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# GEOLOGIC MAP OF THE EASTERN HALF OF THE MCGRATH QUADRANGLE, ALASKA

by

T.K. Bundtzen, E.E. Harris, and W.G. Gilbert

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**DEPARTMENT OF NATURAL RESOURCES**

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Tony Knowles, *Governor*

John T. Shively, *Commissioner*

Milton A. Wiltse, *Director and State Geologist*

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**[in envelope]**

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# GEOLOGIC MAP OF THE EASTERN HALF OF THE MCGRATH QUADRANGLE, ALASKA

by
T.K. Bundtzen,[1] E.E. Harris,[1] and W.G. Gilbert[2]

## INTRODUCTION

This geological synthesis of the eastern McGrath Quadrangle summarizes systematic 1:63,360-scale geologic mapping conducted by the Alaska Division of Geological and Geophysical Surveys (DGGS) from 1980 to 1989 (sheet 1). Geological maps of the McGrath C-1 (Kline and others, 1986), McGrath B-1 (Bundtzen and others, 1997a), McGrath B-2 (Bundtzen and others, 1982), McGrath B-3 (Gilbert and others, 1990), McGrath A-1 (Bundtzen and others, 1997b), McGrath A-2 (Bundtzen and others, 1987), and McGrath A-3 (Gilbert and others, 1988) quadrangles were combined and compiled at 1:125,000 scale (fig. 1). We have completed photo-interpretation of Quaternary deposits on the piedmont north of the Alaska Range mountain front, and added unpublished bedrock information from the McGrath B-2, C-2 and D-1 quadrangles.

The geologic map synthesis has also benefited from regional surficial geologic investigations by Fernald (1960) and Kline and Bundtzen (1986), from regional geologic mapping by Reed and Lanphere (1972) and Reed and Nelson (1980), and from detailed mapping in the Windy Fork area (Herreid, 1968) and Terra Cotta Mountains (Churkin and Carter, 1996).

## GEOGRAPHY

The eastern McGrath Quadrangle lies roughly astride the boundary between the steep, glacially-carved peaks of the Alaska Range-Southern region on the south, and the northwest-sloping piedmont of the Tanana-Kuskokwim Lowland on the north (Wahrhaftig, 1965). The Denali-Farewell high-angle fault system, which exhibits evidence of active (Holocene) movement in the study area, forms this abrupt boundary (sheet 1). The map area is drained by the northerly flowing South, Windy, Middle, and Big Salmon Forks of the Kuskokwim River and smaller tributary streams. Elevations range from approximately 400 ft (122 m) on lower South Fork in the McGrath D-3 Quadrangle to an unnamed 7,880 ft (2,402 m) peak in the west-central McGrath A-2 Quadrangle. Small glaciers occupy cirques and cap the highest mountain massifs in the Windy Fork and Dillinger River drainages.

The map area contains no maintained roads; however, a 5,580 ft (1,700 m) long gravel airstrip is seasonally operative at the former Farewell Federal Aviation Administration (FAA) station immediately north of the mountain front. Smaller private airstrips throughout the map area could be used in emergencies. The historic Iditarod Trail diagonally crosses the map area for about 120 mi (190 km) from Happy Valley near Rainy Pass northwestward to lower South Fork.

## PRE-ACCRETIONARY BEDROCK TERRANES

A geologic sketch of the map area is depicted in figure 2. Bedrock units in the eastern McGrath Quadrangle range in age from Late Proterozoic (?) to Pliocene (fig.3; sheet 1). Most layered rock units were originally described by Brooks (1911) as the Tatina Group, after exposures on the Tatina River in the Eastern McGrath Quadrangle. The predominantly Paleozoic and Mesozoic rocks exposed in the map area have been considered to be the Yukon-Tanana, Pingston, Minchumina, and McKinley terranes, which are exposed north of the Denali-Farewell Fault, and the Dillinger, Mystic, and Kahiltna terranes, which are exposed mainly south of the Denali-Farewell Fault. Jones and Silberling (1979) and Jones and others (1983, 1986) described all of them as discrete, fault-bounded, tectono-stratigraphic terranes. Decker and others (1994) and Plafker and Berg (1994) combined the Dillinger, Nixon Fork (not exposed in eastern McGrath Quadrangle), Minchumina, and Mystic terranes into a Farewell composite terrane (FCT), and believe all four constitute subterranes that are linked to each other in complex but normal stratigraphic relationships; the Farewell composite terrane was later dismembered, and individual subterranes are now separated by major strike-slip faults.

## FAREWELL COMPOSITE TERRANE

### DILLINGER SUBTERRANE

Churkin and others (1977) first presented graptolitic and stratigraphic information for a Lower Paleozoic rock section in the southern Terra Cotta Mountains of the western Alaska Range. Armstrong and others (1977) referred

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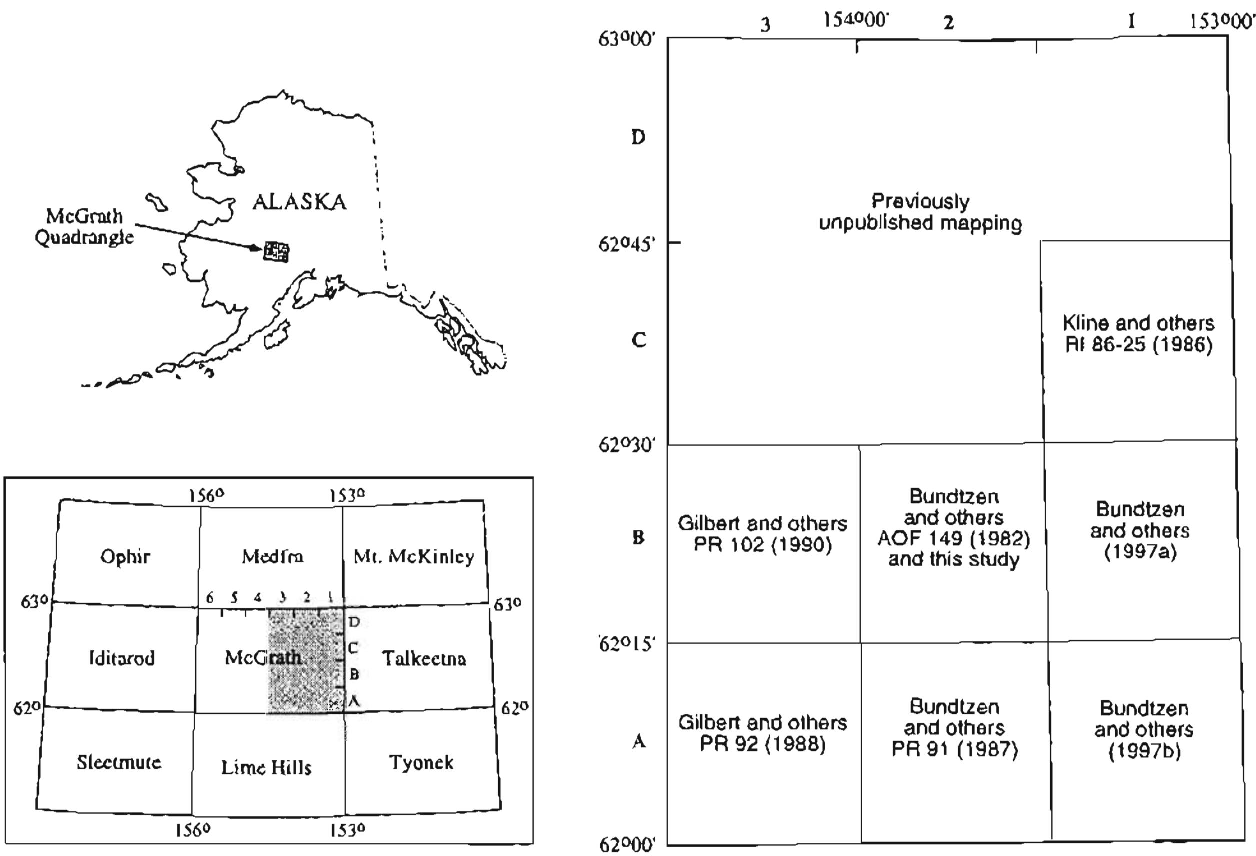


Figure 1. *Index maps showing location and sources of 1:63,360-scale mapping for geologic map of the McGrath Quadrangle, eastern half, Alaska.*

to these rocks as "sedimentary rocks of the Dillinger River." Jones and others (1983) used the term "Dillinger Terrane" to describe a coherent, but complexly-folded assemblage of shale, sandstone, and deep water limestones of Ordovician to Devonian age. For the most part we have adopted the formation nomenclature proposed by Churkin and Carter (1996) for the Dillinger subterrane.

The Dillinger subterrane in the eastern McGrath Quadrangle consists of (1) the Lyman Hills Formation, an Upper Cambrian to Lowest Ordovician (Tremodocian) silty limestone and shale (OCls) containing intraformational gabbro-diorite sills and dikes (MzPzi); (2) the Post River Formation, Lower Ordovician to upper Lower Silurian graptolitic shale, chert, and limestone (SOsh, lSl); (3) the Terra Cotta Sandstone, mid to Upper Silurian sandstone turbidite, shale, and laminated limestone (mSvs, mSs, mSl, uSsl); and (4) the Barren Ridge Limestone, Upper Silurian to Lower Devonian (Pragian Stage) massive laminated limestone, limestone breccia, calcarenite, and calcareous siltstone (DSl). Although we retain the name Post River Formation for Lower Ordovician to upper Lower Silurian graptolitic shales, chert, and limestone, we correlate the "lower siltstone member" of the Post River Formation (Churkin and Carter, 1996) with the top of the Lyman Hills Formation, after a thick sedimentary succession exposed in the Lyman Hills west of the study area (Gilbert, 1981; Bundtzen and others, 1994).

Bundtzen and Gilbert (1983) suggested that the Dillinger subterrane reflects a generally shallowing upwards, marine regression that includes basinal (Lyman Hills and Post River Formations), turbidite fan (Terra Cotta Sandstone), and foreslope (Barren Ridge Limestone) deposits that were emplaced along a displaced part of the North American continental margin. The Lyman Hills, Post River, and Terra Cotta Sandstone Formations contain 21 graptolite zones spanning most of the Ordovician and Silurian systems, one of the most complete graptolite successions in the world (Churkin and Carter, 1996; C. Carter, written commun., 1994; Bundtzen and others, 1994). However, no graptolites from the Ashgillian stage (Late Ordovician) have yet been found.

The Dillinger subterrane in the map area ranges from 6,900 to 9,000 ft (2,100 to 2,750 m) thick reflecting the thickening and thinning nature of the Terra Cotta Sandstone. Individual members change little in lithologic character laterally; however, the prominent limestone unit of Wenlockian age (mSl) is thickest north of the Tatina River and nearly disappears in the Middle Fork and the northwestern western parts of the map area. The Post River Formation becomes more chert rich in a northeasterly direction east of South Fork. Most sandstones in the Terra Cotta Sandstone are feldspathic litharenites (Folk, 1968), and show a recycled orogen provenance; however, petrographic analysis of a thin sandstone unit of Wenlockian age on Tunis Mountain (mSvs) indicates a volcaniclastic provenance distinct from the bulk of the Silurian turbidite fan.

A facies relationship probably existed between the Dillinger subterrane and the coeval, shallow water dominated carbonate platform lithologies of the Nixon Fork subterrane to the north (Bundtzen and Gilbert, 1983; Decker and others, 1994); this suggests that an Upper Cambrian to Lower Devonian shoreline probably existed northwest of the map area. The Terra Cotta Sandstone yields numerous bimodal northeast and southwest paleocurrent measurements (Bundtzen and others, 1987; this study), which suggests that current direction paralleled the axis of the continental margin. A progressive increase in carbonate content in younger clastic rocks of the Dillinger subterrane may indicate that carbonate platform deposits, possibly from the Nixon Fork subterrane, supplied increasing amounts of carbonate detritus as the progressively younger Dillinger deposits regressed shoreward.

We note similarities between the Lyman Hills Formation in the study area and the Rabbit Kettle Formation of Upper Cambrian to Lower Ordovician age, which crops out in the Selwyn Basin of Yukon, British Columbia, and Northwest Territories, Canada (Gordey and Anderson, 1993). Diorite and gabbro sills (MzPzi) that intrude the Lyman Hills Formation are distinctly alkaline (Bundtzen and others, 1994), and are similar to alkalic mafic sills that intrude the Rabbit Kettle Formation in northern British Columbia, Canada (Gabrielse, 1963).

The Post River Formation may correlate with the lower and middle Road River Formation, which overlies the Rabbit Kettle and equivalent lithologies in central Yukon Territory, Canada, and east-central Alaska (Gordey and Anderson, 1993).

The Terra Cotta Sandstone might be equivalent to calcareous sandy siltstone portions of the upper Road River Formation in central Yukon, or poorly mapped clastic deposits of mid to Late Silurian age exposed on the "Cassiar Platform" of northern British Columbia (Gabrielse, 1963; Grant Abbott, oral comm., 1996).

The Barren Ridge Limestone is similar to mapped carbonate debris deposits exposed along the western edge of the Cassiar Platform in British Columbia, Canada (Gabrielse, 1963).

Our speculative correlation of the Dillinger subterrane with coeval rocks in northern Canada implies that up to 950 mi (1,500 km) of cumulative right-lateral offset was taken up along the Denali-Farewell, Tintina, and related strike-slip faults, accompanied by counterclockwise rotation of mainland Alaska. The amount of offset is consistent with the scenario suggested by Plafker and Berg (1994), who proposed that the Farewell Composite Terrane originated along the North American continental margin in Cambrian-Devonian time, and subse-

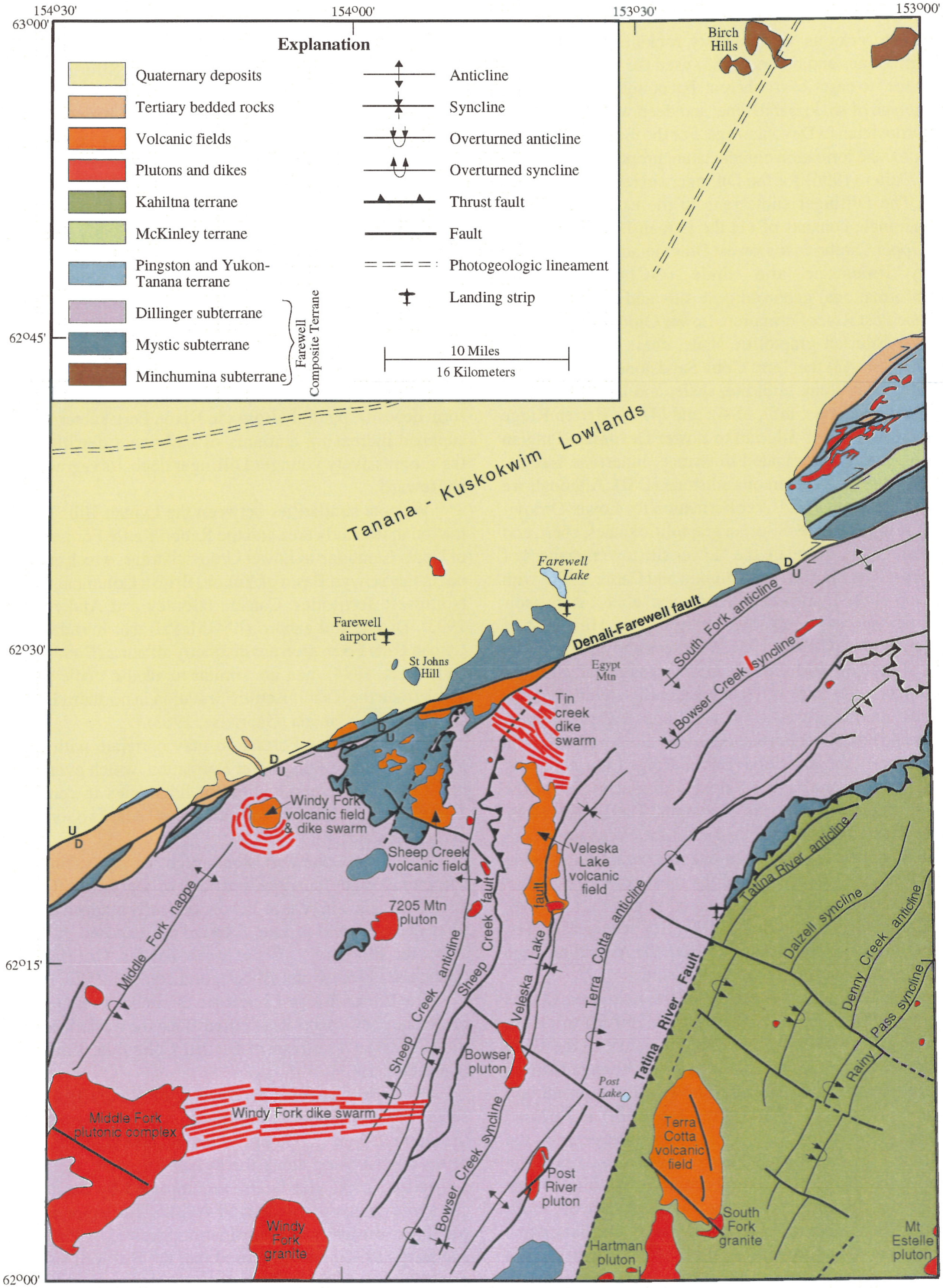


Figure 2. *Sketch map showing terranes and subterranes, volcanic fields, plutons, and major structural features of the eastern half of McGrath Quadrangle, Alaska. Modified from geologic map, this report.*

quently moved into its present position in western Alaska during the Mesozoic and Cenozoic.

## MYSTIC SUBTERRANE

The Dillinger subterrane in the eastern McGrath Quadrangle is both stratigraphically and structurally overlain by sublithic clastic rocks, both shallow and deep water limestones, banded chert, and pillow basalt that range in age from the Emsian stage of the Early Devonian to the Sinemurian stage of the Early Jurassic. These rocks were described as the Mystic terrane by Jones and Silberling (1979) after exposures mapped by Reed and Nelson (1980) in the Talkeetna Quadrangle. South of the Denali-Farewell fault, the base of the Mystic subterrane is the Sheep Creek Formation (PDs), a clastic-dominated section ranging in age from the Eifian stage of the late Early Devonian to Middle (?) Permian. The base of the Sheep Creek Formation south of the Denali-Farewell fault is discontinuously marked by a massive, *Amphipora*-bearing, algal limestone (lDl) that overlies the Dillinger terrane. The middle portion of the Sheep Creek Formation is characterized by coarse grained, plant-rich turbidite sandstone, shallow water, calcareous fusilinid-bearing sublithic sandstone of Pennsylvanian-Permian age, and non-marine, plant rich, pebble conglomerate that contains Middle Pennsylvanian to Middle Permian (?) plant fossils. This latter conglomerate, which is best exposed at the southern boundary of the map area south of Post River, may be correlative with the "Conglomerate of Mount Dall" as described by Reed and Nelson (1980) in the central Talkeetna Quadrangle.

Overlying the Sheep Creek Formation are the Tatina River Volcanics, which consist of volcaniclastic sandstone, chert (Trs), olivine-rich pillow basalt (Trab), and volcaniclastic sandstone, phosphatic shale, and chert pebble conglomerate (lJs) that have yielded Upper Triassic and Lower Jurassic pelecypod collections. Fossil evidence for the time interval of Late Permian to Middle Triassic that separates the Sheep Creek Formation and Tatina River Volcanics has not yet been recognized. Chemically, the pillow basalts are quartz-hyperstene-normative tholeiites.

Pre-Triassic rocks of the Mystic subterrane in the Tatina River area have apparently been removed by low angle faulting probably related to the Tatina Fault, which is part of a 2-km-wide suture zone that separates the Kahiltna terrane (assemblage) from the Dillinger and Mystic subterranes.

North of the Denali-Farewell fault, the Mystic subterrane consists of laminated and massive micritic limestone and siltstone of Early (?) Devonian and early Late Devonian (Frasnian) age (Dls, uDl) overlain by calcareous clastic lithologies of the Sheep Creek Formation (PDs), which are in turn overlain by tholeiitic pillow basalt (Trab) of the Tatina River Volcanics. The base of the Mystic subterrane differs on both sides of the Denali Farewell fault in the eastern McGrath Quadrangle. The prominent section of megafossil-rich Frasnian limestone that flanks Farewell Mountain does not appear on the south side of the fault in the map area. However, carbonate reef deposits of Frasnian age crop out near the base of the Mystic subterrane in the Shellabarger Pass area of the Talkeetna Quadrangle (Reed and Nelson, 1980). The Frasnian section on the south side of the Denali-Farewell fault in the eastern McGrath Quadrangle is represented by a much thinner section of concretion-rich, conodont-bearing limestone and chert. The basal Early (?) Devonian laminated limestone on St. Johns Hill, which forms the base of the Mystic subterrane north of the fault, is believed to be a distal deeper water facies of the *Amphipora*-bearing algal limestone west of Sheep Creek.

We believe that the pillow basalt section exposed north of the Denali-Farewell fault is part of the Mystic subterrane although Kline and others (1986) and Reed and Nelson (1980) consider them to be part of the McKinley terrane. Samples collected during our studies show tholeiitic pillow basalt sections on both sides of the Denali-Farewell fault to be chemically indistinguishable. For example both basalt sections contain copper contents ranging from 250 to 400 ppm and low $K_2O$, Ba, and Rb, and high $TiO_2$.

The Mystic subterrane, which reaches a maximum thickness of about 3,100 ft (945 m), represents less stable tectonic conditions and more diverse local depositional environments than those of the underlying Dillinger subterrane. Facies relationships between individual formations are poorly understood. The existence of tholeiitic pillow basalt of the Tatina River volcanics on top of shallow marine and non-marine deposits of the Sheep Creek Formation is puzzling. Additionally, Early Jurassic clastic rocks that overlie the tholeiitic volcanics contain pelecypod- and cephalopod-rich death assemblages that are believed to have formed in shallow water environments. Bundtzen and Gilbert (1983) suggested that tholeiitic pillow basalt and gabbro sills now assigned to the Tatina River volcanics reflect a continental margin rift. Limited trace element data reported by Reed and Nelson (1980) from Mystic subterrane pillow basalt in the Talkeetna Quadrangle show them to be the ocean floor type (Pearce and Cann, 1973); however, associated rocks also indicate subaerial volcanism.

## MINCHUMINA SUBTERRANE

Metaquartzite and calcareous phyllites of the PzpCs unit poorly exposed in the northeast corner of the map area have been assigned to the Telida subterrane of the

Minchumina subterrane, a northeast-trending belt of deep water limestone, chert, argillite and quartzite of Late Proterozoic (?) and Lower Paleozoic age that extends 188 mi (300 km) from the study area into the central Kantishna River Quadrangle (Patton and others, 1994). Decker and others (1994) and Patton and others (1994) interpret the Minchumina subterrane to be part of an extensive, but discontinuous, deep water continental margin facies that is, in part, coeval with the Nixon Fork subterrane, and are perhaps low-grade metamorphic equivalents to the Dillinger subterrane.

## MCKINLEY, PINGSTON, AND YUKON-TANANA TERRANES

Three poorly-exposed terranes are structurally juxtaposed against each other north of the Denali-Farewell fault in the northeastern part of the map area. They include siliceous phyllite and meta-chert (uPzc and uPzs) assigned to the Yukon-Tanana terrane (Gilbert and Bundtzen, 1984), limestone and shale (Trls) of the Pingston terrane (Gilbert and others, 1984) and slate and phyllite (KJm) of the McKinley terrane (Gilbert and others, 1984). Gilbert and Bundtzen (1983) suggested that the Yukon-Tanana, Pingston, and possibly McKinley terranes originated at different positions along a common continental margin defined by the Yukon-Tanana block. This interpretation is reinforced by geologic mapping in the eastern McGrath Quadrangle. Limestone and shale (Trls) of the Pingston terrane and slate (KJm) of the McKinley terrane stratigraphically overlie phyllitic chert and phyllites (uPzc) and volcanogenic phyllite (uPzs) that probably represent a distal manifestation of Mississippian volcanism in the Totatlanika Schist (Gilbert and Bundtzen, 1979), a subdivision of the Yukon-Tanana terrane.

## KAHILTNA TERRANE (ASSEMBLAGE)

A thick, tectonically collapsed, isoclinally folded flysch sequence is structurally juxtaposed against the Mystic subterrane in the southeastern portion of the study area. These rocks are correlative with the Kahiltna terrane or assemblage, named after exposures in the upper Kahiltna River area of south-central Alaska (Jones and others, 1983). Three units have been mapped on the basis of clast size and sedimentary facies: sandstone and shale (KJsh), coarse sandstone and siltstone (KJs), and conglomerate and sandstone (KJc). The Kahiltna terrane (assemblage) in the map area is at least 15,000 ft (4,570 m) thick.

Five fossil localities in the eastern McGrath Quadrangle have yielded Neocomian or Hauterivian (Early Cretaceous) pelecypods, the same general age range reported from the "northern Kahiltna assemblage" of Nokleberg and others (1994). About 5 mi (8 km) south of the mouth of the Tatina River near Rohn Roadhouse, a thin limestone member of the KJsh unit contains abundant *Inoceramus* prismite beds, of probable Early Cretaceous age. Eakins and others (1978) reported Kimmeridgian (Late Jurassic) pelecypods from Kahiltna flysch near Lake Clark about 170 mi (270 km) to the southwest of the map area.

The Kahiltna terrane (assemblage) in the eastern McGrath Quadrangle includes slope, inner fan, and mid fan environments, and contains north or northwest directed paleocurrent indicators. In the map area, the northern boundary of the Kahiltna terrane (assemblage) with the Mystic subterrane is marked by a profound low-angle fault zone expressed as a 1-km-wide zone of intense shearing. According to Nokleberg and others (1994), the southern boundary of the Kahiltna terrane (assemblage) formed along the northern edge of the Wrangellia Composite Terrane (WCT) prior to its emplacement along the Alaskan continental margin.

# POST-ACCRETIONARY LAYERED ROCKS

## LATE CRETACEOUS-OLIGOCENE VOLCANIC FIELDS

Four volcanic fields of Late Cretaceous-to-Oligocene age overlie the Kahiltna terrane and Dillinger subterrane mainly south of the Denali-Farewell fault zone; small bodies of probable related younger volcanics also exist north of the Denali-Farewell fault. From oldest to youngest, these are the Late Cretaceous-early Tertiary (65.8 Ma) Veleska Lake volcanic field, the early-to-late Eocene (41.3-48.9 Ma) Sheep Creek volcanic field, and the late Eocene-Oligocene (31.3-41.1 Ma) Terra Cotta and Windy Fork volcanic fields (see Solie and others, 1991, for K-Ar age compilation).

All four fields contain similar morphological, textural, and compositional variations. Hence, although the volcanic fields are spatially and age distinctive, we have depicted the same unit designators in the three mid-Tertiary volcanic fields (see Description of Map Units).

The Veleska Lake volcanic field includes basaltic andesite (TKvm), intermediate and rhyolitic air fall tuff (TKvt, TKvf), and dacite flows and dikes (TKvd) that probably formed near a vent system. Numerous, small subvolcanic intrusions and dikes that intrude the Veleska Lake volcanic field could not always be distinguished from compositionally similar extrusive rocks; they are sometimes included into the volcanic units.

The Terra Cotta volcanic field is characterized by massive and lapilli dacite (Tvld, Tvd) andesite flows and lapilli tuff (Tva), air fall tuff (Tvt), and vent facies dacite

(Tvvd) and green tuff and lahar deposits (Tvgt, Tvl) that were probably deposited immediately over a volcanic vent center (see structural cross section D-D', sheet 1)). The Hartman pluton exposed along the south flank of the Terra Cotta Volcanics is about the same K-Ar age (37.9 Ma) as those obtained from the Terra Cotta volcanic field (31.3-to-41.1 Ma), suggesting the pluton and volcanic field collectively constitute a coeval volcanic-plutonic complex similar to those exposed in the Kuskokwim Mineral Belt of southwestern Alaska (Bundtzen and Miller, 1997).

The Sheep Creek Volcanic Field contains basalt and basaltic andesite flows (Tvm) that are successively overlain by andesite flows and lapilli tuff (Tva), several cycles of coarse- to fine-grained air fall tuff (Tvt), and finally capped by volcaniclastic and lacustrine sediments (Tvs). We speculate that the latter sediments were deposited in a crater lake that formed over a volcanic center. The Windy Fork volcanic field has been largely eroded away leaving only a ring dike complex (Tids) and the root zone of a volcanic center (Tva, Tvf).

Despite some age and compositional differences, rhyolite, dacite, and andesite from the Veleska Lake, Terra Cotta, and Sheep Creek volcanic fields exhibit low $K_2O$ (1.28-2.73 percent), lack of $Fe_2O_3$ + FeO enrichment (2.40-6.60 percent), moderate $Al_2O_3$ (13.39-18.27 percent), and low $TiO_2$ (0.27-0.97 percent), typical of calc-alkaline magmas related to subduction. Moll-Stalcup (1994) suggests that chemical signatures of Late Cretaceous to mid-Tertiary volcanic rocks of central Alaska are related to plate motion and subduction conditions in the Kula and Pacific plates.

Collectively, the Sheep Creek, Windy Fork, and Terra Cotta volcanic fields have a similar age range and similar calc-alkaline compositions to those reported in both the Teklanika Formation (Gilbert and others, 1976) and the Mount Galen volcanics (Decker and Gilbert, 1978), which form early and middle Tertiary volcanic fields in the central Alaska Range about 150 mi (240 km) northeast of the study area.

## TERTIARY AND TERTIARY-QUATERNARY SEDIMENTARY ROCKS

Poorly exposed Tertiary sedimentary rocks crop out discontinuously along the north flank of the Alaska Range immediately north of the Farewell-Denali fault zone. These include sandstone and shale (Ts), coal-bearing sandstone, shale, and conglomerate (Tcg), felsite conglomerate (Tcf), limestone conglomerate (Tcl), and consolidated till and outwash (QTg). Both the Ts and Tcg units are thought to be part of the Little Tonzona coal field exposed at Little Tonzona River in the Talkeetna Quadrangle (Sloan and others, 1979). The coal-bearing section near Windy Fork is 90 percent conglomerate, and contains highly volatile bituminous C or subbituminous A coal beds up to 20 ft (6 m) thick (Gilbert and others, 1990). Samples from one coal seam contain yellow amber barren of pollen; however, pollen from Tertiary conglomerate in the Windy Fork area yielded Eocene-to-middle Oligocene ages (Atlantic Richfield Company unpublished report, 1980).

Paleocurrent indicators and petrographic data from the Tertiary deposits flanking the front of the Alaska Range in the eastern McGrath Quadrangle (Dickey, 1984) are similar to those in the central Alaska Range adjacent to Nenana River valley (Wahrhaftig and others, 1969; Stevens, 1971). During the Eocene and Oligocene, sediments shed from a metamorphic upland to the north were transported southward across the present-day Alaska Range. On the basis of the southward-directed paleocurrents and similarities of conglomeratic-rich sections in the study area and those in the Susitna Lowland, Wahrhaftig and others (1994) suggested that the Little Tonzona coal field area may be the source region for streams of Eocene to Middle Oligocene age that flowed through the Susitna Lowland to the Cook Inlet Region—obviously prior to the formation of the Alaska Range. A shift to a southerly local source took place in Miocene (?) to Pliocene time (Tcf, Tcl), and volcanic and carbonate-rich clasts of local derivation were deposited in an orogenic piedmont environment.

Gravity surveys conducted by the Alaska Department of Natural Resources in 1981 and 1983 (Meyer and Krouskop, 1986; Henning and others, 1984) suggest that much of the piedmont from the Alaska Range mountain front to the Kuskokwim River is underlain by thin to moderately thick Tertiary sedimentary rocks—locally thickened in graben-derived basins.

Tilted, consolidated till and outwash (QTg) that crops out in a thin band near Big Salmon Fork near the eastern boundary of the map is thought to be equivalent to the Pliocene-early Pleistocene Nenana Gravel, an extensive glacio-fluvial deposit overlying the Healy coal bearing group in the central Alaska Range (Wahrhaftig and others, 1969; Thorson, 1986).

## INTRUSIVE ROCKS

The eastern McGrath Quadrangle contains a wide variety of plutons, dikes and sills that range in age from Lower Paleozoic (?) to Miocene. The oldest are considered to be pre-accretionary in age and include Mesozoic-Paleozoic gabbro-diorite sills (MzPzi), Triassic picrite, ankaramite, and diorite sills (Trum), and Jurassic-Cretaceous gabbro-diorite sills (KJg) that intrude intraformationally into the lower Dillinger and upper

Mystic subterranes, and Pingston terrane respectively. The Triassic sills (Trum) are believed to be feeders for mafic volcanism in the Tatina River volcanics. The MzPzi and KJg units probably represent emplacement in rift environments or in sutures between terranes. All three suites exhibit tholeiitic and mildly alkaline chemistry (Bundtzen and others, 1994; Gilbert and others, 1984).

Post accretionary Cretaceous and Tertiary plutonic rocks fall into six age groups: (1) Late Cretaceous and possibly earliest Tertiary (67.4-79.0 Ma) gabbro and granodiorite (TKqm, TKm) that intrude the Dillinger subterrane and Kahiltna terrane (assemblage) mainly east of South Fork; (2) Paleocene (55.6-57.7 Ma) alkali gabbro to granite of the Middle Fork plutonic complex (Tgqm, Tgb, Tgsy, and Tsy; Solie, 1983, 1988) and South Fork Granite (Tgr; Bundtzen and others, 1997b); (3) small Paleocene-to-early Eocene (51.1-61.8 Ma) quartz monzonite to quartz porphyry plutons (Tqm); (4) extensive late Paleocene to Eocene (45.5-55.0 Ma) mafic and intermediate dike swarms (Tim); (5) late Eocene (37.6-39.3 Ma) granodiorite and quartz porphyry (Tgd-Hartman pluton and Veleska Lake intrusion); and (6) Oligocene to early Miocene (20.9-30.1 Ma) trachyandesite-to-basalt dike swarms (Tia) and the Windy Fork peralkaline granite (Twg). Solie and others (1991) provided a K-Ar age compilation for the map area.

There appears to be a progressive younging of intrusive rock ages from east to west although we are unsure of the plutonic and tectonic significance of this trend. Most of the plutons exhibit typical reduced and oxidized, metaluminous, calc-alkaline chemistry (Bundtzen and others, 1987); however, the Windy Fork granite and Middle Fork plutonic complex are peraluminous and display mildly- to strongly-alkaline character (Solie, 1983, 1988), which implies their origins in one or more highly differentiated, shallow, magma chambers. Many plutons from the Tertiary suites contain features associated with magmatic stoping, as indicated by extensive intrusive breccias and xenolith development at the Middle Fork plutonic complex, the Bowser Creek pluton, and dike swarms in the Tin Creek-Veleska Lake area.

## QUATERNARY DEPOSITS

About 55 percent of the eastern McGrath Quadrangle is covered by 19 unconsolidated Quaternary units that were deposited in glacial and glaciofluvial (Qg, Qrg, Qof, Qdo, Qdot, Qdic, Qdt, Qdtf, Qdts, Qdtlm, Qdtplm), fluvial (Qa, Qaf, Qat), colluvial (Qca, Qct, Qcl) and eolian (Qe, Qsp) settings. Quaternary deposits in the many stream valleys of the Alaska Range portion of the study area are relatively thin due to the rapid stripping and flushing downstream toward the piedmont slope, where thick accumulations of alluvial fan deposits, outwash fan deposits, and till are ubiquitous north of the northernmost strand of the Denali-Farewell fault.

Six major periods of glaciation are inferred from drift and diamicton in the eastern McGrath Quadrangle (Kline and Bundtzen, 1986). Where possible, maximum drift limits are depicted on the map as thick, barbed dashes; Roman numeral designations on the drift limits increase sequentially toward the younger deposits. The oldest glaciations, Big Salmon Fork and pre-Lone Mountain, named after highly modified drift near Big Salmon Fork and north of Lone Mountain, are regarded as late Tertiary and Early Pleistocene in age. Drift of the Lone Mountain, Selatna, Farewell I, and Farewell II glaciations are believed to be middle Pleistocene, Illinoian, early Wisconsin, and late Wisconsin in age, respectively (Fernald, 1960; Kline and Bundtzen, 1986). At least two Selatna, two Farewell I, and four Farewell II stades have been recognized. Unnamed recessional drift limits behind the mountain front are assigned early to late Holocene ages; drift not assigned to specific glaciations (Qdt) range in age from Wisconsin to Holocene.

Permafrost is discontinuous in Quaternary deposits of the eastern McGrath Quadrangle, and occurs primarily on slopes of northerly aspect and in older deposits on the piedmont slope. Test pits in peaty material overlying Farewell I drift showed that the top of the permafrost is usually about 1 m below the surface. Peat bogs overlying older Quaternary deposits are frozen nearly from the surface. Active stream channels and some ancestral stream deposits are usually thawed.

# STRUCTURE AND TECTONIC SUMMARY

## FOLDING

North of the Denali-Farewell fault, pre-accretionary rocks were deformed by two or more periods of isoclinal folding; axial surfaces in bedrock outcrops are commonly vertical or near vertical. Pre-mid Cretaceous regional metamorphism recrystallized the Pingston and Yukon-Tanana lithologies to greenschist facies conditions (Gilbert and Bundtzen, 1979). Poor exposure limited detailed structural analyses in these rock units. The fold deformation is younger than the Jurassic-Cretaceous deposition of the McKinley terrane, and older than the emplacement of Cretaceous-Tertiary felsic intrusions (TKf).

South of the Denali-Farewell fault, a strong compressional and low-grade dynamic metamorphic event deformed the pre-accretionary Dillinger and Mystic subterranes, and Kahiltna assemblage, producing a series of sub-isoclinal, generally overturned folds, that range from outcrop to nappe scales (see cross sections, sheet 1). Accompanying the large-scale F1 fold event is a penetrative axial plane foliation (S1) that is subparallel to the limbs of the folds. F1 folds are superseded by kink bands and related slip cleavage. The axes of many F1 fold structures including the Terra Cotta, Sheep Creek, Dalzell, and South Fork anticlines and synclines can be traced for up to 65 mi (105 km) along strike. Many smaller folds that occur on the limbs of the larger fold structures are not depicted in the cross sections. Most sub-isoclinal folds trend N10-40 degrees east, plunge northeast, and are overturned to the northwest. However, west of the Sheep Creek fault and east of Windy Fork, fold asymmetry is reversed, and axes plunge to the southwest and the sub-isoclinal folds are overturned to the southeast. The largest fold structure—the Middle Fork anticline (nappe)—exhibits an amplitude of approximately 10 mi (16 km) in the western part of the map area (see cross section D-D', sheet 1). Collectively the numerous sub-isoclinal folds that deform the Dillinger and Mystic subterranes and Kahiltna terrane are responsible for an estimated 60 mi (96 km) of crustal shortening in the eastern McGrath Quadrangle.

The strongly developed F1 sub-isoclinal folds and related structures in the pre-accretionary terranes south of the Denali-Farewell fault must have taken place after the deposition of the Lower Cretaceous (Hauterivian) Kahiltna terrane flysch and before the emplacement of the oldest dated, early Late Cretaceous (Santonian), nondeformed TKm intrusion (or within the time interval 79-115 Ma). The F1 isoclinal folds have been subsequently deformed by an unusual, very large scale kink (see sheet 1) that might be related to a poorly understood period of left-lateral (?) motion along the Denali-Farewell fault system.

After formation of the Sheep Creek volcanic field in Eocene time, the layered rocks were deformed by east-west to northeast-trending broad open folds with amplitudes ranging from 3 to 12 mi (5 to 19 km). This later folding episode locally steepened thrust faults and sub-isoclinal folds.

## FAULTING

Thrust faults thought to be synkinematic with the mid-Cretaceous F1 folding event observed in the pre-accretionary rock units have been identified west of South Fork and east of Middle Fork. The boundary between the Dillinger and Mystic subterranes in the Sheep Creek area is thought to be a thrusted unconformity. The Tatina River fault zone, which structurally juxtaposes the Kahiltna terrane and Mystic and Dillinger subterranes, is thought to be a low-angle suture, and is locally mapped as one or more thrust faults.

Younger northeast-trending high-angle faults, including the Sheep Creek fault, cut Paleocene-Eocene dike swarms east of Windy Fork. The north to northeast-trending Veleska Lake fault removed unit uSsl north of Bowser Creek, and disrupted the Dillinger subterrane section in the Tin Creek area; related faults may also control the emplacement of linear north-south oriented early Tertiary plutons, and the Terra Cotta and Veleska Lake volcanic fields.

Northwest-trending high-angle faults cut older F1 folds and northeast-trending high-angle and low-angle faults south of the mountain front. The northwest-trending high-angle faults contain left lateral offsets of up to 3 mi (5 km), and vertical displacements of up to 500 ft (152 m) as along the south limit of the Sheep Creek volcanic field; however, commonly, very little offset can be determined along the northwest-trending high-angle faults of the study area. Several structures, including the Bowser Creek and Tin Creek high-angle faults, appear to control emplacement of late Tertiary dikes and plutons related to epigenetic, polymetallic mineralization.

The abrupt mountain front of the eastern McGrath Quadrangle is bounded by the Denali-Farewell fault, a strand of the larger Denali fault system that trends arcuately across Alaska and Yukon Territory, Canada, for a distance of nearly 1,500 mi (2,400 km). This fault zone has, in places, broken the piedmont slope and adjacent foothills of the study area into a linear, 5-mile-wide (8-km-wide) zone of horsts and grabens. The active trace of the fault system shifts to a more southerly strand from west to east across the eastern McGrath Quadrangle. Regional studies indicate that up to 95 mi (150 km) of right-lateral slip has taken place along the Denali-Farewell fault in western Alaska and up to 250 mi (400 km) along the Denali-McKinley fault in the central Alaska Range (Forbes and others, 1974; Nokleberg and others, 1994). Further to the northeast of the study area in the Mt. McKinley Quadrangle, Reed and Lanphere (1974) demonstrated that the McGonagall and Foraker plutons were originally part of a single igneous mass that was right-laterally displaced 24 mi (38 km) along the Denali-McKinley fault since about 38 Ma. Mystic subterrane rock units occur on both sides of the active strand of the Denali-Farewell fault—suggesting that the more fundamental fault boundary lies north of the mountain front, and is largely buried under Quaternary deposits. The rapid reduction of right-lateral offset along the larger Denali Fault system from south-central to western Alaska (250 to 95 mi; 400 to 150 km) might be explained by cumulative offsets along multiple fault strands (i.e., as exposed in the northern map area), and by significant structural shortening generated by the 79- to 115-million-year-old sub-isoclinal folding event that deformed pre-accretionary units south of the Denali-Farewell fault.

Deformation that folded Oligocene-Eocene coal deposits caused the Denali-Farewell fault to act as a structural buttress.

Vertical offsets in Quaternary units and numerous, recently active fault scarps attest to recent vertical displacement along the Denali-Farewell fault zone that is related to uplift of the Alaska Range. Antecedent dissection of streams that cross horsts contain numerous strath terrace deposits, the oldest of which are tilted by vertical movement along the fault. Furthermore, offset glacial deposits, sag ponds, and fault scarps suggest middle and late Quaternary vertical displacement of up to 100 ft (30 m) along the Denali-Farewell fault system.

## ECONOMIC GEOLOGY

Mineral production in the map area has been confined to modest aircraft shipments of selected silver-rich base metal skarn deposits at Bowser Creek in the late 1960s (Reed and Elliott, 1968a,b). The Chip-Loi cobalt-nickel deposit was briefly explored in the 1960s (Herreid, 1968). A base-metal massive sulfide skarn deposit near Smith Lake in the McGrath B-2 Quadrangle was explored by a small adit sometime prior to 1980 (Bundtzen and others, 1982). During the 1980s, modern mineral exploration companies looked at metallic mineral potential throughout the "Farewell mineral belt"; however, most firms ceased activities by about 1990. Table 1 summarizes geologic and geochemical information for 35 selected metallic mineral deposits and energy resources in the eastern McGrath Quadrangle.

The map area contains a variety of polymetallic mineral deposits and energy and industrial mineral resources. Mineral deposit types (after Cox and Singer, 1986) include: (1) numerous copper-magnetite and low-temperature, fracture-controlled lead-zinc-silver-tungsten skarn and replacement bodies as at Rat Fork, Ozzna, Tin, Bowser, and Sheep creeks, Smith Lake, and Post River (Bundtzen and others, 1982, 1987; Reed and Elliott, 1968a,b; Szumigala, 1987); (2) copper-molybdenum porphyry mineralization at Ozzna Creek; (3) disseminated to massive sulfide nickel-cobalt PGE deposits near Sheep Creek, Middle Fork, Post Lake and at the Chip Loi prospect (Foley and others, 1997; Herreid, 1968; Gilbert and others, 1988; Bundtzen and others, 1987); (4) polymetallic veins in the Hartman pluton (Bundtzen and others, 1997b); (5) anomalous uranium, thorium, rare earth elements and semi-precious stones (eudialyte) in the peralkaline Windy Fork pluton and in downstream placer deposits (Reed and Miller, 1980; Gilbert and others, 1988; Gunter and others, 1993); (6) poorly understood, stratiform sedimentary-exhalitive (?) pyrite-sphalerite lenses in upper Lower Silurian shale and chert of the Post River Formation (Bundtzen and others, 1982, 1987); and (7) Creede type epithermal (?) precious metal occurrences in the Terra Cotta volcanic field.

Although highly anomalous copper contents (average=307 ppm) have been found by Bundtzen and others (1994) in Late Triassic pillow basalt of the Tatina River volcanics, no significant volcanogenic massive sulfide mineral occurrences have been discovered in the study area. However, the Tatina River volcanics host significant, cupreous, volcanogenic massive sulfide mineralization at Shellabarger Pass in the Talkeetna Quadrangle (Reed and Eberlein, 1972).

Significant coal resources hosted in the Tertiary sedimentary basins flanking the mountain front have been summarized by Solie and Dickey (1982). Construction materials have been described by Kline and Bundtzen (1986), Gilbert and others (1988, 1990), and Kline and Pinney (1997). The extensive peat deposits overlying much of the piedmont slope might be suitable for energy or horticultural applications.

During our investigations we noted extensive use by both bison and moose of several mineral licks along the active strand of the Denali-Farewell fault south-southwest of Farewell Lake Lodge.

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Besides the numerous geologists recognized in the mapping efforts (see map credits on sheet 1), we would like to acknowledge Michael Churkin Jr. and the late Bruce Reed for their valuable insights concerning regional geology of the area. DGGS geologists D.N. Solie and J.T. Kline participated in geologic mapping and made important contributions toward understanding the Middle Fork Plutonic Complex and glaciation in the area, respectively. Regional terrane correlations benefited from cooperative field exchanges with Canadian geologists Grant Abbott and S.P. Gordey, who have mapped Paleozoic and Mesozoic stratigraphy in northwestern Canada that is similar to rock units in the map area.

In addition we could not have completed the synthesis of the eastern McGrath Quadrangle without the support of many government and private paleontologists; many of whom were former employees of the U. S. Geological Survey. These include Claire Carter and Michael Churkin Jr. (graptolites), R.B. Blodgett and W.A. Oliver (Paleozoic corals and pelecypods), J.W. Miller, N.J. Silberling, and W.P. Elder (Mesozoic pelecypods), R.C. Douglas (fusilinids), C.J. Smiley (Tertiary plant fossils), D.L. Jones and K.M. Reed (radiolaria), and Anita Harris, J.E. Repetski, M.J. Orchard, and Tim Carr (conodonts).

We dedicate this map synthesis and report to our friend and colleague, the late Jeffrey T. Kline.

Table 1. *Summary of selected metallic mineral deposits and energy resources from the Eastern McGrath Quadrangle, Alaska; map numbers keyed to sheet 1*

| | Name of Deposit | Mineral Deposit Type (#)[1]; Principal Commodities | Description and Cited References |
|---|---|---|---|
| 1 | Farewell Mineral Licks | Ungulate Mineral Licks | Series of three licks composed of yellow-brown residual soils; each average 50 m in diameter in Quaternary drift along 0.6 miles (1 km) of active strand, Denali-Farewell Fault. Used extensively by buffalo (*Bison bison.*) and moose (*Alces alces*). (Bundtzen and others, 1982; this study.) |
| 2 | Windy Fork Coal | Subbituminous coal | Contains steeply dipping 20 to 65 ft (6 to 20 m) coal-shale sections with individual coal beds yielding btu values ranging from 7,587 to 11,742. No resource estimate calculated. (Solie and Dickey, 1982; Dickey, 1984.) |
| 3 | Tin Creek North | Copper-iron skarn (deposit #18b); Pb, Zn, Cu, Ag, Cd | Thin 2 to 6 in (5 to 15 cm) johannsenite-garnet-sphalerite (blackjack)-galena replacement zones in argillaceous limestone (mSl unit) near 29 Ma granodiorite dike (Tia). Contains up to 2.25 percent Cu, 1.21 percent Pb, 0.11 percent Zn, 0.13 percent Cd, and 319.8 grams/tonne Ag. (Bundtzen and others, 1982; Szumigala, 1987; this study.) |
| 4 | Tin Creek Midway | Low temperature Pb-Zn skarn (deposit #18c); Pb, Zn, Cu, Ag, Cd | Massive to disseminated sphalerite (blackjack), galena, pyrite, pyrrhotite, and uncommon arsenopyrite, chalcocite and magnetite in exoskarn bodies and sulfide mantos near 25 to 30 Ma granodiorite dike swarm; grades of 0.35 percent Cu, 0.17 percent Pb, 5.55 percent Zn, 0.05 percent Cd, and 13 grams/tonne Ag; at least 352,700 tons (320,000 tonnes) of polymetallic mineralization inferred from Anaconda Minerals diamond drill program. (Bundtzen and others, 1982; Szumigala, 1987; Rob Kell, written commun., 1984.) |
| 5 | Unnamed (81BT428-429) | Low temperature Pb-Zn skarn (Deposit #18c); Pb, Cu, Zn, Cd, Ag, Co | Magnetite-diopside-garnet-sulfide skarn pods developed in argillaceous limestone (mSl unit) near contact with hornblende granodiorite dike. Contains up to 2.30 percent Cu, 0.30 percent Pb, 6.20 percent Zn, 110 grams/tonne Ag, 0.05 percent Cd, 100 ppm Bi, and 100 ppm Co. (Bundtzen and others, 1982.) |
| 6 | Unnamed (81BT549; 89BT316) | Disseminated (Norilsk-like) Cu-Ni-PGE ? (Deposit #5b) Cu, Ni, Cr, Bi | Differentiated picrite-diorite sills that intrude Mystic Terrane have magnetite-rich, sulfide-bearing zones that contain up to 0.02 percent Cu, 0.06 percent Ni, 100 ppm Bi, and 0.10 percent Cr; some network pyrrhotite-pyrite-magnetite textures noted in gabbro-diorite phases of differentiated sills. Anomalous Cu and Ni found in nearby streams eroding prospect area. (Bundtzen and others, 1982; Reed and Elliott, 1968b; this study.) |
| 7 | Tin Creek South | Low temperature Pb-Zn skarn (Deposit #18c); Cu, Pb, Zn, Ag, Cd | High grade, massive sulfide bearing diopside-garnet skarn zone in carbonate xenolith within complex Tertiary dike swarm; contains up to 0.04 percent Cu, 1.30 percent Pb, 14.70 percent Zn, 58 grams/tonne Ag, 300 ppm Co, 1,000 ppm Bi, and 200 ppm Cd. (Bundtzen and others, 1982.) |
| 8 | Little Bird | Polymetallic replacement (Deposit #19a); W, Cu, Au | Replacement zone along northeast trending fault contains scheelite, chalcopyrite, and visible Au. (Bundtzen and others, 1982; Rob Kell, written commun., 1984.) |
| 9 | Post # 2 or Veleska Lake | Polymetallic replacement (Deposit #19a); Cu, Pb, Zn, Ag | Pyrrhotite-rich gossan about 10 ft (3 m) wide in fracture filling in basaltic-andesite flow (TKvm unit); contains 1.17 percent combined Cu-Pb-Zn with 7 grams/tonne Ag. (Bundtzen and others, 1982; Smith and Albanese, 1985.) |

[1]After Cox and Singer (1986).

| | Name of Deposit | Mineral Deposit Type (#); Principal Commodities | Description and Cited References |
|---|---|---|---|
| 10 | Unnamed (81JC 102) | Low temperature Pb-Zn skarn (Deposit #18c): Cu, Pb, Zn, Ag, Co | Massive sulfide skarn near felsic sill contains 0.50 percent Cu, 0.11 percent Pb, 13.0 percent Zn, 26 grams/tonne Ag, and 300 ppm Co. (Bundtzen and others, 1982.) |
| 11 | Unnamed (81BT339) | Polymetallic vein (Deposit #22c); Cu, Pb, Zn, Ag, Au | Silicified vein breccia in sandstone and limestone (mSs, mSl units) with disseminated chalcopyrite and galena along east-west fracture; contains 0.85 percent Cu, 0.98 percent Pb, 0.58 percent Zn, 86 grams/tonne Ag, and 0.85 grams/tonne Au.(Bundtzen and others, 1982.) |
| 12 | Unnamed (81BT322-345) | Sedimentary exhalitive Pb-Zn ? (Deposit #31a); Pb, Zn, Ag, V | Random exposures of sulfurous-rich shale (SOsh unit) contain up to 0.06 percent Pb, 0.17 percent Zn, 2.7 grams/tonne Ag, and 1,000 ppm V. (Bundtzen and others, 1982.) |
| 13 | Smith Lake | Polymetallic vein (Deposit #22c): Cu, Pb, Zn, Ag, Co, Bi | N45E trending massive pyrrhotite-galena-sphalerite shear zone about 3 ft (1 m) thick in sandstone (mSs unit) explored by 15 ft (4 m) adit; contains up to 1.05 percent Cu, 1.74 percent Pb, 5.22 percent Zn, 42 grams/tonne Ag, 100 ppm Co, and 100 ppm Bi. (Bundtzen and others, 1982; Smith and Albanese, 1985.) |
| 14 | Sheep Creek or Dall | Polymetallic replacement (Deposit #19a): Cu, Zn, Ag | Disseminated to massive pyrite-chalcopyrite replacement zones in granite porphyry dike and SOsh shale; contains up to 5.40 percent Cu, 3.48 percent Zn, and 165 grams/tonne Ag. Drilled by Anaconda Minerals in 1981-82. (Rob Kell, written commun., 1984; Smith and Albanese, 1985.) |
| 15 | Rat Fork | Copper-iron skarn (Deposit #18b): Cu, Pb, Zn, Ag, Fe, Cd, Co, Au, Sn | Aerially extensive zone of sulfide-rich endo- and exoskarn developed in 1 mile wide (1.5 km) granodiorite dike swarm. Disseminated to massive chalcopyrite, pyrrhotite, magnetite, and sphalerite formed paragenetically late garnet-wollastonite diopside skarn traceable for about 80 ft (25 m) and widths of 8 ft (2.4 m). Selected zones contain up to 2.00 percent Cu, 300 grams/tonne Ag, 2.0 grams/tonne Au, 9.18 percent Pb, 14.10 percent Zn, 0.12 percent Cd, 276 grams/tonne Ag, and 200 ppm Sn. Two old drill pads observed on steep cirque headwall. (Bundtzen and others, 1982; Reed and Elliott, 1968b; Smith and Albanese, 1985; this study.) |
| 16 | Ozzna Creek | Porphyry copper-molybdenum ? (Deposit #21a); Cu, Pb, Zn, Ag | Disseminated chalcopyrite in extensive pyrite-rich halo around quartz monzonite breccia pipe at 7,205 Mtn. Contains up to 0.08 percent Cu, 1.50 percent Pb, 1.00 percent Zn, 15.0 grams/tonne Ag, and 2.7 grams/tonne Au. (Reed and Elliott, 1968b; Bundtzen and others, 1982.) |
| 17 | Robert's PGM or Middle Fork | Disseminated (Norilsk) Ni-Cu-PGE ? (Deposit #5b); PGE, Ni | Disseminated to massive pyrrhotite chalcopyrite, bravoite, and sphalerite in network-textured, gabbro-diorite sill intruding Triassic pillow basalt of Tatina River Volcanics. Bench-test studies conducted by U.S. Bureau of Mines show up to 4.71 percent Ni, 0.16 percent Co, 4.68 percent Cu, 6.16 grams/tonne Pt, 7.7 grams/tonne Pd, and 4.7 grams/tonne Au as recovered from a sulfide flotation concentrate. (W.S. Roberts, written commun., 1984; Foley and others, 1997.) |
| 18 | Chip-Loi | Limassol Co-Ni-Cu ? (Deposit #8c), Cu, Ni, Co | Massive and disseminated pyrrhotite, chalcopyrite, and bravoite mineralization 1 to 2.5 ft (0.3 to 0.75 m) thick in both phyllitic sandstone (mSs unit) and mafic diabase (Tim unit); both host rocks contain up to 1.14 percent Cu, 2.21 percent Ni, 0.15 percent Co, and 37.6 percent Fe. Network sulfides common in diabase. At least 275,600 tons (250,000 tonnes) of massive and disseminated sulfide mineralization inferred. (Gilbert and others, 1988; Herreid, 1968; W.S. Roberts and T.K. Bundtzen, written commun., 1984.) |

| | Name of Deposit | Mineral Deposit Type (#); Principal Commodities | Description and Cited References |
|---|---|---|---|
| 19 | Unnamed (82MK92-93) | Sedimentary exhalitive Pb-Zn ? (Deposit #31a), Zn, Mo | 13 ft (4 m) thick pyrite-sphalerite bearing section of Lower Silurian graptolite zone in SOsh unit averages 395 ppm Zn. (Bundtzen and others, 1987; this study.) |
| 20 | Unnamed (88BT177) | Polymetallic vein (Deposit #22c) As, Au | N70E quartz vein cuts Kahiltna flysch; contains 0.16 percent As and 150 ppb Au. (Bundtzen and others, 1997b; this study.) |
| 21 | Bowser Creek Northeast | Low temperature Pb-Zn Skarn (Deposit #18c); Pb, Zn, Ag | Massive sulfide-galena-sphalerite pods up to 10 ft (3 m) wide in laminated limestone of DSl unit; contains up to 24.0 percent Pb, 22.1 percent Zn, and 391 grams/tonne Ag. (Red and Elliott, 1968a; Bundtzen and others, 1987.) |
| 22 | Bowser Creek Central and South | Low temperature Pb-Zn skarn and Polymetallic vein (Deposit #18c and 22c) | Bowser Creek Central contains several sphalerite-chalcopyrite-quartz veins hosted in 60 Ma quartz porphyry phase of Bowser Creek pluton; veins can be traced for about 450 ft (137 m); Bowser Creek South is massive galena-sphalerite (blackjack)-pyrrhotite-johannsenite pods in marble front adjacent to monzonite breccia pluton. Best assays from both deposits are 1.09 percent Cu, 23.7 percent Pb, 12.3 percent Zn, 169 ppm Co, and 2,510 grams/tonne Ag. Modest production of high grade silver ore shipped by aircraft in 1969-73. (Reed and Elliott, 1968a; Bundtzen and others, 1987.) |
| 23 | Unnamed (83BT303) | Sedimentary exhalitive Pb-Zn ? (Deposit #31a) Zn, Ag | Three 4 in (10 cm) thick pyrite bands in SOsh unit contain disseminated sphalerite; one sample contained 700 ppm Zn, 1.2 grams/tonne Ag, and 31 ppm Mo. (Bundtzen and others, 1987.) |
| 24 | Windy Fork Placer | Ilmenite-REE alluvial placer (Deposit # not available) Ilmenite-REE, Zr | Extensive alluvium sampled at the intersection of tributary stream draining Windy Fork pluton and Windy Fork averages several percent ilmenite and monazite, and up to 2.0 percent zircon. Cerium concentrations noted in trace element analyses. (Jim Barker, written commun., 1996); Gilbert and others, 1988.) |
| 25 | Unnamed or Eudialyte | Polymetallic vein (Deposit #18c) U, Th, Zr, REE, gemstones | Hematite-quartz feldspar veins in joints of Windy Fork Granite contain up to 490 ppm U, and 404 ppm Th in two localities; eudialyte (a zirconium-REE silicate) was observed in talus associated with a hornblende pegmatite phase of the pluton. (Reed and Miller, 1980; Gilbert and others, 1988.) |
| 26 | Unnamed (82BT321) | Sedimentary exhalitive Pb, Zn ? (Deposit #31b), Pb, Zn, Ag | Chip samples of sulfurous shales of SOsh unit contain up to 0.87 percent Zn, 0.02 percent Pb, and 4.5 grams/tonne Ag. (Bundtzen and others, 1987.) |
| 27 | Unnamed (82BT316,486) | Sedimentary exhalitive Pb, Zn ? (Deposit #31b), Zn, Cu, Ag | Random chip samples of sulfurous SOsh shales in Lower Silurian graptolite zone contain up to 1.37 percent Zn, 0.12 percent Cu, and 13.6 grams/tonne Ag. (Bundtzen and others, 1987.) |
| 28 | Post River Pluton | Polymetallic vein (Deposit #22c); W, Sn, Cu, Pb, Ag | Three ft (1 m) wide chalcopyrite-scheelite-quartz vein in skarn and several small veins in border phase of 62 Ma Post River pluton contain up to 1.15 percent Cu, 0.18 percent Pb, 0.03 percent W, 0.09 percent Sn, and 98 grams/tonne Ag. (Bundtzen and others, 1987.) |

| | Name of Deposit | Mineral Deposit Type (#); Principal Commodities | Description and Cited References |
|---|---|---|---|
| 29 | Post Lake Prospect | Polymetallic replacement (Deposit #19a); Cu, Zn, As, Co, Ni | Fracture controlled massive pyrrhotite deposits cut altered shale (SOsh unit) in bedrock canyon near contact with quartz monzonite stock. Sulfide zones range from 1.5 to 6 ft (0.5 to 2 .0 m) wide and 65 to 260 ft (20 to 80 m) long and contain up to 570 ppm Cu, 156 ppm Co, 378 ppm As, 302 ppm Zn, and 637 ppm Ni. (Bundtzen and others, 1987.) |
| 30 | Unnamed (88HA5,6) | Au placer (Deposit #39a), Au | Pan concentrate from second order stream cutting Eocene Terra Cotta volcanic field contains several grains of gold. (This study.) |
| 31 | Unnamed (88BT169) | Creede epithermal vein ? (Deposit #25b), As, Au, (Co), W, Sb | Sulfide gossan zone in quartz-eyed rhyodacite tuff yields 240 ppb Au, 0.22 percent As, 880 ppm W, 110 ppm Co, and 200 ppm Sb. (This study.) |
| 32 | Unnamed (88HA8,10,11,12) | Alluvial placer Sn (Deposit #39e); Sn, W | Pan concentrates from several first and second order streams cutting Kahiltna terrane and 59 Ma South Fork Granite contain 0.022 to 1.00 percent Sn, 0.023 to 0.14 percent W, and up to 11 ppm Ta. (This study.) |
| 33 | Unnamed (88BT150, 151) | Creede epithermal vein ? (Deposit #25b); As, Au, Sb, Zn | Intense zone of adularia-kaolinite-ferricrete hydrothermal alteration in dacite-andesite flows of Eocene Terra Cotta volcanic field. Grab samples of fault breccia and gossan zone over 350 feet (107 m) of strike and 150 ft (46 m) in width contains 0.42 percent As, 360 ppb Au, 0.21 percent Zn, and 150 ppm Sb. (This study.) |
| 34 | Unnamed (88BT163-165) | Polymetallic vein (Deposit #22c); Au, W, As, Ag, Cu | Grab samples of galena-chalcopyrite-pyrite-quartz vein stockwork in Hartman pluton from core to eastern edge contains up to 180 ppb Au, 710 ppm W, 830 ppm As, and 27 grams/tonne Ag. (This study.) |
| 35 | Unnamed (88DNS107) | Creede epithermal vein ? vein (Deposit #25b); Au, As, W, Sb | Pyrite rich-quartz veins, which locally carry galena, cut dacite intrusion and dacite lapilli tuff near contact with Kahiltna flysch. Talus grab samples carry up to 0.40 percent As, 2,100 ppb Au, 550 ppm W, and 110 ppm Sb. (This study.) |

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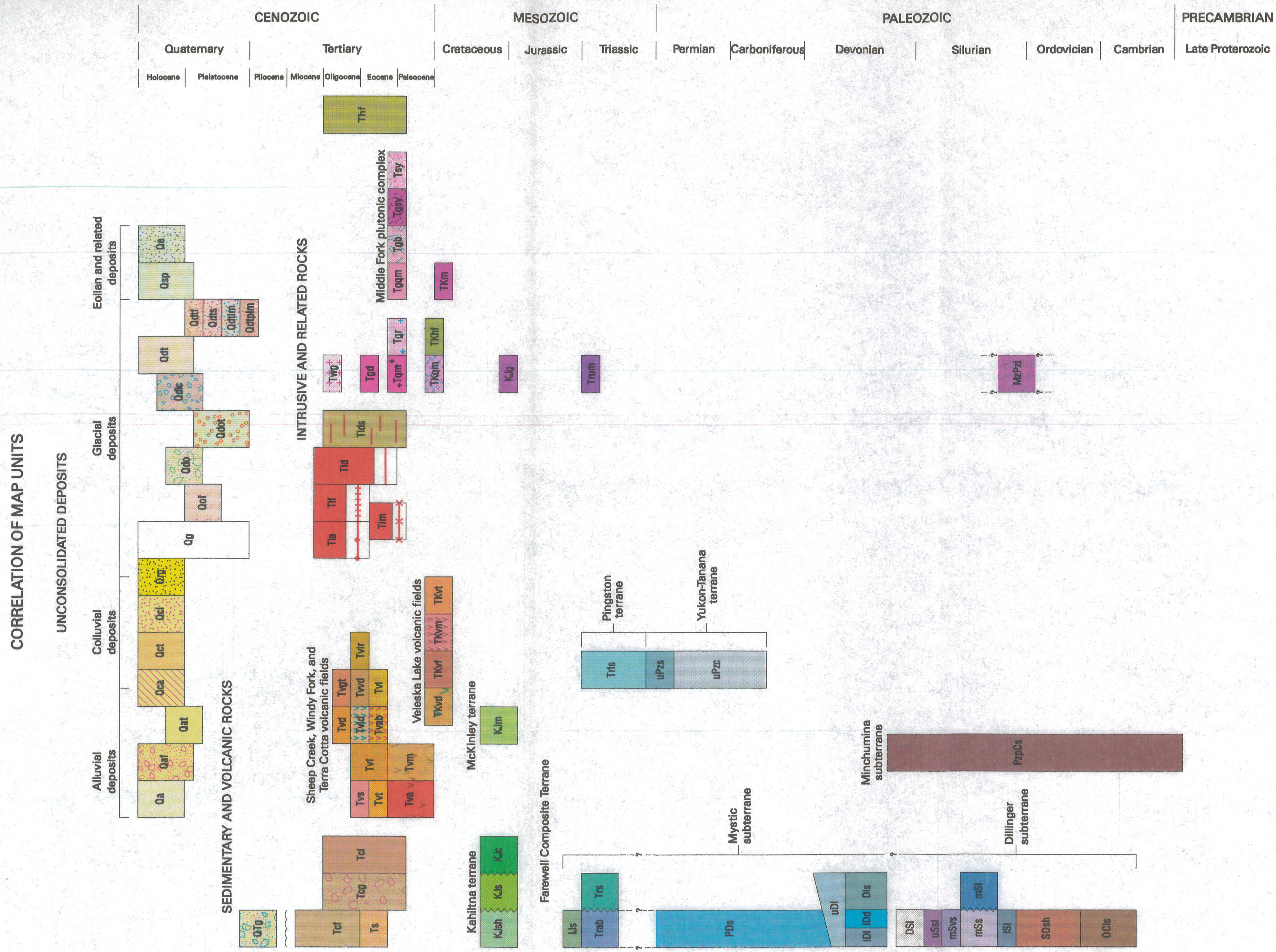


Figure 3 - to accompany sheet 1

# DESCRIPTION OF MAP UNITS

## UNCONSOLIDATED DEPOSITS

### ALLUVIAL DEPOSITS

Qa STREAM ALLUVIUM, UNDIFFERENTIATED–Fluvial silt, sand, and gravel deposited by streams in Holocene floodplains, fans, and meandering to distributary stream channel deposits. Grain size, sorting, and degree of stratification vary according to stream size, bedrock source, gradient, and flow regime. Clasts of local and distal derivation indicate a mixture of local bedrock and glacial provenance. Unit ranges from a few meters thick in small gulches to 35 ft (11 m) thick in alluvial fans, plains, and piedmont slopes. Unit Qa is Holocene in age throughout study area. Very nonresistant and unconsolidated; generally thawed, except where covered by climax vegetation.

Qaf ALLUVIAL-FAN DEPOSITS–Poorly to moderately well sorted, gray to tan (oxidized), fluvial silt, sand, and gravel deposited where first- and second-order tributaries join third- and fourth-order streams. Unit appears as deltaic fans in the Alaska Range, and as extensive piedmont aprons that flank foothills north of the Denali-Farewell fault zone, northwest of St. John's Hill. Smaller Qaf deposits that originate in steep streams and gullies tend to be poorly sorted, whereas larger Qaf accumulations in third- and fourth-order streams are better sorted and more mature. Qaf ranges from late Wisconsin to Holocene. Unit is moderately resistant due to calcareous cementation of Alaska Range deposits. Generally thawed except in zones of northerly aspect. Unit ranges from 6.5 to 50 ft (2 to 15 m) thick, and can be considered an excellent source of construction materials where not covered by eolian silt and sand.

Qat TERRACE ALLUVIUM–Moderately to well sorted, well stratified, gray to tan (oxidized), fluvial silt, sand, and gravel of varying ages deposited on former floodplains that now lie above or beyond the normal depositional regime of Holocene streams. Unit is generally preserved in larger third- and fourth-order stream valleys, covered by pioneer to climax vegetation, dissected by Holocene streams, and blanketed with eolian silt and sand. Unit ranges in age from Wisconsin to early Holocene, and ranges from 10 to 35 ft (3 to 11 m) thick in exposed stream cuts. Cementation and permafrost may both be present. Older Qat deposits may contain highly weathered clasts in a silty matrix, and thus may not be suitable as construction materials.

### COLLUVIAL DEPOSITS

Qca COLLUVIAL-ALLUVIAL DEPOSITS–Mixed or alternating, poorly to moderately sorted, silt, sand, gravel and diamicton of colluvial and alluvial origins. In study area unit appears in the Alaska Range and northeastern foothills within steep gullies, and at the intersection of first-order tributary and second- or higher-order streams. Colluvial-alluvial fans are most active when intense freeze-thaw cycles occur and large quantities of meltwater are present. Engineering applications vary widely due to large grain size and sorting properties. Generally frozen in steep mountain settings. Ranges from several to 100 ft (30 m) thick.

Qct TALUS–Angular, unsorted debris derived from frost riving of bedrock followed by rapid gravity transport on steep slopes, cirque headwalls, steep gullies, and avalanche chutes. Unit forms most commonly as cones or aprons that lie at, or near, the angle of repose along valley walls; distal, upvalley ends may grade into rock glacier deposits. Usually frozen and widely varies from 10 to 30 ft (3 to 9 m) thick.

Qcl LANDSLIDE DEPOSITS–Chaotically deformed colluvium derived from relatively sudden mass movement of bedrock or surficial deposits along a plane of failure. Surface of deposit is characteristically hummocky and commonly lies below a well-defined failure scarp. Recent landslide deposits display surface disturbances such as randomly tilted trees, disrupted vegetation, and water-filled depressions. All Qcl deposits are frozen and Holocene age.

## EOLIAN AND RELATED DEPOSITS

Qsp SILT AND PEAT–Poorly stratified, black to brown, organic rich, alluvial, eluvial, lacustrine, and bog silt and peat. Unit Qsp formed in extensive wetlands overlying outwash fan deposits (Qof) on the piedmont plain in north-central portion of study area. Unit generally consists of multiple stacked palsas each up to 10 ft (3 m) thick. Usually frozen except near stream cuts. Ranges in age from Late Wisconsin to Holocene; some silt and peat are forming today. Unit might be suitable for horticultural or energy applications.

Qe EOLIAN DEPOSITS–Well-sorted sand and silt transported and deposited by wind. Appears near cliff heads and bluffs where unit is up to 60 ft (18 m) thick. A widespread tephra layer of Holocene age (about 1,800 yr old; Kline and Bundtzen, 1986) occurs in loess banks in several localities along South Fork and Big Salmon Fork. Sand deposits are usually dry and thawed, but do not make good construction materials. Silt is commonly frozen and ice-rich when buried under climax vegetation.

## GLACIAL AND RELATED DEPOSITS

Qg ACTIVE GLACIERS–Occupy cirques having base levels above 4,800 to 6,100 ft (1,500 to 1,900 m) elevation; most glaciers exhibit a strong northerly aspect. Glaciers range in size from 0.4 to 5 square miles (1 $km^2$ to about 12 $km^2$); the largest are nested in Middle Fork and Windy Fork intrusive massifs. Termini are generally 4,300 to 5,000 ft (1,300 to 1,500 m) in elevation. Most glaciers in study area appear to be in retreat.

Qrg ROCK GLACIERS AND ROCK-GLACIER DEPOSITS–Unsorted, angular, frost-shattered cobbles and boulders, commonly containing considerable interstitial ice (up to 55 percent in active rock glaciers). Unit generally originates at 3,500 to 5,000 ft (1,100 to 1,500 m) elevation in north-facing cirques or on steepened slopes of blocky-weathered, resistant bedrock; may transcend into true glaciers or talus. We recognize three morphological types in the eastern McGrath Quadrangle: (1) lobate forms 165 to 660 ft (50 to 200 m) across that lie at the base of valley walls and are moving toward the valley axis; (2) tongue-shaped forms that head in cirques and have their longest dimension parallel to flow direction; and (3) transitional forms that are elongated down-valley in direction of flow (heads may be true glaciers). Unit appears throughout Alaska Range portion of map area, but is particularly well developed in areas underlain by Mesozoic Kahiltna flysch terrane, and intrusive rocks of all ages. Fronts of active rock glaciers are very steep and unstable. Generally not suitable for construction materials due to large clast size. Usually frozen. Resistant due to interstitial ice component.

Qof OUTWASH-FAN DEPOSITS–Glaciofluvial sand and silt derived from streams originating near ancestral glacial margins. Anastomosing channel scars appear on many outwash-fan surfaces; the most prominent have become reactivated as modern alluvial deposits (Qa). Qof forms extensive piedmont aprons that flank the mountain front along the Farewell-Denali fault and extend northward for several tens of kilometers. Unit ranges in thickness from 13 to 26 ft (4 to 8 m), is covered by extensive surface vegetation, and is frequently frozen. Qof ranges in age from middle Pleistocene to early Wisconsin; ages assigned to deposits depend on correlation with specific glaciation.

Qdo OUTWASH–Stratified drift consisting of coarse subrounded gravel that contains sand and silt lenses deposited by sideglacial and proglacial meltwater streams. Anastomosing channel scars appear on many outwash surfaces that have otherwise little or no surface relief. Deposits tend to be progressively finer grained downstream from terminal glacial sources, but coarser grained than sediments in outwash fan deposits (Qof). May be excellent sources of sand and gravel, but suitability depends on testing specific sites for engineering properties. Generally Wisconsin in age throughout study area and considered younger than Qof. Thickness is variable (10 to 16 ft; 3 to 5 m); unit is usually frozen, but contains less than 10 percent ice.

Qdot OUTWASH TERRACE–Remnant of former outwash fan or plain deposit (Qof) that has been dissected by Wisconsin to Holocene streams (Qa). Terrace believed to be Early to middle Pleistocene in age, and may not be suitable for construction (sand and gravel) due to in situ weathering of clasts. Thickness unknown.

Qdic ICE-CONTACT DEPOSITS–Stratified gravel, sand, and flowtill deposited on, against, or under stagnant masses of glacial ice by meltwater streams. Individual layers within the deposit are extremely variable in lateral extent, degree of sorting, and thickness. Extreme surface relief is common, and kame and kettle terraces are conspicuous geomorphological features of unit. Both Wisconsin and early Holocene Qdic deposits mapped in study area. Thicknesses not measured; generally thawed and locally suitable for construction materials.

Qdt TILL, UNDIFFERENTIATED–Unsorted to poorly sorted clay, silt, sand, and gravel deposited by glacial ice. Cobble and boulder clasts are commonly polyhedrally faceted, striated, and subangular to rounded. In study area unit includes till deposited during Farewell II glaciation of late Wisconsin age, but mainly consists of till of several unnamed Holocene glaciations in the Alaska Range (Kline and Bundtzen, 1986). Till comprising moraines near mountain front is commonly frozen, and covered by up to 34 ft (10 m) of peat. Thickness can achieve 164 ft (50 m) locally, but averages 34 ft (10 m) throughout map area.

Qdtf TILL OF FAREWELL GLACIATIONS–Unsorted to poorly sorted clay, silt, gravel, and boulders deposited by glacial ice as ground, terminal, and lateral moraines. Unit Qdtf mainly comprises till of Farewell I and Farewell II glaciations (Fernald, 1960) which are regarded as early and late Wisconsin in age, respectively (Kline and Bundtzen, 1986). Farewell I till is marked by moraines of at least two major advances or stades, and is covered by poorly drained, permafrost-rich soils; a few ponds and lakes that cover Farewell I till are of thermokarst rather than glacial origin. Farewell II till contains moraines of at least four major stades or advances and is covered by crevasse-fill kame terraces, locally well developed kame deltas, up to 35 kettles per square mile (20 kettles per $km^2$), and fresh glacial erratics of mainly granitic origin. Large glacial lakes including Farewell Lake formed in moraine in the first Farewell II advance. Unit exhibits differing engineering properties depending on drainage and age. Generally poor source of sand and gravel because of poor sorting and high clay content; however, some thin outwash gravels in or on top of till may be useable. Bearing strength depends on permafrost content, slope aspect, and silt and peat content.

Qdts TILL OF SELATNA GLACIATION–Unsorted to poorly sorted clay, silt and gravel deposited by glacial ice in ground moraines. Unit is characterized by highly modified moraine along the South Fork and Windy Fork of the Kuskokwim River (Fernald, 1960). Moraines form an arcuate pattern of discontinuous segments broken by trains of outwash (Qdo). Loess cover on unit Qdts thickens distally from the mountain front and is more than 34 ft (10 m) thick on Lone Mountain immediately west of the western map boundary. Kettle topography is still present but most lakes are partially to totally drained; about half of the circular kettle-like depressions are actually of thermokarst origin. Generally considered a poor source of sand and gravel; no outwash identified in unit. High peat content and permafrost make for poor bearing strength.

Qdtlm TILL OF LONE MOUNTAIN GLACIATION–Isolated patches of unsorted to poorly sorted silt, gravel, and highly eroded erratics deposited by glacial ice. Named for till exposed along ridgelines of Lone Mountain west of study area (Kline and Bundtzen, 1986). Unit lacks primary morainal topography and is covered by extensive deposits of silt, peat, and vegetation. Kettles are completely filled with sediment, and most kettle-like circular depressions are thermokarst features rather than glacial in origin. Thought to be Early or possibly middle Pleistocene in age (Kline and Bundtzen, 1986). Bearing capacity considered low, due to silt and peat cover and permafrost; construction suitability unknown.

Qdtplm TILL OF PRE-LONE MOUNTAIN GLACIATION–Isolated patches of unconsolidated to weakly cemented, diamicton largely recemented by calcite-forming tillite. Forms elongate, isolated patches of highly modified till up to 13 miles (20 km) beyond the known limits of Lone Mountain glaciation. No morainal topography recognized; unit is largely covered by 10 to 34 ft (3 to 10 m) thick silt and peat bogs, and climax vegetation. May correlate with deformed till and outwash (QTg) of Big Salmon Fork glaciation, which is regarded as late Tertiary to earliest(?) Pleistocene in age (Kline and Bundtzen, 1986). A less plausible correlation would assign Qdtplm to an earlier stade of the Lone Mountain glaciation. Unit Qdtplm is everywhere frozen, except where Holocene streams dissect till. Suitability for construction materials or bearing strength is untested and unknown.

## SEDIMENTARY AND VOLCANIC ROCKS

QTg CONSOLIDATED TILL AND OUTWASH–Weakly to well cemented diamicton, interbedded with crudely stratified outwash, which contains local and exotic lithologies. Faceted cobbles and striations on some cobbles and boulders suggest glacial transport for some of unit. Although outcrops are weathered, some crude stratification is present in outcrop, and is clearly visible with photo-geologic analysis. Regional tilting to the south reaches a maximum of 12 degrees, and is slightly disconformable with underlying Tertiary coal-bearing group units (Tcg, Ts). Although absolute age control is lacking, we correlate unit QTg with the Nenana Gravel exposed along the north flank of the Alaska Range, which is interpreted to be glacial outwash and tillite of Pliocene-Pleistocene age (Wahrhaftig and others, 1969; Thorson, 1986). Kline and Bundtzen (1986) regarded unit QTg as drift of Late Tertiary(?) Big Salmon Fork glaciation after exposures on Big Salmon Fork in northeast corner of study area.

Tcf FELSITE CONGLOMERATE–Thick-bedded, poorly indurated, orange-weathered, light brown granule, cobble conglomerate that contains up to 50 percent clasts of felsic igneous rocks. Unit is crossbedded in a few places and dips slightly to moderately northwest where exposed. Overlies Ts unit below. Minimum thickness of 1,000 ft (300 m) in western part of study area. Judged to be correlative with the coal-bearing group in the Nenana coal field (Wahrhaftig and others, 1969) of Oligocene-to-Miocene age.

Tcg COAL-BEARING SANDSTONE, SHALE AND CONGLOMERATE–Thin- to thick-bedded, poorly to moderately indurated, buff-weathered, gray-brown, granule, cobble conglomerate, minor sandstone, and interbedded dark gray carbonaceous shale and coal. Conglomerate clasts are moderately sorted, subangular to rounded, and consist mainly of quartz (20 to 40 percent), volcanic rock fragments (up to 20 percent), and sedimentary-lithic fragments (30 to 70 percent). Matrix ranges in size from silt to granules. Beds are both massive and cross-stratified, and dip steeply to vertically in exposed canyon walls. Unit is estimated to be 4,790 ft (1,460 m) thick along Windy Fork. Solie and Dickey (1982) reported that 20 to 65 ft (6 to 20 m) thick shale-coal sections from Windy Fork to Middle Fork contain low rank, thin bituminous coal beds showing British Thermal Unit (btu) values ranging from 7,587 to 11,742. Eocene to Oligocene pollen reported during Atlantic Richfield Company investigations of coal-bearing strata on Windy Fork (unpublished report, 1980); however, unit Tcg was correlated by Dickey (1984) with unit Ts, which is considered to be pre-Middle Eocene in age (see below). Hence unit Tcg may range in age from Late Paleocene(?) to Oligocene. We correlate unit Tcg with similar coal-bearing units in Tonzona River area about 38 miles (60 km) northeast of Windy Fork area (Sloan and others, 1979). Some unconsolidated conglomerate beds might be excellent sources of sand and gravel.

Ts SANDSTONE AND SHALE–Thin- to thick-bedded, moderately indurated, red-brown weathered, buff, medium-grained, lithoquartzose sandstone interbedded with poorly indurated, laminated, fissile, carbonaceous shale and fine sandstone. Sandstone clasts are moderately sorted, subangular to rounded, and consist of argillite (30 to 60 percent), quartz (20 to 50 percent), carbonaceous material (up to 20 percent), and volcanic lithic fragments (up to 10 percent). Plant-bearing mudstone intruded locally by Middle Eocene dike (45.5 Ma; Solie and others, 1991); hence, age is considered to be pre-Middle Eocene.

Tcl LIMESTONE CONGLOMERATE–Thick- to thin-bedded, moderately indurated, green-gray granule conglomerate exposed in fault sliver near Khuchaynik Creek. Unit contains up to 80 percent limestone clasts; the remainder composed of basalt and lithic fragments. Matrix size ranges from clay to sand, and beds appear structureless. Although compositionally distinct, Tcl crops out near units Ts and Tcg, and is correlated with them. Hence age is considered to range from Late Paleocene(?) to Oligocene.

### SHEEP CREEK, WINDY FORK AND TERRA COTTA VOLCANIC FIELDS
### (This study)

Tvs VOLCANICLASTIC SANDSTONE AND LACUSTRINE SILT–Brown to gray, medium- to fine-grained volcaniclastic sandstone that has a distinctive 50 ft (15 m) thick section of flora-rich paleosols and finely laminated, varved shales of probable lacustrine origin. A plant fossil assemblage rich in *Metasequoia cuneata* and *Glyptostrobus europaeus* (Bundtzen and others, 1982) is judged to be of Eocene age. Unit Tvs in upper Sheep Creek directly overlies a progressive sequence of volcanic flows, proximal vent facies, volcanic breccias, and air-fall tuff, and may represent lacustrine and related sediments deposited in a crater lake (?) during the waning stages of volcanism in the Sheep Creek volcanic field. Very non-resistant and at best forms hand-specimen sized rubble.

Tvt INTERMEDIATE TO FELSIC AIR-FALL TUFF–Composite unit of light- to medium-green-gray, well laminated medium to very coarse grained, crystal-rich, air-fall tuff. Sheep Creek volcanic field includes at least four 50 to 80 ft (15 to 25 m) thick air-fall sequences consisting of a 10 ft (3 m) thick basal layer of angular, boulder-to-cobble-sized ejecta fining upward to well laminated, pebble- to sand-sized tuff. Also includes poorly exposed welded(?) tuffs along mountain front south of St. Johns Hill. In Sheep Creek drainage unit is probably a vent facies near a volcanic center. Individual air-fall sequences are covered by paleosols rich in petrified wood, dicotyledon leaves, and *Metasequoia*. In the Sheep Creek volcanic field, unit Tvt underlies lacustrine-bearing deposits (Tvs), but overlies mafic and intermediate flows (Tvm, Tva). Total thickness is estimated to be 590 ft (180 m) on Sheep Creek. Nonresistant and forms weathered, flaggy rubble.

Tva ANDESITE FLOWS AND LAPILLI TUFF–Dark-gray to green-gray andesite flows and locally banded (red, green, purple, bleached) lapilli tuff. Groundmass of flows is aphanitic to fine-grained intersertal and consists of andesine accompanied by abundant hornblende, clinopyroxene, opaque minerals, and rare quartz. Euhedral hornblende phenocrysts to 5mm long are common. Propylitization is pervasive, producing carbonate, chlorite, and epidote. Lapilli tuff fragments are extensively chloritized. In Windy Fork volcanic field, Tva unit yielded whole rock K-Ar age of 37.1 Ma (Solie and others, 1991); Tva unit in Sheep Creek and Terra Cotta volcanic fields are unknown . Estimated to range from 65 to 260 ft (20 to 80 m) thick at Windy Fork, Sheep Creek, and Terra Cotta volcanic fields. Moderately resistant and forms blocks to 3 ft (1 m) in diameter.

Tvd MASSIVE DACITE–Light- to medium-gray, porphyro-aphanitic, hornblende-bearing massive dacite of Terra Cotta volcanic field. Does not contain breccias and sedimentary rock fragments typical of underlying (Tvld and Tvvd) units. Whole-rock $Ar^{40}$-$Ar^{39}$ minimum age of 31.3 Ma obtained from near stratigraphic top of Terra Cotta volcanic field (Solie and others, 1991). Resistant and forms large angular blocks to 10 ft (3 m).

Tvld LAPILLI DACITE–Light gray to bleached white with yellowish staining, locally banded (purple, white), lapilli dacite and tuff. Lapilli fragments are commonly chloritized. Thickness and age unknown but part of Terra Cotta volcanic field that ranges in age from 31.3 to 41.3 Ma (Solie and others, 1991). Moderately resistant and forms flaggy, weathered rubble.

Tvvd VENT FACIES DACITE–Very distinctive, light gray, distinctly tan weathering, hornblende and K-spar-rich, propylitically altered dacite containing very abundant angular clasts of sedimentary rocks (mainly Kahiltna terrane flysch) that comprise up to 30 percent of groundmass. Clasts range in size from approximately 1 inch to 10 ft (several centimeters to 3 m) in diameter, suggesting unit represents vent facies or magma chamber that stoped upward through the enclosing Kahiltna terrane flysch during eruptive cycles in Terra Cotta volcanic field. Estimated to be 1,300 ft (400 m) thick where exposed in cliff walls along South Fork, McGrath A-1 Quadrangle. Resistant and forms large blocks to 10 ft (3 m) in diameter.

Tvab ANDESITE BRECCIA–Medium-gray, purple-hued weathering, porphyritic, pyroxene andesite containing distinctive zones of pyroclastic breccia consisting of in situ andesite fragments averaging 2 inches (5 cm) in diameter; exclusively mapped in Terra Cotta volcanic field. Some agglomerate interbedded in andesite breccia flows. Groundmass of flows is aphanitic to intersertal and consists of andesine, hornblende, clinopyroxene, and opaque minerals, similar to mineralogy of Tva flows mapped in other volcanic fields of map area. $Ar^{40}$-$Ar^{39}$ hornblende age of 41.1 Ma determined from andesite breccia near base of Terra Cotta volcanic field. Resistant and forms large blocky rubble.

Tvlr LAPILLI RHYODACITE–Light- to medium-gray, porphyro-aphanitic, K-spar-rich rhyodacite flows containing conspicuous layers of purple, green, and red lapilli tuff beds 5 to 15 ft (1.5 to 4.5 m) thick. Lapilli tuff is composed of chlorite-rich fragments 4 to 45 mm long of no preferred shape; matrix is mainly silt-sized K-spar and quartz. Unit Tvlr forms a prominent 800 ft (245 m) thick pile near southern end of Terra Cotta volcanic field near the co-magmatic(?) Hartman Pluton (Tgd), which suggests that the Hartman Pluton and Terra Cotta volcanic field might constitute a volcanic-plutonic complex similar to those mapped in the Kuskokwim mineral belt of southwestern Alaska (Bundtzen and Miller, 1997). Somewhat resistant, and forms moderately blocky rubble.

Tvgt GREEN TUFF–Distinctly mid- to dark-green, fine to medium grained, ash flow(?) tuff containing very minor blocks of darker green, altered agglomerate composed of rounded clasts to 4 inches (10 cm) in diameter. Unit forms a useful marker bed in Terra Cotta volcanic field that can be traced throughout the lower portion of the volcanic succession stratigraphically above the basal andesite breccia flows for at least 2.5 miles (4 km) of strike. Estimated to be 35 to 45 ft (11 to 14 m) thick; generally nonresistant.

Tvl LAHAR DEPOSITS–Medium- to dark-green-gray, very coarse grained lahar deposit. Unit consists of chaotic mixtures of volcanic-derived mud, andesite flow fragments, epiclastic breccia, and blocks of the Kahiltna terrane flysch. Tvl was deposited in debris flows at the base of the Terra Cotta volcanic field. Estimated to be 65 ft (20 m) thick; generally nonresistant.

Tvf FELSIC TUFF AND FLOWS–Bleached to light-gray, locally banded, hypocrystalline rhyolite tuff and flows; consists of sericitic alkali feldspar and resorbed, fine-grained quartz phenocrysts in an aphanitic quartzo-feldspathic groundmass. Devitrification sperulites common. May include a band of welded(?) tuff on north end of Sheep Creek volcanic field. Unit occurs at various stratigraphic positions in the Windy Fork, Sheep Creek, and Terra Cotta volcanic fields; hence no stratigraphic position implied. Estimated to range in age from 31.3 to 48.9 Ma or the collective age range of all volcanic units within this group. Tvf ranges in thickness from 115 to 500 ft (35 to 152 m). Generally resistant and forms large elongate blocks in scree slopes.

Tvm BASALT AND BASALTIC ANDESITE–Dark gray to maroon, locally porphyritic, olivine bearing, augite basalt and basaltic andesite flows. Groundmass frequently altered to chlorite, epidote, and secondary opaque minerals. Columnar jointing readily expressed in outcrops. Occurs as both an interlayer sandwiched between andesite flows and at the base of the volcanic flows of the Sheep Creek volcanic field. In Sheep Creek volcanic field, unit has yielded four K-Ar ages ranging from 41.3 Ma (minimum age) to 48.9 Ma (Bundtzen and others, 1982; Solie and others, 1991).

## VELESKA LAKE VOLCANIC FIELD
## (This study)

TKvd DACITE FLOWS AND DIKES–Light- to medium-gray, aphanitic to porphyro-aphanitic, chloritized hornblende dacite flows; flow banding uncommon. Located west of Veleska Lake, and intruded by numerous hornblende granodiorite dikes of similar appearance and hence lumped with TKvd. Unit is similar to volcanic rocks of similar composition in Terra Cotta volcanic field described above, except that TKvd appears to be more altered. One K-Ar hornblende age of 65.8 Ma determined from flow section near base of unit. Resistant and forms blocky rubble on scree slopes; estimated to be 1,150 ft (350 m) thick.

TKvf RHYOLITE TUFF–White- to light-gray, locally banded, hypocrystalline rhyolite; typically consists of sericitic alkali feldspar and resorbed fine-grained phenocrysts, and angular glassy shards. Occurs near the top of unit TKvd. Age and thickness unknown; nonresistant and forms small, flaggy rubble.

TKvm BASALTIC ANDESITE–Medium-gray-green, fine-grained, augite-rich basaltic andesite and minor andesite flow breccia mapped near the base of Veleska Lake volcanic field near Veleska Lake. Similar to both Tvm and Tva of younger volcanic fields, except always more ubiquitously altered. Estimated to be about 130 ft (40 m) thick; moderately resistant where not brecciated.

TKvt AIR-FALL TUFF OF INTERMEDIATE COMPOSITION–Light- to medium-green-gray, well laminated, crystal tuff consisting of 3 to 14 ft (1 to 4 m) thick beds; deposits contain pebble- to sand-sized clasts. In upper Tin Creek, TKvt contains 1 ft (30 cm) thick paleosol, rich in undated plant fossils. Estimated to be 80 ft (25 m) thick; nonresistant and weathers to sandy scree.

## KAHILTNA TERRANE
**[Mapped southeast of Tatina River Fault]**

KJsh SANDSTONE AND SHALE–Medium- to very dark-gray, fine-grained, lithic sandstone, siltstone, and shale; comprises about 75 percent of the Kahiltna terrane. From a distance, color of unit is almost black–earning it the colloquial term "Black Crap" clastics. Contains angular to subangular clasts of chert and quartz (40 percent), lithic fragments (25 percent), volcanic clasts (25 percent), feldspar (5 percent), and white mica and opaques (5 percent). Flutes, ripple marks, and flame structures are locally abundant, and sand intervals contain cyclic, graded Bouma Tbcde intervals (after Mutti and Ricci Lucchi, 1972), which indicate deposition in turbidity currents. Sand-to-shale ratios average 1:3. In McGrath B-1 and A-2 quadrangles, unit includes collections of *Inoceramus murgalensis* of the Neocomian stage and *Inoceramus peltiformis pochialaynen* of the Hauterivian stage–both indicating an Early Cretaceous age (Bundtzen and others, 1987; this study). Unit is complexly deformed, which prevents an accurate thickness estimate. Unit KJsh is nonresistant and forms flaggy scree.

KJs COARSE SANDSTONE AND MINOR SILTSTONE–Medium-gray to distinctly tan-weathered, lithic sandstone containing clasts of volcanic rocks (25 percent), sandstone and shale (25 percent), granitic(?) rocks (15 percent), quartz (20 percent), and lime-rich sediments (15 percent). Flute casts and ripple marks are common, and sand intervals contain cyclic graded Bouma Tabc intervals (after Mutti and Ricci Lucchi, 1972) up to 6.5 ft (2 m) thick. Sand-to-shale ratios average 5:1. Unit KJs is interbedded with KJsh, which contains Early Cretaceous pelecypods. Thickness poorly constrained but at least 1,000 ft (300 m) in McGrath B-1 Quadrangle. Moderately resistant and forms angular scree to 8 inches (25 cm) in diameter.

KJc PEBBLE TO BOULDER CONGLOMERATE AND MINOR SANDSTONE–Light-gray, tan weathered, pebble to boulder conglomerate. Pebbles are sub-angular to rounded clasts of granite and quartz diorite (30 percent), in situ lithic sandstone and shale (25 percent), quartz (20 percent), and mixed volcanic-lithics (25 percent). Some massive conglomerate layers measured 80 ft (25 m) thick south of Tatina River. *Inoceramus murgalensis* of Early Cretaceous age found in one KJc locality. Two graded Bouma Tab intervals (after Mutti and Ricci Lucchi, 1972) recognized; otherwise, unit does not contain turbidity current deposits. Sand-shale ratios average 10:1. Thickness of 1,150 ft (350 m) estimated south of Tatina River, but highly variable along strike. Unit crops out in several bands in Kahiltna terrane, which are interpreted to be the same horizon repeated by large-scale sub-isoclinal folds. Resistant and forms large 3.3 ft (1 m) long blocky rubble in landslide deposits and cirque debris.

## MCKINLEY TERRANE
**[Mapped north of Denali-Farewell Fault]**

KJm SLATE AND METASILTSTONE–Very thin-bedded, fissile, rusty-brown-weathered, black slate, metasiltstone, micaceous metasandstone, and rare silty limestone turbidite. Minor quartz-carbonate veinlets parallel cleavage. Mesozoic radiolaria and megafossils were collected in unit exposed in Talkeetna C-6 Quadrangle (Reed and Nelson, 1980; Jones and others, 1983). Non-resistant. Thickness unknown due to intense structural deformation.

## PINGSTON TERRANE
**[Mapped north of Denali-Farewell Fault]**

Trls LIMESTONE AND SHALE–Thin-bedded, medium gray quartzitic limestone; gray, silty limestone, and shale. Basal beds are predominantly fine-grained, gray sandstone and siltstone and subordinate cherty limestone that contains black chert clasts. Unit is commonly cut by thin quartz-carbonate veins. Late Triassic *Monotis sp.* pelecypod collected from limestone-shale horizon near eastern edge of map area (Kline and others, 1986). Unit correlates with the Pingston terrane exposed in the Mount McKinley region 90 miles (155 km) northeast of the study area (Jones and others, 1983). Thickness estimated to be 330 ft (100 m) in map area; moderately resistant where quartz-rich lime beds exceed 50 percent of unit.

## YUKON-TANANA TERRANE
**[Mapped north of Denali-Farewell Fault]**

uPzs VOLCANOGENIC PHYLLITE–Dark gray-green to distinctly maroon, pyrite-rich volcanogenic phyllite cut by thin quartz-carbonate veins. Stratigraphic relationships imply that uPzs overlies uPzc; however, no age control is available. Nonresistant and forms flaggy debris on scree slopes. Thickness unknown but less than 660 ft (200 m).

uPzc PHYLLITIC CHERT AND SILICEOUS PHYLLITE–White-weathered, gray-green, banded phyllitic ribbon chert. Pennsylvanian through Permian radiolaria identified at one locality in map area (Kline and others, 1986). Radiolaria and conodonts of Mississippian through Permian age collected by Jones and others (1983) immediately east of the map area. In one area, uPzc is fault-bounded between Trab on the south and KJm on the north; it apparently stratigraphically underlies Trls near the head of the Big Salmon Fork. Gilbert and Bundtzen (1984) suggested that uPzc and uPzs are in the upper part of the Yukon-Tanana terrane, a major tectono-stratigraphic terrane underlying much of interior Alaska north of the Denali-Farewell fault. Thickness estimate not possible due to structural deformation. Generally nonresistant due to high phyllite content.

## FAREWELL COMPOSITE TERRANE

### MYSTIC SUBTERRANE
[Mapped north and south of Denali-Farewell Fault]

**Tatina River Volcanics (This study)**

lJs PHOSPHATIC SHALE AND GREEN VOLCANICLASTIC SANDSTONE–Medium- to very-dark-gray, distinctly bleached bluish-white, phosphatic shale (25 percent); green, medium grained, concretion-rich, volcaniclastic sandstone (60 percent); and minor tan chert-cobble pebble conglomerate (15 percent). Contains *Entolium sp.* and *Eopecten(?) sp.* of Jurassic age (J.W. Miller and W.P. Elder, written commun., 1984) in Tatina River area, McGrath B-1 Quadrangle. Probably correlative with Arietitid ammonite-bearing phosphatic beds of Lower Jurassic age (Sinemurian stage) that was mapped at the top of the Mystic subterrane in the Talkeetna C-6 Quadrangle (Reed and Nelson, 1980; J.W. Miller and W.P. Elder, written commun., 1984). Estimated to be 150 ft (45 m) thick; nonresistant due to high shale content.

Trab PILLOW BASALT AND GABBRO–Dark green-gray, massive, aphanitic to medium-grained, olivine-clinopyroxene rich, pillow basalt, olivine diabase and gabbro sills, and mafic agglomerate. Composition of mafic sills ranges from picrite to diabase, but all are titanium rich and tholeiitic. Pillow structure well developed locally, but basalts and agglomerate frequently altered to serpentinite, or orange silica-carbonate rock; unit is extensively chloritized. Fossils of Late Triassic age found in several localities of unit Trs (see below), which interfingers with Trab. Unit Trab appears on both sides of the Denali-Farewell fault, where it overlies the clastic-rich Sheep Creek Formation (PDs). Trab contains very high copper content regionally (average is 307 ppm, from nine analyzed samples). Estimated to be 500 to 660 ft (152 to 200 m) thick. Very resistant when fresh, but nonresistant where altered.

Trs SHALE, COARSE VOLCANICLASTIC SANDSTONE, AND CHERT–Tan to greenish-gray, buff to orange weathered, pebble rich, immature conglomerate, coarse volcaniclastic sandstone, distinctly brown silty shale, and light gray, green, and black chert. Interbedded with pillow basalt and gabbro (Trab) described above. Unit Trs contains *Monotis subcircularis* in McGrath B-1 Quadrangle and *Halobia cf. fallax,* or *H. cf. cordillerana* in the Lime Hills Quadrangle; both indicate the late Early-to-early Late Norian stage of the Late Triassic (Bundtzen and others, 1994; N. Silberling, written commun., 1984). Unit Trs varies from 130 to 330 ft (40 to 100 m) thick; nonresistant due to flaggy nature of weathered sedimentary rocks.

**Sheep Creek Formation (This study)**

PDs SUBLITHIC SANDSTONE, LIMESTONE-CHERT CONGLOMERATE, AND MINOR LIMESTONE–Medium-gray, distinctly brown-red weathered, medium- to coarse-grained, sublithic sandstone and pebble conglomerate that contains clasts of limestone (40 percent), chert (20 percent), lithic fragments (15 percent), volcanic clasts (5 percent), and polycrystalline quartz (20 percent). Clastic units lack detrital white mica and calcite cement that is abundant in Dillinger subterrane lithologies, but instead contains plant fossils, which are absent in the latter. Rip-up clasts are very common and graded bedding is present as Bouma Tab intervals (after Mutti and Ricci Lucchi, 1972) indicating a coarse turbidite facies. Sand-to-shale ratios in main clastic section average about 8:1. However, the limestone chert conglomerate, which caps the PDs section, lacks graded beds, and exhibits distinct channeling suggestive of fluvial deposition. Calcareous sandstones from three localities midway in the PDs section of the McGrath B-2 Quadrangle contain fusilinids that have an advanced "schwagerinid wall", which indicates a Late Pennsylvanian to possibly Permian age (R.C. Douglas, written comm., 1983). Two zones of limestone concretions in black shale above the massive algal limestone (lDl) near the base of unit in the Sheep Creek area contain: (1) *Palmatolepis sp.* and *Polygnathus sp.* conodonts of Frasnian (Late Devonian) age (M.J. Orchard, written comm., 1991); and (2) *Dendrostrella sp. cf. D. trigemme* (coral) of Late Eifelian and Givetian (Middle Devonian) age (W.A. Oliver, written commun., in Bundtzen and others, 1982). Hence existing evidence suggests an age range for PDs from Middle Devonian to Permian. Reed and Nelson (1980) described Middle(?) Pennsylvanian plant fossils from non-marine, conglomerate-rich Mystic subterrane rocks at Mount Dall in the western Talkeetna Quadrangle, which we correlate with the limestone-chert conglomerate near the stratigraphic top of the PDs unit. Bundtzen and others (1994) mapped a thin, shallow water limestone, interbedded midway within the PDs unit, that contains Late Mississippian fossils in the central Lime Hills Quadrangle. Unit is estimated to be 1,640 ft (500 m) thick in the Sheep Creek area. Generally nonresistant due to weathering.

lDl MASSIVE ALGAL LIMESTONE–Massive, thick-bedded, medium-gray limestone, rich in algal laminations and *Amphipora sp.* Varies greatly in thickness along strike from 33 to 660 ft (10 to 200 m) reflecting rapid thinning and thickening of a shallow water, lagoonal carbonate facies. *Amphipora*-bearing lime mudstone collected in lDl unit in McGrath B-2 Quadrangle yielded *Ozarkodina* sp. indet. or *Kockelella* sp. indet. of Middle Silurian-to-early Devonian age (A.G. Harris and J.E. Repetski, written commun., 1989). Stratigraphically underlies Middle and Late Devonian fossil localities in PDs unit (see above); units lDl and lDd form base of Mystic subterrane in Sheep Creek area south of Denali-Farewell fault. Locally very resistant and cliff-forming; forms large blocks at base of cirques.

lDd DOLOMITE–Light gray, dolomitized, algal(?) limestone similar in appearance to lDl; unit exhibits complete dolomitization. No age control available, but thought to be correlative with lDl unit. Very resistant due to dolomitization. About 80 ft (25 m) thick.

**St. Johns Hill Formation (This study)**

uDl MASSIVE MICRITIC LIMESTONE–Medium-gray, massive- to thick-bedded, micritic limestone that contains crypto-algal laminations, thin, black chert partings, and dolomitic nodules. Unit contains an abundant and diverse fauna of rugose corals, brachiopods, and pelecypods on St. Johns Hill and in the Farewell Mountain area, which indicate a Frasnian (early Late Devonian) age (Bundtzen and others, 1982). Unit varies greatly in thickness from 3.3 to 660 ft (1 to 200 m), and in some areas is apparently absent from the section. We interpret this to reflect the rapid thinning and thickening of a shallow water, reef carbonate facies. Unit uDl underlies PDs unit on Farewell Mountain. Resistant due to massive nature of limestone. Unit of identical age and character described by Reed and Nelson (1980) near base of Mystic subterrane south of the Denali-Farewell fault in Talkeetna Quadrangle.

Dls LIMESTONE AND MINOR SILTSTONE–Brown to terra cotta, micaceous, slightly pyritic, thinly laminated mudstone, siltstone, limestone, and medium-grained lithic sandstone that underlies uDl on St. Johns Hill in McGrath B-2 Quadrangle. Locally contains thin black chert partings. Tentatively correlative with basal portion of PDs unit; it may be a deeper water facies of the algal limestone (lDl) exposed on the south side of the Denali-Farewell fault.

DILLINGER SUBTERRANE
[Mapped south of Denali-Farewell Fault]

**Barren Ridge Limestone** (Churkin and Carter, 1996)

DSl CALCARENITE, CALCAREOUS SILTSTONE, AND LAMINATED LIMESTONE–Thin- to thick-bedded, buff to orange-weathered, light- to medium-gray, phyllitic calcarenite, thin-bedded orange to buff siltstone, and light gray silty limestone all in approximately equal amounts. Basal portion of unit is more limestone rich. Contains channelized limestone breccia bodies, limestone conglomerate, and graded coarse pebble sandstone. Finer grained clastics exhibit both stacked foreset beds and Bouma Tbced intervals; we interpret unit to represent proximal turbidite or foreslope depositional facies. Conodonts (Bundtzen and others, 1994; this study) range from Late Silurian to Late Devonian; however, Blodgett and Gilbert (1992) reported conodont fauna of Lochkovian to Pragian age (Early Devonian) from unit DSl in Lime Hills D-4 Quadrangle. Deformation makes true thickness estimates difficult, but unit is approximately 1,000 ft (300 m) in map area. Resistance variable due to heterogeneous nature of unit

**Terra Cotta Mountains Sandstone** (Churkin and Carter, 1996)

uSsl THIN-BEDDED CALCAREOUS SANDSTONE, GRAPTOLITIC SHALE, AND SILTY LIMESTONE–Thin-bedded, gray to tan, micaceous sandstone, silty limestone, and dark gray graptolitic shale. Clast compositions indicate feldspathic litharenite (Folk, 1968), containing up to 6 percent white mica. Flute casts and ripples observed locally. Carbonate content estimated to be about 15 percent. Probably equivalent to Upper Limestone member of Churkin and Carter (1996). Sand-to-shale ratios average about 2:1. *Monograptus cf. M. pseudodubius, Lobograptus progenitor,* and *Pristiograptus cf. P. tumescens* from the *Neodiversograptus nilssoni* zone, Ludlovian stage (Late Silurian) identified (Bundtzen and others, 1982; Bundtzen and others, 1994). Unit uSsl is the top of the Terra Cotta Mountains Sandstone as defined by Churkin and Carter (1996). Estimated to be 250 to 330 ft (75 to 100 m) thick. Relatively nonresistant and forms flaggy scree on slopes.

mSvs PHYLLITE, VOLCANICLASTIC SANDSTONE, AND CHERT–Thin-bedded, complexly folded, maroon to green phyllite, medium-green, medium-grained volcaniclastic sandstone, and green-gray chert. Appears to be stratigraphically above mSl unit, and under uSsl unit on Tunis Mountain near Veleska Lake. Sands composed of andesite and felsite grains (40 percent), quartz (20 percent), framework grains (20 percent), and chert (20 percent). Some thin sections suggest the presence of thin 5 cm thick ash(?) layer in silty sand beds. Unit can be traced for about 5 miles (8 km) of strike but was not mapped beyond Tunis Mountain area. Estimated to be a maximum 130 ft (40 m) thick. Nonfossiliferous, but constrained by Wenlockian and Ludlovian graptolite collections below and above mSvs outcrops respectively. Nonresistant; forms loose rubble on hill slopes and does not crop out well.

mSl ARGILLACEOUS GRAPTOLITIC LIMESTONE–Medium- to dark-gray and brown weathered limestone containing graptolite-bearing silty sandstone intervals. Unit forms distinctive wall-like outcrops throughout map area, and is interbedded with the larger mSs clastic unit. Generally equivalent to Middle Limestone member of Churkin and Carter (1996). Graptolite-bearing beds in mSl have yielded *Pristiograptus dubious, Monograptus cf. M. ludensis,* and *Monograptus digitatus* that represent two graptolite zones of the upper Wenlockian stage of the Silurian (Churkin and Carter, 1996; Bundtzen and others, 1987; Bundtzen and others, 1982). However, unit mSl, as depicted on plate 1, may also include locally the lower limestone member of Churkin and Carter (1996), which is stratigraphically lower than limestone containing the *P. dubius* and *M. ludensis* graptolite zones (see mSs below). Unit mSl has also yielded orthoconic nautiloid cephalopods, cardiolid bivalves, and ribbed atrypacean brachiopods, all nondiagnostic, but probably of Silurian age (Bundtzen and others 1987, 1994). Unit mSl ranges widely in thickness, which varies from 80 to 500 ft (25 to 152 m); maximum thicknesses are obtained in the eastern portion of the quadrangle, but unit becomes very thin near Big River on the western edge of the map area. Unit is resistant and forms prominent cliffs and exposures throughout map area.

mSs FELDSPATHIC-LITHIC SANDSTONE, LIMEY SILTSTONE, AND ARGILLITE–Medium olive gray to terra cotta, medium- to coarse-grained, thin-bedded to massive, calcareous lithic sandstone, and siltstone containing local gray shale intervals and minor pebble conglomerate beds. Major components are polycrystalline quartz (25 percent), chert (20 percent), detrital carbonate (15 percent), matrix (15 to 20 percent), altered feldspar (10 percent), and white mica and opaques (10 percent). Petrography of representative samples indicate that sands in unit are feldspathic litharenites after Folk (1968) with a recycled orogen provenance (Dickinson and Suczek, 1979). Sandstones contain well developed oscillation ripples, flute casts, graded bedding with Bouma Tabcd intervals (after Mutti and Ricci Lucchi, 1972), and planar crossbedding indicating deposition in a mid-fan(?) turbidite environment. Numerous paleocurrent measurements indicate bimodal N20-40E and S25-45W populations. Sand-to-shale ratios average 10:1. Limey beds in lower mSs member that are thought to be equivalent to the Lower Limestone member of Churkin and Carter (1996) contain *Monograptus* aff. *M. priodon*, and *Cyrtograptus lundgreni* which represent zones in the middle to early Wenlockian stage of the Silurian. Unit mSs is estimated to range from 660 to 1,310 ft (200 to 400 m) thick throughout the map area, and is the dominant unit of the Terra Cotta Mountains Sandstone. Generally resistant especially the thick sandstone layers, which form blocky rubble on steep slopes.

**Post River Formation** (Churkin and Carter, 1996)

lSl BOUNDARY LIMESTONE–Thin, dark gray, fetid, laminated limestone with thin (3 cm thick) silty sand layers, and thin interbeds of black cherty argillite. Contains *Cyrtograptus centrifugus* of *C. centrifugus* zone, earliest Wenlockian stage, late Early Silurian. Although only 34 to 80 ft (10 to 25 m) thick, lSl forms a distinctive marker unit between clastic dominated turbidites of Terra Cotta Mountains Sandstone and finer grained basinal facies of the Post River Formation–hence our term "Boundary Limestone." Nonresistant and does not always crop out.

SOsh GRAPTOLITIC SHALE, SILTSTONE AND CHERT–Medium- to dark-gray, fetid, fissile, isoclinally folded, carbonaceous shale, siltstone, and black bioturbated, siliceous siltstone and chert. Very thin Bouma Tcde intervals (after Mutti and Ricci Lucchi, 1972) up to 10 cm thick occur locally but only make up a few percent of the unit. Distinctive sulfurous plumes in some outcrops readily distinguish SOsh from other fine-grained, clastic Dillinger subterrane units. In the northeastern portion of the map area, unit is composed of approximately 70 percent black chert and 30 percent fine-grained clastic rocks. West of South Fork, fine-grained clastic lithologies dominate, and chert is only a minor (less than 10 percent) component of the section. Thin (<1 m) bioturbated zones appear as silicified, brown-marbly textured zones where original bedding has been destroyed by burrowing organisms. Contains numerous graptolite fauna including 15 graptolite zones that represent five of six Ordovician stages (Ashgillian stage graptolites not yet found) and most of the Landoverian stage of the Early Silurian, one of the most complete Ordovician-Lower Silurian graptolite successions in the world. Unit includes the Mudstone, Upper Siltstone, and Graptolite Canyon members of Churkin and Carter (1996). Unit SOsh is roughly equivalent to Road River Formation in east-central Alaska and Yukon, Canada. Unit SOsh is complexly deformed but estimated to range from 130 to 400 ft (40 to 122 m) thick. Very nonresistant and frequently buried under vegetation and talus of more resistant units.

**Lyman Hills Formation** (This study; Bundtzen and others, 1994)

OCls SILTY LIMESTONE AND SHALE–Rhythmically layered, thin-bedded, orange to buff, light gray when fresh, limestone, silty shale, and light olive shale. Individual lime units range from 5 to 25 cm thick, and exhibit parallel and cross laminations. Shale and siltstone exhibit ripple-laminated structures with amplitudes of 5 to 70 cm. Most distinctive sedimentary structures are stacked, wedge-shaped cosets in silty limestone. Some limestone beds contain thin Bouma Tcde intervals (after Mutti and Ricci Lucchi, 1972). As defined here, unit includes the lower Siltstone member of the Post River Formation as originally defined by Churkin and Carter (1996), which contains the *Adelograptus* graptolite zone of the early Early Ordovician. Sample of silty limestone from core of Terra Cotta Anticline in McGrath A-2 Quadrangle yielded *Teridontis nakamurai*, which is part of the *Cordylodus lindstromi* zone, of late Late Cambrian-to-early Early Ordovician age (D. Podson, written commun., 1983). We have named the OCls unit, which ranges from 2,130 to 3,300 ft (650 to 1,000 m) in thickness, the Lyman Hills Formation after extensive exposures in the Lyman Hills immediately west of the map area (Gilbert, 1981). We tentatively correlate OCls with the Rabbit Kettle Formation in Yukon, Canada, a Cambro-Ordovician basinal facies underlying the Road River Formation (Gordey and Anderson, 1993). Relatively nonresistant due to its thinly bedded nature.

MINCHUMINA SUBTERRANE
[Mapped north of Denali-Farewell Fault]

PzpCs METAQUARTZITE AND CALCAREOUS PHYLLITE–Light- to medium-gray, fine- to coarse-grained, metaquartzite, quartz-feldspar "grit", calcareous phyllite, and minor metachert exposed in extreme northeast corner of map area. Presence of quartz+albite+chlorite mineral assemblage in phyllite indicates PzpCs experienced lower greenschist metamorphic conditions. Unit is included in the Telida subterrane of the Minchumina subterrane, which is assigned a Late Proterozoic-to-Paleozoic age (Patton and others, 1994); however, PzpCs might also correlate with the Yukon-Tanana terrane (see above). Thickness unknown due to poor exposures. Quartz-rich "grits" locally resistant and produce blocky rubble to 20 inches (50 cm) in diameter.

## INTRUSIVE ROCKS AND HORNFELS

### TERTIARY INTRUSIVE ROCKS AND HORNFELS

Tia ANDESITE-TRACHYANDESITE SILLS AND DIKES–Green-gray, fine-grained, hypidiomorphic-granular, porphyritic andesite dikes less than 65 ft (<20 m) thick; local variety-granodiorite. Consists of variable amounts of hornblende, alkali feldspar, biotite, and clinopyroxene. Alteration to chlorite and carbonate is common. Contact effects with enclosing host rocks include metalliferous skarns at Tin and Bowser creeks and intense brecciation near Windy Fork (Bundtzen and others, 1982, 1987). Five K-Ar ages from Tia dikes range from 20.9 to 39.3 Ma (Solie and others, 1991). Resistant; forms ribs protruding through layered rocks.

Tif FELSIC SILLS AND DIKES–Felsic dikes and sills up to 16 ft (5 m) thick cut layered rocks in Bowser Creek and Sheep Creek areas. Generally light pinkish tan to white; aphanitic- to fine-grained; rarely medium-grained. Exhibits hypocrystalline as well as holocrystalline textures and contains phenocrysts of plagioclase and alkali feldspar. Unit locally rich in sulfides. Although no age control is available, Tif usually cuts Tim dikes and sills. Somewhat resistant but less so than Tia dikes and sills.

Tim MAFIC SILLS AND DIKES–Mafic sills and dikes up to 34 ft (10 m) thick cut stratigraphy throughout map area. Consist of dark brown, pandiomorphic-granular, locally porphyritic basalt, gabbro and diabase. Contains abundant clinopyroxene and lesser olivine biotite, and hornblende grains in a plagioclase-rich matrix (An 65). Unit contains three K-Ar mineral ages ranging from 45.5 to 55.0 Ma (Solie and others, 1991).

Tid UNDIFFERENTIATED SILLS AND DIKES–Undifferentiated sills and dikes composed of dikes ranging from mafic to felsic compositions. Usually distinguished by extensive alteration and multiple compositions of dikes. Age data summarized above.

Tids DIKE SWARM AND HORNFELS–Large linear zones of multiple dikes of variable composition and size that create extensive hornfels aureole and includes fragments of layered country rocks. Includes compositions of dikes described above (Tid, Tim, Tia, Tif). Formation of sulfide skarns evident where swarms intrude calcareous rocks.

Twg WINDY FORK GRANITE–White to pink and locally blue-gray, medium- to coarse-grained, peralkaline arfvedsonite granite of Windy Fork pluton. Composed of perthite, quartz, and arfvedsonite, and lesser riebeckite, plagioclase, and red-brown biotite. Accessory minerals include zircon, fluorite, apatite, monazite, uranothorite, and eudialyte (Gunter and others, 1993). Has yielded K-Ar pyroxene age of 23.4 Ma and K-Ar biotite and hornblende ages of 30.1 and 29.0 Ma respectively (Gilbert and others, 1988; Solie and others, 1991). Very resistant and forms cliffs, tors, and high upland at the head of Windy Fork.

Tgd HARTMAN PLUTON GRANODIORITE–Medium- to coarse-grained, equigranular, hornblende-biotite granodiorite; CI=35 and plagioclase has An 60 composition. A strong hornfels aureole up to 1.25 mile (2 km) wide rings the intrusion. Quartz-sulfide vein stockwork in both hornfels and intrusion contains molybdenite, chalcopyrite, galena, and abundant pyrite in several localities. One K-Ar biotite age of 37.9 Ma (Solie and others, 1991) obtained from main intrusion is similar in age to volcanics of Terra Cotta volcanic field immediately to the north, suggesting that volcanics and intrusion may be co-magmatic. Very resistant and forms cliff walls in southern Terra Cotta Mountains.

Tqm QUARTZ MONZONITE, MONZONITE BRECCIA, AND QUARTZ PORPHYRY–Composite unit of mainly light gray, fine- to medium-grained hypidiomorphic to equigranular, biotite quartz monzonite, aegirine-rich monzonite, and altered biotite quartz porphyry. Unit Tqm appears as circular to elongate plutons ranging in area from 1.2 square miles (3 $km^2$) in the southern Veleska Lake volcanic field to 4.8 square miles (12 $km^2$) in the Post River and Bowser Creek bodies. The Bowser and Veleska Lake intrusions are aligned along an 18 mile (30 km) long north-trending fault suggesting structural control for emplacement of the plutons. Other smaller bodies in Sheep Creek basin and at Post River show similar north-south orientations. Strong igneous and sedimentary breccias developed in Bowser Creek and 7205 Mt. plutons. Nine K-Ar mineral ages from five Tqm plutons range from 51.1 to 61.8 Ma and average 58.0 Ma (Solie and others, 1991). Polymetallic mineralization associated with Bowser, Veleska Lake, Post, and Sheep Creek plutonic complexes (Bundtzen and others, 1982, 1987; this study). All Tqm bodies are very resistant and form some of the most rugged terrain in study area.

Tgr SOUTH FORK GRANITE–Light gray, pink, medium- to coarse-grained, equigranular, biotite (muscovite) granite that forms small 1.2 square mile (3 $km^2$) body on west side of South Fork flanking Terra Cotta volcanic field. Large poikilitic K-spar grains comprise up to 20 percent of groundmass. East-west trending felsic dikes intrude core of pluton. K-Ar biotite age of 58.8 Ma. Not so resistant; forms subdued rubble.

Thf HORNFELS AND SKARN–Brown to gray, massive to locally porphyroblastic, garnet-chlorite-biotite hornfels derived from carbonate and clastic rocks. Locally develops into polymetallic skarns containing introduction of garnet, wollastonite, epidote, grossularite, and johannsenite. Largest skarn zone surrounding Hartman pluton (Tgd) is 1.3 miles (2 km) wide, but most are 0.3 miles (0.5 km) wide or less. Some Thf zones associated with dike swarms are only about 10 ft (3 m) wide. Age of hornfels dependent on age of related intrusion. Generally considered resistant throughout map area, and forms equant blocks.

**Middle Fork Plutonic Complex** (Solie, 1983, 1988; Gilbert and others, 1988)

Tgqm GRANITE, QUARTZ MONZONITE, AND MONZODIORITE–Fine- to medium-grained, biotite- and hornblende-bearing plutonic rocks with variable quartz contents and feldspar ratios: predominantly quartz monzonite and monzodiorite. Plagioclase composition ranges from andesine to labradorite; minor clinopyroxene generally present and rimmed by andesine to labradorite; minor orthopyroxene sometimes present and rimmed by hornblende; locally alkali feldspar phenocrysts. Accessory zircon and apatite are common; tourmaline is present locally. Fine-grained mafic enclaves common, some retain layering of sedimentary origin. Three samples of quartz monzonite yielded K-Ar mineral ages of 56.1, 56.6, and 57.2 Ma. Eastern margin of the Middle Fork plutonic complex is medium- to coarse-grained peralkaline granite very similar in mineralogy to Windy Fork granite (Twg) and appears gradational with syenite unit (Tsy below). Eudialyte samples noted in granite talus in two locations. Two samples from the eastern margin granite yielded K-Ar mineral ages of 57.7 and 55.6 Ma. Outcrop typically massive and weather in large blocks.

Tgb ALKALI GABBRO–Dark green-brown, fine- to medium-grained, biotite-olivine-pyroxene gabbro. Composed of andesine, clinopyroxene, biotite, olivine, and green to brown hornblende after pyroxene. Minor constituents include opaque minerals, alkali feldspar, orthopyroxene, and accessory apatite. Secondary minerals include chlorite, iddingsite, serpentine, actinolite, carbonate, and apophyllite. Gabbro typically weathers to brown grus, which forms rounded outcrops.

Tgsy GRANITE TO QUARTZ SYENITE–Fine- to coarse-grained, granite to quartz syenite. Contains hornblende, clinopyroxene, and biotite, and minor opaque minerals, apatite, and zircon; arfvedsonite and riebeckite present locally. Alkali feldspar generally perthitic and common in hand specimen. Unit typically weathers to white grus.

Tsy SYENITE–Green-gray, white-gray weathering, medium- to coarse-grained, olivine-clinopyroxene syenite; locally iron stained. Composed of perthitic alkali feldspar, green-brown hornblende after pyroxene, clinopyroxene, plagioclase, olivine and magnetite alteration rims, and interstitial quartz. Minor constituents are biotite, opaque minerals, rutile needles, apatite, zircon, fluorite(?), and monazite(?). Secondary minerals include chlorite, carbonate, iddingsite, actinolite, and epidote. Typically forms massive, jointed cliffs.

## LATE CRETACEOUS INTRUSIVE ROCKS AND HORNFELS

TKqm MOUNT ESTELLE GRANODIORITE–Fresh, medium-gray, medium-grained, equigranular, hornblende-biotite granodiorite and locally contains plagioclase(?) phenocrysts to 5 mm long. $Ar^{40}$-$Ar^{39}$ biotite age of 67.4 Ma obtained from pluton in southeast corner of map area.

TKm GABBRO-GRANODIORITE–Heterogeneous dike swarms consisting of augite gabbro, hornblende granodiorite, and monzodiorite. Euhedral hornblende and piokilitic biotite phenocrysts are unusually fresh; unit is not hydrothermally altered like younger Tim dikes in map area. K-Ar biotite and hornblende ages of 69.7 and 79.0 Ma from biotite and hornblende, respectively, for small bodies east of South Fork.

TKhf HORNFELS AND SKARN–Brown to gray, massive to locally porphyroblastic, garnet-chlorite-biotite hornfels derived from carbonate and clastic rocks. Locally develops into polymetallic skarns with introduction of garnet, wollastonite, epidote, grossularite, and johannsenite. Most hornfels are 0.3 miles (0.5 km) wide or less. Some associated with dike swarms are only a few meters wide. Age of hornfels dependent on age of related intrusion. Generally considered resistant throughout map area, and forms equant blocks.

## PRE-CRETACEOUS INTRUSIVE ROCKS

KJg GABBRO AND DIORITE–Buff-weathered, dark green-gray gabbro and diorite that intrude both Upper Paleozoic cherts and volcaniclastic rocks (uPzs) of the Yukon-Tanana terrane and Triassic limestone (Trls) of the Pingston terrane. Although no age control is known, unit may be equivalent to a Jurassic-Cretaceous gabbro-diorite swarm that intrudes along a major suture separating the Pingston Terrane from the Yukon-Tanana terrane in Denali National Park (Jones and others, 1983).

Trum ULTRAMAFIC TO DIORITE SILLS–Dark green-gray, fine- to coarse-grained, ultramafic (picrite and ankaramite) sills, olivine gabbro, and diorite usually 50 to 66 ft (15 to 20 m) thick but some thinner intrusions also observed. Sills in Sheep Creek area differentiated into mafic or ultramafic bases and dioritic tops. Locally magnetite so abundant (up to 40 percent) that rocks can be picked up with a magnet. Compositions plot in tholeiitic field. Creates extensive zones of hydrothermal alteration, including carbonate alteration and serpentinization in host Mystic subterrane sedimentary rocks (PDs). No absolute age control is available; we envision Trum as feeders for Late Triassic volcanism of Tatina River Volcanics; hence Trum assigned a Late Triassic age. Unit Trum is relatively resistant when fresh but non-resistant when hydrothermally altered.

MzPzi GABBRO AND DIORITE SILLS AND DIKES–Brownish weathered, dark green-gray, very fine- to medium-grained phaneritic, locally micropegmatoidal, olivine, aegirine-augite, gabbro, diorite, and uncommonly alkali syenite. Quartz rare or absent. Large olivine and clinoproxene grains to 5 mm in diameter remarkably fresh, although groundmass ubiquitously altered. Larger sills create zones of hornfels although not depicted on map sheet. Unit is everywhere olivine normative and sometimes nepheline normative and chemically exhibits a tholeiitic, alkaline character. MzPzi exclusively intrudes Lyman Hills Formation (OCls) and Post River Formation (SOsh, lSl) of the Dillinger subterrane, and never younger units. Hence we believe an Early Paleozoic age seems likely. A less plausible alternative is that MzPzi dikes are feeders for Triassic volcanism (Trab) in the Mystic subterrane (Tatina River volcanics). Resistant and forms blocky rubble standing in relief against host OCls and SOsh lithologies.

Bundtzen, Harris, and Gilbert—GEOLOGIC MAP OF THE EASTERN HALF OF THE MCGRATH QUADRANGLE, ALASKA—DGGS Report of Investigations 97-14a