE CONGLOMERATE—Gray to medium greenish gray, indurated, fine to coarse grained, volcaniclastic sandstone interbedded with pebble sandstone and pebble conglomerate. Some layers exhibit high calcium carbonate content; clast composition, based on three thin sections, is polycrystalline quartz (24 percent), mixed volcanic fragments mainly intermediate composition (35 percent), chlorite (8 percent), white mica (5 percent), calcite (10 percent), shale rip-ups (15 percent), and other (2 percent). Bulk of Ksc formed by turbidity currents as exhibited by coarse Bouma T_{abc} intervals recognized in outcrop. Commonly, presence of *Inoceramus sp.* prisms indicate Cretaceous age. Unit estimated to range from 150 to 250 m thick; wedge shaped in cross section. Moderately resistant as compared to other Kuskokwim Group lithologies.

Kss NONCALCAREOUS LITHIC SANDSTONE AND SHALE—Light to medium gray, subangular to rounded, medium-grained lithic sandstone and micaceous shale. Hand specimen and limited thin section examination show variable sedigenic and metamorphic provenance for sands in Kss unit. Graded T_{abcd} Bouma intervals and flutes suggest deposition by turbidity currents. No reliable thickness estimate available; repeated section on Kuskokwim River may be at least 500 m thick. Generally nonresistant.

Kslt LIMEY SANDSTONE AND SHALE—Heterogeneous unit of medium greenish gray, distinctly tan-weathered, fine to coarse grained, limey sandstone and shale. Sandstone and siltstone exhibit flute casts, rip-ups, and Bouma T_{bcde} intervals indicating turbidity current deposition. Sand:shale ratio is about 1:3. Equivalent to much of the basinal portions of Kuskokwim Group described by Bundtzen and others (1992) and Miller and Bundtzen (1994). No thickness estimate available. Forms very nonresistant rubble-covered hillslopes and depressions.

Ksh SHALE AND SILTSTONE—Medium to dark gray, finely laminated siltstone and shale. Thin sandstone interbeds averaging 2 cm thick contain clasts of radiolarian chert, mica, chlorite, and volcaniclastic debris. Forms base of Cretaceous Kuskokwim Group section southeast of Iditarod–Nixon Fork fault near Iditarod River. Estimated to be about 150 m thick, but base of unit is not exposed. Generally nonresistant and forms loose rubble along vegetated hilltops.

Kssf QUARTZITE SANDSTONE, SHALE, AND SLUMP BRECCIA—Unusual section of light gray to nearly white, bleached, quartz-rich sandstone interbedded with organic-rich shale, bone coal, and fragments of plant-rich beds each 10 to 20 cm thick. Large-scale rotated blocks of quartzite sandstone up to 4 m in diameter in upper part of the section might suggest marine foreslope environment, or channel slumping in a marine estuary. Sand:shale ratios vary from 1:1 in plant-rich zones up to 10:1 in massive channel (?) facies. Section is best exposed along

Holokuk River about 4 km above its mouth. Kssf section estimated to be about 600 m thick. The upper and lower limits of the Kssf unit are encased in deeper water turbidite and shallow water facies of the Kuskokwim Group. Generally friable and nonresistant and forms eroded lowlands in lower Holokuk River valley.

Kssq **Fine-grained sublithic sandstone and siltstone**—Light to dark gray, locally olive green, mostly fine to very fine grained, tight, siliceous volcaniclastic, sublithic sandstone, and light gray, organic-rich, leaf-bearing siltstone. Invertebrate fossils rare or absent. Thought to be stratigraphically below altered tuffs and sandstone (Kvti unit) of Iditarod Volcanics. Estimated to be about 150 m thick in study area; similar unit is 400 m thick near Flat in Iditarod Quadrangle (Bundtzen and others, 1992). Generally nonresistant and forms rubble on rounded slopes.

Kssp **Coarse-grained, proximal turbiditic sandstone and siltstone**—Medium gray, medium to coarse grained, lithic and sublithic sandstone, and minor siltstone. Flutes and graded Bouma T_{ab} and T_{abc} intervals, coupled with sand:shale ratio exceeding 10:1, suggest proximal turbidite depositional environment. In addition, death assemblage of *Inoceramus sp.* up to 1 m thick found at Gibraltar Point fossil locality would indicate proximity to shoreline or shallow water environment. Cady and others (1955) reported *Inoceramus athabaskensis* and *I. nahwisi* from this locality; both species are regarded as Turonian (stage)or early Late Cretaceous in age. Kssp is overturned; we estimate unit is 150 m thick at Gibraltar Point. Kssp is moderately resistant.

Kus **Undifferentiated sandstone, shale, and siltstone**—Heterogeneous unit of generally gray to green gray, fine to medium grained, lithic sandstone and micaceous shale and siltstone. Forms monotonous repeated section along Kuskokwim River and undifferentiated unit throughout study area. No specific thickness estimate available; repeated section along Kuskokwim River in eastern Sleetmute C-8 Quadrangle estimated to be 1,200 m true thickness. Forms generally nonresistant upland rubble and moderately resistant bluffs along riverbanks.