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Geologic and Isostatic Gravity Map of the Nenana Basin Area, Central Alaska

By Gina M. Frost, David F. Barnes, and Richard G. Stanley

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INTRODUCTION

The Nenana basin area is a prospective petroleum province in central Alaska, and this geologic and isostatic gravity map is part of a petroleum resource assessment of the area.

The geology was compiled from published sources (Chapman and others, 1971, 1975a, 1975b, 1982; Chapman and Yeend, 1981; Csejtey and others, 1986; Jones and others, 1983; Péwé and others, 1966; Reed, 1961; and Weber and others, 1992), as shown on the index map (map sheet). Map units are organized and presented according to the scheme of lithotectonic terranes proposed by Jones and others (1987) and Silberling and Jones (1984); we recognize, however, that this terrane scheme is controversial and likely to be revised in the future. In some cases, we combined certain terranes because we were unable to match the terrane boundaries given by Jones and others (1987) and Silberling and Jones (1984) with specific faults shown on existing geologic maps. Postaccretion cover deposits represent overlap assemblages that depositionally overlie accreted terranes. Plutonic igneous rocks shown on this map include several plutons that are clearly postaccretionary, based on isotopic ages and (or) field relations. It is possible that some of the plutons predate accretion, but this has not been demonstrated. According to Jones and others (1982), the terranes in the area of our map were assembled during late Mesozoic or earliest Cenozoic time.

The gravity contours are derived from data used in earlier compilations (Barnes, 1961, 1977; Hackett, 1981; Valin and others, 1991; Frost and Stanley, 1991) that are supplemented by some National Oceanic and Atmospheric Administration data along the Alaska Pipeline level line (W.E. Strange, written commun., 1980). The earlier compilations were used for simple Bouguer maps, prepared primarily by non-digital methods, and are superseded by this map. The present map is the result of digital processing that includes the 1967 Geodetic Reference System, the IGSN-71 datum, digital terrain corrections, and conversion to isostatic gravity so that geologic structures on the margin of the Alaska Range are more clearly portrayed (Simpson and others, 1986). Computation procedures are described in part by Barnes (1972, 1984), Jachens and Roberts (1981), and Barnes and others (1994). The calculations used a crustal density of 2.67 g/cm^3, a density contrast at the base of the isostatic root of 0.4 g/cm^3, and a root thickness at sea level of 25 km. The distribution of data within the map area is uneven and locally controls the shape of the computer-generated contours. Altimetry was used for most of the elevation control and its inconsistency is responsible for many of the small contour irregularities. Ninety percent of the measurements are estimated to have an accuracy of about 1.5 mgal or about a quarter of the 5 mgal contour interval. Data collection and analysis were assisted by R.V. Allen, R.C. Jachens, M.A. Fisher, T.R. Bruns, J.G. Blank, J.W. Bader, Z.C. Valin, J.W. Cady, R.L. Morin, and P.V. Woodward.

The most promising area for petroleum exploration is a prominent 25 mgal isostatic gravity low north of Nenana (T. 2 S., R. 8 W.). This gravity low probably corresponds to the deepest part of a sedimentary basin filled by Cenozoic strata that includes nonmarine fluvial and lacustrine deposits of the Eocene to Miocene Usibelli Group. Smaller gravity lows are associated with outcrops of these sedimentary rocks north of Suntrana (T. 12 S., R. 6-9 W.) and Sable Pass (T. 16 S., R. 11 W.). A broad low on the north flank of the Alaska Range east of the Wood River (T. 10 S., R. 1 E.) indicates another basin under the Tanana lowland that extends eastward off the map area towards Delta Junction, where its presence was confirmed by both gravity and seismic data (Barnes and others, 1991).

Gravity modelling suggests that the base of the Usibelli Group in the area north of Nenana (T. 2 S., R. 8 W.) is about 3,000 to 3,350 m beneath the ground surface (Barnes, 1961; Hite and Nakayama, 1980; Kirschner, 1988). Organic geochemical studies indicate that mudstones and coals in the Usibelli Group are potential sources of petroleum; calculations based on borehole temperatures suggest that, in the area of the gravity low, these rocks may have been buried deeply enough to generate oil and gas (Stanley and others, 1990). Two exploratory wells, the Union Nenana No. 1 and the ARCO Totek Hills No. 1[1], were drilled some distance away from the gravity low in areas where the Usibelli Group is thin (Grether and Morgan, 1988; Kirschner, 1988). Mudlogs show that both wells were dry holes that bottomed in schist and had gas shows associated with coal beds in the Usibelli Group, but no reported signs of oil.

We thank Florence R. Weber and Richard W. Saltus for their reviews of this effort, and Béla Csejtey, Jr., and Robert M. Chapman for their reviews of an earlier effort.

[1] Additional gravity and some seismic data in the vicinity of the Union Nenana No. 2 well may be found in: Sinclair Oil and Gas Co., Union Oil Co. of Calif., the Pure Oil Co., and the Ohio Oil Co., 1962, Geologic report to accompany application for the Nenana development contract: unpublished report on file at U.S. Geological Survey, Anchorage, Alaska, 3 pages, 2 plates.

DESCRIPTION OF MAP UNITS

[References listed in brackets at the end of each map unit description are the principal ones used in preparing the description and showing the unit's distribution on the map. Map units and (or) unit ages are queried as they are in the mapping sources.]

POSTACCRETION COVER DEPOSITS

Qs **Surficial deposits (Quaternary)**—Unconsolidated gravel, sand, silt, and clay. Includes lake deposits, colluvium, swamp deposits, landslide debris (including blocks of bedrock), flood-plain alluvium, stream gravel, alluvial fan deposits, dune sand, morainal deposits, glacial outwash, loess, tailings, and perennially frozen silt. [Chapman and others, 1971, 1975a, 1975b, 1982; Chapman and Yeend, 1981; Csejtey and others, 1992, 1986; Jones and others, 1983; Péwé and others, 1966; Reed, 1961; and Weber and others, 1992]

Qv **Volcanic rocks (Quaternary)**—Basaltic pyroclastic debris associated with cinder cones or maars located southwest of Buzzard Creek (T. 10 S., R. 4-5 W.). Radiocarbon ages indicate that the debris erupted about 3,000±230 years ago. [Albanese, 1982; Péwé and others, 1966; Wahrhaftig, 1970a]

Thd **Hornblende dacite (Pliocene)**—Shallow intrusive rocks of Jumbo Dome (T. 11 S., R. 6 W.). K-Ar age determination on basaltic hornblende yielded 2.79±0.25 Ma. Apparently intrudes Nenana Gravel (unit Tn). [Csejtey and others, 1992, 1986; Wahrhaftig, 1970d]

Tvs **Volcanic and sedimentary rocks (Tertiary)**—Rhyolitic lava, breccia, tuff, and welded tuff; flow banding, lamination, and spherulitic texture common. Gray cherty rocks are rare and form thin beds or nodules; tuffaceous siltstone, shale, and argillite are thin bedded to laminated. Tertiary age inferred from structural setting and lack of rock alteration; relation to Upper Cretaceous to Miocene sedimentary rocks (unit TKs) is uncertain. Thickness unknown, probably at least 90 to 120 m. Unit Tvs occurs at T. 5-6 N., R. 13-15 W. [Chapman and others, 1982]

Tn **Nenana Gravel (Pliocene and Miocene)**—Mainly buff to reddish-brown, poorly consolidated, pebble to boulder conglomerate and coarse sandstone that contains minor interbeds of mudstone and lignite. These rocks are exposed at T. 8-16 S., R. 1 E.-R. 18 W. Unit Tn is more than 1,300 m thick. Thickness and pebble size decrease northward; imbrication and crossbedding indicate deposition by northward-flowing streams. The Nenana Gravel rests unconformably on the underlying Tertiary Usibelli Group (unit Tu), is overlain by Quaternary surficial deposits (unit Qs), and appears to be deformed around an intrusion of Pliocene hornblende dacite (unit Thd). Because of the lack of diagnostic fossils, the age of the Nenana Gravel is uncertain, but it is younger than the underlying upper Miocene Grubstake Formation of the Usibelli Group and older than the Pliocene hornblende dacite intrusive rocks of Jumbo Dome. The Nenana Gravel represents a series of coalescing alluvial fans that developed on the north side of the Alaska Range as it rose during late Miocene and Pliocene time. [Csejtey and others, 1992, 1986; Wahrhaftig, 1987]

TKs **Sedimentary rocks (Miocene to Late Cretaceous)**—Well-consolidated to friable nonmarine conglomerate, sandstone, mudstone, and coal. In places these rocks are arranged in repeated fining-upward sequences, suggesting deposition by streams. Fossil plant leaves and pollen indicate a range in age from Late Cretaceous to Miocene. Thickness may be as much as 1,500 m. Unit TKs is present along T. 4-5 N., R. 14-22 W. [Chapman and others, 1982; Paige, 1959]

Tu **Usibelli Group (Miocene to Eocene)**—Poorly consolidated nonmarine conglomerate, sandstone, mudstone, subbituminous and lignite coal, and minor tuff. This unit crops out widely in the northern foothills of the Alaska Range (T. 8-16 S., R. 1 E.-R. 14 W.) and also is present in the subsurface of the middle Tanana basin, where it has been penetrated by two exploratory wells (both dry holes), the Union Nenana No. 1 and the ARCO Totek Hills No. 1. The Usibelli Group is generally less than 900 m thick. Locally, the Usibelli Group is divided into five formations; in ascending order, these are the Healy Creek, Sanctuary, Suntrana, Lignite Creek, and Grubstake Formations. Much of the Usibelli Group consists of repeated fining-upward sequences of conglomerate, sandstone, mudstone, and coal that were deposited by streams flowing southward across the present site of the Alaska Range, which then did not exist. Interstratified with these fluvial deposits are locally thick sequences of mudstone that probably accumulated in large, shallow lakes. Fossil plant leaves and pollen and a single radiometric age from an interbed of volcanic tuff indicate that the Usibelli Group ranges in age from Eocene to Miocene. Coal has long been produced in commercial quantities from mines in the Healy Creek and Lignite Creek areas (T. 11-12 S., R. 6-7 W.). Geochemical studies show that coals and mudstones in the Usibelli Group are potential source rocks of petroleum. [Buffler and Triplehorn, 1976; Csejtey and others, 1992, 1986; Stanley, 1987a, 1988; Stanley and others, 1990; Wahrhaftig and others, 1969; Wahrhaftig, 1987]

Tmg **Mount Galen Volcanics of Decker and Gilbert (1978) (early Oligocene and late Eocene)**—Andesitic and basaltic lava flows, breccia, and tuff north of Mount Galen, which is just south of the map area (T. 17 S., R. 15 W.). Thickness to 1,000 m. K-Ar ages on plagioclase and hornblende range from 40.1±1.2 Ma to 34.8±1.4 Ma. [Decker and Gilbert, 1978; Jones and others, 1983]

Tv **Volcanic rocks (Oligocene to Paleocene)**—Compositions range from rhyolite to basalt; includes extrusive rocks (flows, tuffs, and breccias) as well as dikes, sills, and shallow intrusive rocks. K-Ar age determinations range from 54.7±2.4 Ma to 32.5±1.0 Ma. These rocks crop out in the vicinity of Sugar Loaf Mountain (T. 13 S., R. 6-7 W.), the Dora Peak area (T. 12-13 S., R. 6 W.), near Mount Healy (T. 13 S., R. 8 W.), south of Moody Creek at T. 13 S., R. 5 W., near Mount Lathrop (T. 12 S., R. 4 W.), near Needle Rock (T. 11 S., R. 4-5 W.), the Wyoming Hills area (T. 14 S., R. 12 W.), south of Hines Creek at T. 14 S., R. 8 W., northeast of Fairbanks (T. 1 S., R. 1 E.), near Carlo Creek (T. 15-16 S., R. 6 W.), and in isolated outcrops at T. 11 S., R. 11 W. and T. 13 S., R. 3 W. [Albanese and Turner, 1980; Csejtey and others, 1992, 1986; Péwé and others, 1966; Robinson and others, 1990]

Cantwell Formation (Paleocene and Late Cretaceous)—Divided into:

Tcv **Volcanic rocks (Paleocene)**—Unit Tcv, termed the Teklanika Formation by Gilbert and others (1976), is a moderately deformed sequence of andesite, basalt, rhyolite and dacite flows, felsic pyroclastic rocks, related intrusive rocks, and a few interbeds of sandstone and mudstone. The contact with the underlying sedimentary rocks (unit KTcs) is conformable in places but unconformable in others. Unit Tcv is reportedly more than 3,700 m thick. Radiometric ages and field relations suggest that the volcanic rocks were erupted during the Paleocene. These rocks are exposed at T. 14-17 S., R. 5-13 W. [Csejtey and others, 1992, 1986; Gilbert and others, 1976; Wolfe and Wahrhaftig, 1970]

KTcs **Sedimentary rocks (Paleocene and Late Cretaceous)**—Mainly well-indurated nonmarine conglomerate, sandstone, mudstone, and bituminous coal; locally includes interstratified volcanic rocks resembling those in unit Tcv. In many places the sedimentary rocks are intruded by dikes and sills that range in composition from basalt to rhyolite and by granitoids of Cretaceous to Tertiary age (units TKgr and Tgr). The maximum reported thickness is about 3,000 m. The sedimentary rocks rest with pronounced angular unconformity on deformed and metamorphosed rocks of Precambrian(?) to Cretaceous age. Much of the conglomerate, sandstone, mudstone, and coal in the Cantwell Formation is repeated in fining-upward sequences of fluvial origin. Intercalated with the fluvial deposits are thick sequences of mudstone that, most likely, were deposited in lakes. The age of the Cantwell Formation is based on the occurrence of Late Cretaceous and Paleocene palynomorphs, Paleocene plant fossils, and Paleocene radiometric ages from volcanic rocks. Geochemical studies indicate that some mudstones and coals are potential source rocks of petroleum. Unit KTcs crops out at T. 14-17 S., R. 1 E.-R. 15 W. [Csejtey and others, 1992, 1986; Gilbert and others, 1976; Stanley, 1987b; Wolfe and Wahrhaftig, 1970; R.G. Stanley, Hideyo, Haga, and R.A. Ballog, unpublished biostatigraphic data; Ridgway and others, 1994]

Kv **Volcanic rocks (Late Cretaceous)**—Gray to black porphyritic basalt that forms a swarm of dikes limited to a small area at T. 13 S., R. 4 W. K-Ar age is 79.1 Ma. [Csejtey and others, 1992, 1986]

PLUTONIC ROCKS

Tgr **Granitic rocks (Oligocene to Paleocene)**—Wide variety of epizonal granitic rocks that consist of granite, granodiorite, tonalite, and quartz monzodiorite, quartz monzonite, and syenite. K-Ar ages range from about 62 to 37 Ma and are interpreted to represent Paleocene to early Oligocene ages of intrusion. Unit Tgr is exposed at Manley Hot Springs Dome (T. 2-3 N., R. 15-16 W.), Tolovana Hot Springs Dome (T. 6 N., R. 6 W. and T. 4 N., R. 8 W.), Nenana Mountain (T. 16 S., R. 1-2 W.), south of the McKinley Fault (T. 17 S., R. 2-4 W.), between the Wyoming Hills (T. 14-15 S., R. 12-13 W.) and Brooker Mountain (T. 16 S., R. 18 W.), Pyramid Mountain (T. 15 S., R. 5 W.), near Panorama Mountain (T. 16 S., R. 5 W.), and in an isolated outcrop at T. 15 S., R. 4 W. [Chapman and others, 1982, p. 11; Csejtey and others, 1992, 1986; Weber and others, 1992]

TKgr **Granitic rocks (Paleocene and Late Cretaceous)**—Plutons, dikes, and stocks of granite, granodiorite, granite porphyry, monzonite, quartz monzonite, syenite, diorite, and dacite. K-Ar ages range from about 71 to 59 Ma and are interpreted to represent Late Cretaceous to Paleocene ages of intrusion. Unit TKgr crops out north of the Bitzshtini Mountains (T. 2-3 S., R. 22 W.), along the Yukon River between Stevens and Morelock Creeks (T. 5-7 N., R. 16-18 W.), south of Cascaden Ridge, which is just off the map area (T. 7 N., R. 7 W.), east of Fang Mountain near Riley Creek (T. 15 S., R. 8 W.), along the Nenana River near McKinley Village (T. 15 S., R. 6-7 W.), near Chilchukabena Lake (T. 10-11 S., R. 20 W.), northeast of Fairbanks (T. 1 S., R. 1 E.), in isolated outcrops between Murphy Dome (T. 2 N., R. 4 W.) and Pedro Dome (T. 2 N., R. 1 E.), near Ester Dome (T. 1 N., R. 3 W.), and in isolated outcrops between the Minto Fault and Slate Creek (T. 6-7 N., R. 4-5 W.). [Chapman and others, 1982, p. 11, 1975b; Chapman and Yeend, 1981, p. B31; Csejtey and others, 1992, 1986; Péwé and others, 1966; Weber and others, 1992]

Kgr **Granitic rocks (Cretaceous)**—Tonalite, quartz monzonite, monzonite, granite, and some granodiorite, quartz diorite, diorite, quartz monzodiorite, and syenite. K-Ar ages on rocks from the Healy quadrangle range from about 106 to 49 Ma; however, the early Tertiary ages are suspected to represent a Tertiary reheating event as indicated by discordant ages on biotite-hornblende mineral pairs on some of the rocks (Csejtey and others, 1992, 1986, p. 34). Unit Kgr occurs at Roughtop Mountain (T. 4 N., R. 16 W.), Elephant Mountain and Wolverine Mountain (T. 5-6 N., R. 11-12 W.), Pedro Dome (T. 2 N., R. 1 E.), Sawtooth Mountain (T. 6 N., R. 9-10 W.), Eureka Dome (T. 4-5 N., R. 13-14 W.), Mystic Mountain (T. 11 S., R. 1 W.), Nenana Mountain (T. 15-16 S., R. 1 E.), the Anderson Mountain area (T. 12-13 S., R. 1 E.-R. 3 W.), south of Keavy Peak (T. 12 S., R. 2-3 W.), south of the Hines Creek Fault at T. 13-14 S., R. 1 E., and south of the McKinley Fault at T. 17 S., R. 1 E. [Chapman and others, 1982; Csejtey and others, 1992, 1986; Weber and others, 1992]

ACCRETED TERRANES

Baldry and Ruby terranes, undivided

PDa **Argillaceous rocks (Permian? to Middle or Late Devonian?)**—Gray siltstone, slate, phyllite, argillite, and minor sandstone. Contact relations, thickness, and age uncertain; apparently younger than unit Oc and older than unit KJcs (Manley terrane). Most probable ages are Middle or Late Devonian to Permian (Chapman and others, 1982, p. 7). Probably about 300 m thick. Mapped only near Boulder Ridge (T. 4 N., R. 16-17 W.). These rocks were mapped as unit Pzar by Chapman and others (1982) and as unit Pzcs by Chapman and others (1975a). [Chapman and others, 1982, 1975a]

PDs **Schistose rocks (Permian? to Devonian?)**—Quartz-mica-garnet schist, some quartzite schist, calcareous schist, marble and slate-phyllite; schistose chert, hornfels, and skarn occur locally. Pegmatite, quartz, and felsic dikes are common; some mafic dikes are present. A small body of gneissic granite and pegmatite at the head of Garnet Creek (T. 6 N., R. 14 W.) is included. Ages and protoliths of rocks uncertain; age probably Devonian to Permian. Unit may conformably overlie unit DOl, but contacts are poorly exposed. Thickness unknown but may be as much as 600 to 900 m. This unit is mapped only in the Russian-Ruby-Garnet Creeks area (T. 6-7 N., R. 13-14 W.). These rocks were mapped as unit Pzsr by Chapman and others (1982, 1975a). [Chapman and others, 1982, 1975a]

DSl **Limestone, dolomite, greenstone, schist, and chert (Devonian and Silurian)**—Limestone, dolomite, greenstone, and chloritic schist. Minor amounts of phyllite, calcareous schist, quartz-mica schist, quartzite, and chert are included. Mapped only along and north of the Yukon River (T. 4-7 N., R. 16-22 W.), but rocks are similar to those in unit DOl, which crops out south of the Yukon River. Poorly preserved colonial rugose corals from Raven Ridge (T. 7 N., R. 16-17 W.) are identified as ranging in age from Silurian to Permian; however, field relations suggest that a Silurian to Devonian age is most probable (Chapman and others, 1982, p. 9). Unit is presumed to correlate in part with unit DSt (White Mountains terrane) (Chapman and others, 1982, p. 9). Upper and lower contacts poorly defined. Thickness unknown, but probably at least 460 m. These rocks were mapped as unit Pzlc by Chapman and others (1982, 1975a). [Chapman and others, 1982, 1975a]

DOl **Limestone, dolomite, greenstone, and schist (Devonian, Silurian, and Ordovician?)**—Dominantly light-gray crystalline limestone and dolomite; minor chert. Some basaltic greenstone, chloritic schist, argillite, phyllite, quartz-mica schist, quartzite, and metachert are included. No fossils or continuous sections. Interpreted by Chapman and others (1982) to include rocks of Ordovician(?), Silurian, and Devonian age. Apparently overlies unit Oc. Several thin chert-pebble conglomerate beds in basal

30 to 60 m; upper contact of unit DOl not seen. Mapped only south of the Yukon River (T. 4-6 N., R. 13-21 W.). May be correlative in part with unit DSl north of the Yukon River, unit DSt (White Mountains terrane), and part of unit SZa (Livengood terrane) (F.R. Weber, written commun., 1992). Thickness uncertain, but probably at least 150 m to as much as 460 m. These rocks were mapped as unit Pzl by Chapman and others (1982, 1975a). [Chapman and others, 1982, 1975a]

Pzc **Clastic rocks (middle and early Paleozoic?)**—Upper part contains gray calcareous schistose siltstone and sandstone. Lower part contains poorly sorted sandstone, granule conglomerate, siltstone, and semischist with commonly 15 to 46 m of gray metachert near the top. Subordinate phyllite interbedded throughout upper and lower parts. Age uncertain; probably early Paleozoic (possibly Devonian) (Chapman and others, 1982, p. 8). Thickness unknown, but probably at least 900 to more than 1,200 m. Mapped only in Minook Creek area (T. 5-7 N., R. 12-15 W.). These rocks were mapped as units Pzc and Pzw by Chapman and others (1982, 1975a). [Chapman and others, 1982, 1975a]

SOvs **Volcanic and sedimentary rocks (Silurian and (or) Ordovician)**—Foliated basaltic lava, tuff, slate, slaty shale, phyllite, and some limestone and chert. Volcanic rocks are partly altered and include some diabasic rocks. Sedimentary rocks are generally thin bedded. Sequence apparently overlies unit Oc and is overlain by unit DOl; both contacts are gradational. These field relations suggest that unit SOvs is of Ordovician and (or) Silurian age (Chapman and others, 1982, p. 10). May be correlative in part with part of unit SZa (Livengood terrane) (F.R. Weber, written commun., 1992). Mapped only in the area between Rock and Minook Creeks (T. 5-6 N., R. 13-14 W.) and just north of Roughtop Mountain (T. 4 N., R. 16 W.). Thickness unknown, but probably at least 70 to 100 m. These rocks were mapped as unit Pzvs by Chapman and others (1982). [Chapman and others, 1982, 1975a]

Pzp€sq **Schist, quartzite, phyllite, and slate (early Paleozoic and Precambrian)**—Quartz-mica schist, quartzite, phyllite, slate, and minor amounts of chert, shaly limestone, siltstone, and graywacke. Unit is mapped only north of the Yukon River (T. 4-6 N., R. 17-22 W.). Underlies unit DSl (Baldry and Ruby terranes, undivided), but the contact is poorly defined. Age uncertain; unit is generally correlative with pelitic schist units of the Melozitna, Bettles, and Beaver quadrangles (Chapman and others, 1982, p. 11). Thickness unknown, but probably at least 600 m. These rocks were mapped as unit Pzp€sq by Chapman and others (1982) and as unit Pzsq by Chapman and others (1975a). [Chapman and others, 1982, 1975a]

Oc **Chert (Late Ordovician)**—Gray chert and minor interbedded slaty shale, chert breccia, and quartzite. Chert is thin to medium bedded, sheared, and fractured. These rocks occur in T. 4-7 N., R. 12-19 W. Nature of upper and lower contacts uncertain; probably grades upward into unit SOvs. Interpreted to be correlative with the Livengood Dome Chert (unit Old, Livengood terrane, T. 7 N., R. 9-11 W.) by Chapman and others (1982, p.10; 1980) and is therefore assigned a Late Ordovician age. May be correlative in part with part of unit SZa (Livengood terrane) (F.R. Weber, written commun., 1992). Thickness unknown, possibly 300 to 600 m. [Chapman and others, 1982, 1980, 1975a]

Dillinger terrane

DOsa **Sandstone, argillite, and limestone (Middle Devonian to Ordovician)**—Gray sandstone, black argillite, and thin gray limestone interbeds. A 200-m-thick interbed of gray massive crystalline limestone lies near the top of the section. Complexly folded and faulted, regionally metamorphosed, and stratigraphically upward-shallowing marine sequence of slope and basinal turbidites, hemipelagic deposits, and lesser amounts of shelf deposits. These rocks are exposed north of the McKinley Fault at T. 16-17 S., R. 9-10 W. Gastropod fossils in one of the thin limestone interbeds provided Ordovician to Devonian ages; Middle Devonian fossils were reported from a massive limestone interbed near the headwater area of the Sanctuary River (T. 16 S., R. 9 W.). Limestone pebbles that occur in the overlying Cantwell Formation (unit KTcs) were probably derived from unit DOsa and contain conodont fossils ranging in age from Ordovician to Early Devonian. Based on the above fossil data, unit DOsa is considered to range in age from Ordovician to Middle Devonian. These rocks were mapped as unit DOs by Csejtey and others (1986) and as unit Pzd by Jones and others (1983). [Csejtey and others, 1992, 1986; Jones and others, 1983, 1982]

Livengood terrane

Dq **Quail unit (Late Devonian)**—Informal unit of Weber and others (1992). Phyllite, calcareous phyllite, siltstone, quartzose sandstone, graywacke, and conglomerate. Limestone bodies at the base are as much as 30 m thick and have a lateral extent of several hundred meters; Weber and others (1992) interpreted them to be local biogenic buildups on unit Dt. Age based on fossils (corals, stromatoporoids, and conodonts). This unit is mapped at the Sawtooth Mountain area (T. 6-7 N., R. 8-11 W.). These rocks were mapped as unit Dcl by Chapman and others (1971), unit Dcg by Frost and Stanley (1991), and part of the Middle Devonian Cascaden Ridge unit of Weber (1989). [Chapman and others, 1971; Frost and Stanley, 1991; Weber, 1989; Weber and others, 1992]

Dt **Troublesome unit (Devonian?)**—Informal unit of Weber and others (1992). Argillite, chert, siliceous slate, and extensive mafic intrusive and extrusive rocks. No identifiable fossils, but radiolaria have been reported (Weber and others, 1992). This unit is mapped at the Sawtooth Mountain area (T. 6-7 N., R. 8-11 W.). These rocks were mapped as unit Pzu by Chapman and others (1971), unit Pc by Frost and Stanley (1991), and part of the Middle Devonian Cascaden Ridge unit of Weber (1989). [Chapman and others, 1971; Frost and Stanley, 1991; Weber, 1989; Weber and others, 1992]

Dc **Cascaden Ridge unit (Middle Devonian)**—Informal unit of Weber and others (1992). Shale, siltstone, graywacke, conglomerate, and minor limestone. Age based on abundant invertebrate fossils in the limestone sections (Weber and others, 1992). Thickness unknown; contacts not exposed. This unit is mapped south of Cascaden Ridge, which is just north of the map area (T. 7 N., R. 7 W.). These rocks were mapped as part of unit Dcl by Chapman and others (1971), unit Dcg by Frost and Stanley (1991), and part of the Cascaden Ridge unit of Weber (1989). [Chapman and others, 1971; Frost and Stanley, 1991; Weber, 1989; Weber and others, 1992]

SZa **Amy Creek unit (Silurian? to Late Proterozoic?)**—Informal unit of Weber and others (1992). Siliceous dolomite, dolomitic mudstone, wackestone, and packstone, dolomite, chert, and argillite. Minor lime mudstone that contains interbedded chert and basaltic greenstone and lenses of tuff, tuffaceous siltstone, shale, and volcaniclastic graywacke. Basaltic flows and flow breccia are present locally in the argillaceous rocks at Amy Creek, just beyond the mapped area (T. 8 N., R. 4 W.). Age range based on sponge spicules in chert (Weber and others, 1992). At least 1,150 m thick. This unit is mapped at the Sawtooth Mountain area (T. 6-7 N., R. 10-12 W.). These rocks were mapped as unit DOd by Chapman and others (1971), unit Op€d by Frost and Stanley (1991), and the Precambrian(?) to Ordovician Amy Creek unit of Weber (1989). [Chapman and others, 1971; Frost and Stanley, 1991; Weber, 1989; Weber and others, 1992]

Old **Livengood Dome Chert (Late Ordovician)**—Chert, siliceous slate, and rare greenstone, tuff, and limestone. Age based on graptolites in shaly layers within the chert (Chapman and others, 1980). At least 1 km thick. This unit is mapped between Sawtooth Mountain (T. 6-7 N., R. 9-11 W.) and Livengood Dome, which is just north of the mapped area (T. 9 N., R. 4-5 W.). [Chapman and others, 1980; Weber and others, 1992]

€Zum **Ultramafic and mafic rocks (Early Cambrian and (or) Late Proterozoic)**—Serpentinite and greenstone intruded by gabbro and diorite. Serpentinite is sheared and foliated to massive. Gabbros yield radiometric ages from 643 to 518 Ma (Weber and others, 1992). Rocks are generally green and dark green to black and are commonly overlain by barren to thinly vegetated soil and rubble patches on upper slopes and hilltops. This unit is mapped at the Sawtooth Mountain area (T. 6-7 N., R. 8-11 W.) and at Cascaden Ridge (T. 7 N., R. 7 W.) and is spatially associated with unit SZa. These rocks were mapped as unit Pzsp by Chapman and others (1971), unit €Zsp by Frost and Stanley (1992), and as part of the mafic and ultramafic complex by Weber (1989). [Chapman and others, 1971; Frost and Stanley, 1991; Loney and Himmelberg, 1987; Weber, 1989; Weber and others, 1992]

Manley terrane

KJcs **Clastic sedimentary rocks (Cretaceous and Late? Jurassic)**—Graywacke, quartzose sandstone, quartzite, siltstone, shale, slate, argillite, and conglomerate. Sandstone beds preserve sole marks and are commonly normally graded. The entire unit is tightly folded and faulted. Rare invertebrate and plant fossils indicate Late(?) Jurassic and Cretaceous ages. Thickness poorly known; probably not less than 1,000 m and may be as much as 2,700 m. Unit KJcs crops out at T. 1-7 N., R. 3-19 W. and at T. 4 S., R. 22 W. Mapped as unit KJgs by Chapman and others (1975b), units KJs and KJc by Chapman and others (1971), and units Km, Kwcc, Kwcs, and KJw by Weber and others (1992). [Chapman and others, 1982, 1975a, 1975b, 1971; Weber and others, 1992]

MzPzp **Phyllite, schistose phyllite, quartzite, siltite, amphibolite, diorite, and greenstone (Mesozoic or Paleozoic)**—Gray, pyritized phyllite and schistose phyllite, quartzite, and very finely layered siltite intruded by mafic rocks that include amphibolite, diorite, and greenstone. Amphibolite yielded a K-Ar age of 163.88±21.1 Ma. (Weber and others, 1992). These rocks are limited to two outcrops north of the Beaver Creek Fault at T. 5 N., R. 8 W. and T. 4 N., R. 9 W. [Weber and others, 1992]

€Zsp **Serpentinite and mafic rocks (Early Cambrian and (or) Late Proterozoic)**—Serpentinite, diabase, gabbro, and some metadiorite and rodingite; includes some thin layers of slaty to schistose rocks, phyllite, and mafic volcaniclastic rocks. Based on lithologic similarity, Loney and Himmelberg (1987) interpret these rocks to be correlative with the Late Proterozoic to Cambrian ultramafic rocks of the Livengood area (unit €Zum, Livengood terrane) lying structurally above and possibly in fault contact with unit KJcs in the Manley Hot Springs area (T. 3-4 N., R. 15-18 W.). Chapman and others (1982) previously interpreted these rocks to intrude the sedimentary rocks of unit KJcs and assigned them a Late Cretaceous age. Unit €Zsp occurs along Serpentine Ridge (T. 3-4 N., R. 15-18 W.). These rocks were mapped as unit Ksp by Chapman and others (1982) and Frost and Stanley (1991). [Chapman and others, 1982; Frost and Stanley, 1991; Loney and Himmelberg, 1987]

McKinley and Pingston terranes, undivided

KJf **Flysch (Early Cretaceous and Late Jurassic)**—Monotonous, very thick (probably several thousands of meters) turbidite sequence that includes argillite, graywacke, conglomerate, a few thin interbeds of chert, and some thin beds of limestone. The entire sequence has been compressed into tight folds and complexly faulted, including thrust faults. These rocks unconformably overlie unit TRbd east of the Nenana River; elsewhere the contact is tectonic or covered by surficial deposits. Depositional age span is well established based on fossils; age of metamorphism is about mid-Cretaceous, but may span from Late Jurassic to early Tertiary based on K-Ar age determinations on mineral separates (Csejtey and others, 1992, 1986). Unit KJf crops out at T. 15-16 S., R. 1 E.-R. 14 W. These rocks were mapped as unit KJf by Csejtey and others (1986) and as unit Ks by Jones and others (1983). [Csejtey and others, 1992, 1986; Jones and others, 1983, 1982]

TRbd **Basalt, diabase, gabbro, and subordinate interbedded sedimentary rocks (Late Triassic; Norian and Karnian)**—Several-hundred- to several-thousand-meters-thick submarine sequence of mostly pillow basalts and gabbro and diabase sills and dikes that also cut the underlying unit TRPs; subordinate interbedded sedimentary rocks are gray to green sandstones, siltstones, and argillites. This unit probably represents a series of subaqueous basalt flows that contain minor intercalated clastic and pelagic sedimentary materials that were deposited in a deep marine environment. Fossils are rare, but a bivalve of Late Triassic (Karnian and Norian) age and radiolarians of Late Triassic (late Norian) age have been identified. These rocks crop out in a narrow, discontinuous, fault-bounded, east-west-trending belt between Panorama Mountain (T. 16 S., R. 6 W.) and the Toklat River (T. 16 S., R. 13 W.). Metamorphic grade is prehnite-pumpellyite. Depositionally overlies unit TRPs. These rocks were mapped as unit TRbd by Csejtey and others (1992, 1986) and as unit TRbg by Jones and others (1983). [Csejtey and others, 1992, 1986; Jones and others, 1983, 1982]

TRcs **Calcareous sedimentary rocks (Late Triassic; Norian and Karnian)**—Thin-bedded calcareous marine shale, argillite, sandstone, siltstone, and argillaceous limestone, which include numerous dikes, sills, and small plugs of altered diabase and gabbro that are constrained by crosscutting relations to range in age from Jurassic to Early Cretaceous. These rocks are intensely and penetratively deformed and locally metamorphosed to greenschist and amphibolite facies. Unit TRcs is interpreted to represent a marine regressive sequence that has deep continental slope deposits at the base that are overlain by progressively shallower slope deposits, then by outer shelf deposits, and finally by inner shelf deposits. The age range is based on conodonts and pelecypods. Unit TRcs overlies unit Dy in slight angular unconformity as indicated in a good exposure south of the Wood River (T. 14 S., R. 1-2 W.); the top of the sequence is not exposed. Correlated with unit TRcs (Nenana terrane) south of the McKinley fault by Csejtey and others (1986). Preserved thickness is uncertain, but it is estimated to be several hundred meters. These rocks crop out at T. 14-16 S., R. 1 E.-R. 9 W. Mapped as unit TRs by Jones and others (1983). [Csejtey and others, 1992, 1986; Jones and others, 1983, 1982]

ŦIPs **Flysch-like sedimentary rocks (Late Triassic to Pennsylvanian)**—Conglomerate, sandstone, siltstone, argillite, a few thin interbeds of limestone, and chert intercalated with argillite near the top. These rocks are intensely folded, several hundred meters thick, and massive to thin bedded. The depositional environment of this unit may have been slope to base-of-slope. Age based on abundant fossils of marine macroinvertebrates, conodonts, and radiolarians. Metamorphic grade is prehnite-pumpellyite. Depositionally underlies unit Ŧbd. Unit ŦIPs crops out at T. 16 S., R. 7-13 W. [Csejtey and others, 1992, 1986; Jones and others, 1983, 1982]

Dy **Yanert Fork sequence (Late Devonian)**—Informal unit of Csejtey and others (1992, 1986). Intensely deformed metasedimentary and metavolcanic rocks that consist of mudstone, argillite, shale, slate, phyllite, and quartzite. Also contains interbeds of chert, metatuff, metabasalt, schistose metaconglomerate, and marble. Diabase and gabbro intrusions are present that are lithologically similar to those in units Ŧcs (McKinley and Pingston terranes, undivided) and Ŧcs (Nenana terrane) and presumably of the same age (Jurassic to Early Cretaceous). Exposed mainly in the headwater region of Yanert Fork (T. 14-15 S., R. 2 E.-R. 5 W.). Overlain in slight angular unconformity by unit Ŧcs; basal contact is not exposed. Thickness unknown, but estimated to be at least 1,000 m. Metamorphic grade is lower greenschist facies; metamorphism probably occurred during mid-Cretaceous time. Age span imperfectly known, but conodont fossils present in a marble interbed yielded a Late Devonian (Famennian) age (Csejtey and others, 1992, 1986). Lithologies, depositional environment, metamorphic grade, age, and structural style are the same north and south of the Hines Creek Fault. These rocks were mapped as unit Pzy by Csejtey and others (1986). [Csejtey and others, 1992, 1986; Jones and others, 1983, 1982]

Minook terrane

Ŧc **Black shale and chert (Triassic)**—Black shale and slate locally interlayered with light-olive-gray, thinly to thickly bedded chert and light-greenish-gray tuff. Radiolarians in chert identified as Triassic in age (Karen Wheeler, oral commun., 1992). These rocks crop out west of Sawtooth Mountain at T. 7 N., R. 11-12 W. [Weber and others, 1992]

Ps **Sedimentary rocks (Permian)**—Shale, slaty and in part phyllitic, siltstone, argillite, graywacke, pebble-to-granule conglomerate, and minor interbedded unfossiliferous chert. Graded bedding is common in sandstones; siltstones are interbedded with shales and phyllites. Sparsely fossiliferous clastic limestone crops out rarely in thin discontinuous beds. Age is based on crinoid fragments and bryozoans in conglomerate. Thickness unknown, but probably at least 300 m in the Minook-Hoosier Creeks area (T. 6-7 N., R. 12-13 W.). Contact with unit KJcs (Manley terrane), which is lithologically similar, is a poorly exposed unconformity or possibly a fault. These rocks were mapped as unit Ps by Chapman and others (1982, 1975a), unit Pzc by Chapman and others (1971), and unit Ps by Weber and others (1992). [Chapman and others, 1982, 1975a, 1971; Patton and others, 1989; Weber and others, 1992]

Nenana terrane

Ŧsc **Sedimentary calcareous rocks (Late Triassic)**—Lithologically similar to unit Ŧcs (McKinley and Pingston terranes, undivided) but occurs only south of the McKinley Fault (T. 16 S., R. 1-4 W.). Correlated by Csejtey and others (1986) with unit Ŧsc (McKinley and Pingston terranes, undivided). [Csejtey and others, 1992, 1986]

Nixon Fork and Minchumina terranes, undivided

Dls **Limestone and siltstone (Late? Devonian)**—Dominantly gray limestone; forms prominent ridges; minor siltstone is gray, shaly to phyllitic, and calcareous in part. Unit Dls occurs at T. 1-2 S., R. 22 W. Fossils from a locality 8 mi south of Redlands Lake, just west of mapped area (T. 3 S., R. 24 W.), yielded an early Late Devonian (Frasnian) age. Thickness unknown; probably at least 150 m. [Chapman and others, 1975b]

DOc **Chert (Early Devonian to Ordovician)**—Gray, thin- to thick-bedded chert that has thin interbeds of siliceous siltstone, shaly to slaty mudstone, and shaly tuffaceous argillite. Overlies unit DOs; contact may be gradational. Radiolarians of early Paleozoic (Ordovician to Early Devonian) age are present in both chert and argillite; Ordovician graptolites were found in thin shale beds at one site. May be correlative in part with unit Pzcs (White Mountains terrane, Wickersham terrane, and Yukon-Tanana terrane north of Tanana River, undivided) in the Dugan Hills area (T. 2 N.-T. 1 S., R. 11-13 W.). Correlated with the Livengood Dome Chert (unit Old, Livengood terrane) by Chapman and others (1981, p. B33; 1975b). These rocks occur at T. 4-9 S., R. 19-23 W., and were mapped as unit Oc by Chapman and others (1975b). [Chapman and Yeend, 1981; Chapman and others, 1981, 1975b]

DOs **Shaly rocks (Early Devonian to Ordovician)**—Mudstone, argillite, grit, quartzite, calcareous quartz-chert arenite, sandy limestone, and minor amounts of chert and quartz-mica schist. Age range based on the presence of Ordovician graptolites and a coral of "probable Early or Middle Devonian" age in a lakeshore cobble (Chapman and others, 1981). Probably underlies unit DOc. These rocks crop out at T. 7-13 S., R. 19-22 W. May be correlative in part with unit ₽zma at Mooseheart Mountain (T. 2-3 S., R. 17-18 W.) and the Bitzshtini Mountains (T. 5-6 S., R. 22-23 W.) and in part with unit €Zwa (White Mountains terrane, Wickersham terrane, and Yukon-Tanana terrane north of Tanana River, undivided) in the Dugan Hills area (T. 2 N., R. 11-13 W.). [Chapman and others, 1981; Chapman and Yeend, 1981]

₽zma **Mudstone, argillite, grit, quartzite, calcareous quartz-chert arenite, sandy limestone, and minor chert and quartz-mica schist (early Paleozoic?)**—Lithologically similar to unit DOs. Lithology at Mooseheart Mountain (T. 1-2 S., R. 17-18 W.) comprises brown slates and quartzites (Richard G. Stanley, field notes, 1986). Unit ₽zma crops out northwest of unit DOc in the Bitzshtini Mountains (T. 5-6 S., R. 22-23 W.). The same rocks were mapped as units €qs and O€sl by Chapman and others (1975b) and as unit DOs by Chapman and others (1981). [Chapman and others, 1981, 1975b]

Seventymile terrane

PMum **Ultramafic and mafic rocks (Early Permian? to Mississippian?)**—Diorite and serpentinized peridotite; these rocks are present at Wood River Buttes (T. 5 S., R. 3 W.) and are lithologically similar to mafic and ultramafic rocks along the Salcha River in the Big Delta quadrangle to the northeast. An intense linear magnetic anomaly that extends from the Wood River Buttes to the Salcha River outcrops suggests that the mafic and ultramafic rocks in the two areas are parts of a single belt (Péwé and others, 1966). In the Salcha River area and farther east, the mafic and ultramafic rocks are associated with slightly recrystallized cherts that contain radiolarians and conodonts of Early Permian age and radiolarians of Mississippian age (Foster and others, 1987, p. 42). The rocks at Wood River Buttes were mapped as unit Dmu by Péwé and others (1966). [Foster and others, 1987; Péwé and others, 1966]

Tozitna terrane

TRMms **Mafic igneous rocks and sedimentary rocks (Triassic to Mississippian)**—Volcanic, sedimentary, and ultramafic rocks that include tuffs, greenstones, breccias, and basaltic, diabasic, and rarely andesitic lavas; pyroclastic tuffaceous rocks apparently grade into sedimentary tuffs and chert. Intrusive rocks are fine- to coarse-grained diabase-gabbro and some diorite that are present as sills several meters to at least 90 m thick and commonly form prominent ridges, knobs, and bluffs. Serpentinized ultramafic rocks have been reported at a few locations (Chapman and others, 1975a, p. 6). Sedimentary rocks are argillite, chert, graywacke, shale, and limestone. Referred to as the Rampart Group by Chapman and others (1975a), Jones and others (1984), Weber (1989), and Weber and others (1992). Age range of Mississippian to Triassic is based on fossils (radiolarians in chert and invertebrates in limestone) and a hornblende K-Ar age of 205±6 Ma on a gabbroic intrusive body (Weber and others, 1992). Lower contact may be an unconformity, thrust fault, or both. Thickness unknown but probably at least 900 to 1,200 m. Unit TRMms crops out north of the Bitzshtini Mountains at T. 2-3 S., R. 21-22 W., north of the Yukon River (T. 6-7 N., R. 20-22 W.), and north and south of Garnet Creek (T. 6-7 N., R. 12-15 W.). Part of this unit may be correlative with unit Ps (Minook terrane). These rocks were mapped as units TRPv and TRm by Chapman and others (1975a and 1975b, respectively) and units TRMrv and TRMrs by Weber and others (1992). [Chapman and others, 1982, 1975a, 1975b; Jones and others, 1984; Patton and others, 1989; Weber, 1989; Weber and others, 1992]

White Mountains terrane, Wickersham terrane, and Yukon-Tanana terrane north of Tanana River, undivided

TRm **Mafic igneous rocks (Triassic)**—Gabbro, diorite, metadiorite, diabase, basalt, metabasalt, and greenstone. Intrudes unit Mg (White Mountains terrane). Unpublished radiometric data by J.K. Mortensen (Canadian Geological Survey) have identified a zircon as Triassic (232.1±4.5 Ma) in age (Weber and others, 1992). Unit TRm crops out only south of the Beaver Creek Fault at T. 3-7 N., R. 2-10 W. Mapped as unit ₽zm by Chapman and others (1971) and

Frost and Stanley (1991) and as part of the Globe unit of Weber (1989). [Chapman and others, 1971; Frost and Stanley, 1991; Weber, 1989; Weber and others, 1992]

Mg **Globe unit (Mississippian)**—Informal unit of Weber and others (1992). Vitreous quartzite, phyllite, and slate. Age is based on lithologic similarity to the informally named Keno Hill quartzite of Tempelman-Kluit (1970). These rocks crop out only south of the Beaver Creek Fault along a narrow band at T. 2-7 N., R. 2-13 W. Intruded by unit ₮m. Unit Mg is mapped as part of the Globe unit of Weber (1989), unit ₽zq by Frost and Stanley (1991), and unit Oq by Chapman and others (1971). [Chapman and others, 1971; Frost and Stanley, 1991; Weber, 1989; Weber and others, 1992]

M€bh **Birch Hill sequence (Mississippian to Cambrian)**—Informal unit of Robinson and others (1990). Phyllite, micaceous calcschist, calc-amphibolite, quartzite, and minor felsic tuff. Age based on evidence from Robinson and others (1990). Stratigraphically overlies unit M€cr. According to Robinson and others (1990), these rocks are intruded by and are overlain by basalts that are part of unit Tv, Postaccretion Cover Deposits. Contains lower-greenschist-facies mineral assemblages and may be correlative with the Keevy Peak Formation (unit ₽zkp, Yukon-Tanana terrane south of Tanana River) of the central Alaska Range. These rocks crop out in a narrow belt northeast of Fairbanks near Fort Wainwright (T. 1 S., R. 1 E.). [Robinson and others, 1990]

M€cr **Chena River sequence (Mississippian to Cambrian)**—Informal unit of Robinson and others (1990). Banded amphibolite, tremolite marble, coarse-grained garnet-muscovite schist, biotite-rich schist, micaceous calcschist, and pale-green metachert. Age based on evidence from Robinson and others (1990). Mineral assemblages and textural maturity suggest these rocks were metamorphosed to lower-amphibolite-facies grade. Structurally overlies the Fairbanks schist unit (unit Zf). These rocks crop out in a narrow belt north of the Tanana River near Fairbanks (T. 2 S.-T. 2 N., R. 1 E.-R. 2 W.). [Robinson and others, 1990]

Dcg **Conglomerate, graywacke, and slate (Devonian?)**—Chert-pebble conglomerate; graywacke has interbedded siltstone and slate, which contain unidentifiable plant fragments (Weber and others, 1992). Age based on fossils (Chapman and others, 1971). These rocks occur south of the Beaver Creek Fault near the confluence of Beaver and Wickersham Creeks (T. 7 N., R. 1 W.). The southern boundary is overthrust by unit €Zwa. True thickness is unknown, but it is at least 90 m thick (Weber and others, 1992). Beaver Bend unit of Weber and others (1992). Mapped as unit Dcl by Chapman and others (1971) and unit Dc by Frost and Stanley (1991). [Chapman and others, 1971; Frost and Stanley, 1991; Weber and others, 1992]

DSt **Tolovana Limestone (Middle Devonian to Early Silurian)**—Thickly bedded to massive, finely crystalline, gray limestone; in places rich in peloids and ooids. Forms prominent ridge near Dugan Hills (T. 2 N., R. 12-13 W.), COD Lake (T. 3 N., R. 6-7 W.), and at T. 6-7 N., R. 1-3 W. near the southern end of the White Mountains, which are north of the map area (T. 8-10 N., R. 1-2 E.). Contains crushed zones recemented by white calcite and quartz; chert is rare or absent. Fossils (conodonts, brachiopods, and corals) from the White Mountains have been identified as Silurian in age, and corals from the Dugan Hills-COD Lake area have been identified as Middle Devonian in age (Blodgett and others, 1987; Oliver and others, 1975; Weber and others, 1992). Unit DSt disconformably overlies unit Of; this contact is well exposed just off the map area to the northeast (65°37'16" N, 147°21'11" W) (Blodgett and others, 1987). Thickness exceeds 1,200 m in the White Mountains area. Weber and others (1992) separate unit DSt into an upper subunit of Middle Devonian age that is exposed in the Dugan Hills-COD Lake area and is at least 457 m thick, and a lower main body of Silurian age exposed in the White Mountains. [Blodgett and others, 1987; Chapman and others, 1971; Oliver and others, 1975; Péwé and others, 1966; Weber, 1989; Weber and others, 1992; Wheeler and others, 1987]

₽zcs **Chert and siliceous shale (early Paleozoic)**—Thin- to thick-bedded chert and thin interbeds of siliceous slaty shale. These rocks crop out in the Dugan Hills area (T. 1 S.-T. 2 N., R. 11-13 W.). Age is inferred from lithologic similarity to unit DOc (Nixon Fork and Minchumina terranes, undivided), which contains Ordovician and Devonian fossils. These rocks are probably correlative with the sedimentary part of the Fossil Creek Volcanics (unit Of, White Mountains terrane, Wickersham terrane, and Yukon-Tanana terrane north of Tanana River, undivided) (F.R. Weber, written commun., 1992). This unit was mapped as unit DOc by Chapman and Yeend (1981), unit Oc by Chapman and others (1982, 1975a), and unit nc by Péwé and others (1966).

[Chapman and others, 1982, 1975a; Chapman and Yeend, 1981; Péwé and others, 1966]

P̶zch **Chatanika unit (early Paleozoic)**—Informal unit of Weber and others (1992). Allochthonous, garnet-bearing quartz-biotite-muscovite schist and quartzite. Primarily epidote-amphibolite facies, but includes eclogitic rocks. These rocks structurally overlie unit Zf in fault contact. Age and origin are uncertain, but a Rb-Sr date of 509 Ma on muscovite and K-Ar ages up to 470±35 Ma on amphiboles were interpreted as an Ordovician metamorphic event by Chapman and others (1971). (The Rb-Sr date can be interpreted as Late Cambrian to Early Ordovician in age based on the 1983 chronologic chart of the U.S. Geological Survey, Geologic Names Committee.) Younger K-Ar ages (178 to 103 Ma) and Rb-Sr ages (157±8 Ma to 137±8 Ma) suggest that older rocks were overprinted during Mesozoic metamorphism (Weber and others, 1992). Weber (1989) mentions an Ordovician K-Ar age on amphibolite in the eclogitic rocks and assigns the entire sequence a Paleozoic(?) age. Unit P̶zch crops out at T. 3 N., R. 1 E.-R. 1 W. These rocks are part of the Birch Creek Schist of former usage. Unit P̶zch is mapped as unit eaf by Chapman and others (1971), unit ec by Foster and others (1987), unit P̶zs by Frost and Stanley (1991), and the Chatanika unit by Weber (1989). [Chapman and others, 1971; Foster and others, 1987; Frost and Stanley, 1991; Nokleberg and others, 1989; Weber, 1989; Weber and others, 1992]

Of **Fossil Creek Volcanics (Late to Early Ordovician)**—Alkali basalt, agglomerate, volcaniclastic conglomerate, and minor limestone and sandstone; also, shale, chert, and limestone intruded by gabbro. Lower part is composed primarily of sedimentary rocks; grades laterally and upward into a sequence of basalt, tuff, and agglomerate that is generally capped by a thin layer of volcanic-rich sedimentary rocks. Fossil invertebrates (brachiopods, conodonts, gastropods, and trilobites) indicate Early to Late Ordovician ages. Disconformably underlies unit DSt (this contact is well exposed just northeast of the map area at 65°37'16" N, 147°21'11" W) and unconformably overlies unit Zwg (Blodgett and others, 1987). Thickness exceeds 610 m. Unit Of crops out in a northeast-southwest-trending belt along the Beaver Creek Fault (T. 2-7 N., R. 2-12 W.). This unit is mapped as unit SOvs by Chapman and others (1971), unit Ovs by Frost and Stanley (1991), and the Fossil Creek Volcanics by Weber (1989). It is divided into units Ofv and Ofs by Weber and others (1992). [Blodgett and others, 1987; Chapman and others, 1975a, 1971; Frost and Stanley, 1991; Péwé and others, 1966; Weber, 1989; Weber and others, 1992; Wheeler and others, 1987]

ЄZwa **Wickersham unit (Early Cambrian and Late Proterozoic)**—Informal unit of Weber and others (1992). Maroon and green argillite, grit, quartzite, siltstone, graywacke, and phyllite. Includes thin beds of dark limestone. These rocks occur at T. 3-7 N., R. 1 E.-R. 4 W. southwest of the White Mountains, which are north of the map area (T. 8-10 N., R. 1-2 E.), and at Sawtooth Mountain (T. 7 N., R. 9-11 W.). Intruded by gabbro (unit T̶Rm, White Mountains terrane) at T. 6 N., R. 3 W. southwest of the White Mountains. Age is based on the occurrence of *Oldhamia*, a trace fossil, near the top of this unit (Moore and Nokleberg, 1988), and a K-Ar age of 1.35±40.6 Ga on white mica (Weber and others, 1992). The contact exposed along the Elliott Highway between units ЄZwa and Zwg (White Mountains terrane, Wickersham terrane, and Yukon-Tanana terrane north of Tanana River, undivided) was interpreted as a thrust fault by Chapman and others (1971), Weber (1989), and Weber and others (1992). Alternatively, according to Moore and Nokleberg (1988), the contact in the vicinity of Cache Mountain (northeast of the map area) between units Zwg and ЄZwa is conformable and gradational with unit Zwg structurally and stratigraphically overlying unit ЄZwa. There is still much controversy about which of the two units is stratigraphically higher. Together units Zwg and ЄZwa may be as much as 7,000 m thick. In the Dugan Hills area (T. 1 S.-T. 2 N., R. 11-13 W.), these rocks are lithologically similar to, and perhaps correlative with, unit DOs (Nixon Fork and Minchumina terranes, undivided), which contains Ordovician and Devonian(?) fossils. The rocks of unit ЄZwa were interpreted by F.R. Weber (written commun., 1992) to be correlative with similar rocks farther to the northeast in the Wickersham Dome area (T. 4-5 N., R. 2-4 W.) and were mapped as unit DOs by Chapman and Yeend (1981), unit Єal by Chapman and others (1982, 1975a), unit P̶zsr by Frost and Stanley (1991), and unit ng by Péwé and others (1966). Elsewhere, unit ЄZwa was mapped as unit Єal by Chapman and others (1971), unit ЄpЄsl by Frost and Stanley (1991), and the maroon and green slate subunit of the Wickersham unit by Weber (1989). [Chapman and others, 1971; Frost and Stanley, 1991; Moore and Nokleberg, 1988; Weber, 1989; Weber and others, 1992]

Zwg **Grit (Late Proterozoic)**—Grit, quartzite, graywacke, conglomerate, limestone, phyllite, slate, and argillite. Contact with the underlying unit Zf is gradational. Unit Zwg crops out in the Wickersham Dome area (T. 2-6 N., R. 1 E.-R. 10 W.) and in the Dugan Hills (T. 1 S.-T. 2 N., R. 11-13 W.). F.R. Weber (written commun., 1992) interpreted the rocks in the Dugan Hills area to be correlative with similar rocks farther to the northeast in the Wickersham Dome area (T. 4-5 N., R. 2-4 W.). The Dugan Hills rocks were mapped as unit DOs by Chapman and Yeend (1981), unit Ꞓal by Chapman and others (1982, 1975a), unit Pzsr by Frost and Stanley (1991), and unit ng by Péwé and others (1966). In the Wickersham Dome area, unit Zwg was mapped as unit Ꞓgq by Chapman and others (1971), unit ꞒpꞒg by Frost and Stanley (1991), and the basal grit subunit of the Wickersham unit by Weber (1989). [Chapman and others, 1971; Frost and Stanley, 1991; Moore and Nokleberg, 1988; Weber, 1989; Weber and others, 1992]

Zf **Fairbanks schist unit (Late Proterozoic)**—Greenschist facies muscovite-chlorite schist, quartzite, and phyllite. Age based on correlation with Windermere Supergroup in Canada and field relations (Weber and others, 1992). Nokleberg and others (1989) considered these rocks to be part of a metamorphosed Devonian to Mississippian igneous arc and associated metamorphosed wall rocks. U-Pb geochronology of primary zircon in metarhyolite from the Cleary subunit yields a Late Devonian age (369±3 Ma, Aleinikoff and Nokleberg, 1989), while detrital zircons indicate an Early to Middle Proterozoic or older age (2.3 to 2.1 Ga, Aleinikoff and Nokleberg, 1989; 3.3 to 1.1 Ga, F.R. Weber and J.K. Mortensen, written commun., 1992). Unit Zf crops out at T. 6 N.-T. 4 S., R. 1 E.-R. 7 W. These rocks are part of the Birch Creek Schist of former usage. Unit Zf is mapped as unit gf by Chapman and others (1971), unit qq by Foster and others (1987), unit MDqs by Frost and Stanley (1991), unit bc by Péwé and others (1966), and the Fairbanks schist unit by Weber (1989). Locally subdivided into the Cleary subunit (mapped as unit Zfc by Weber and others, 1992), which is a facies characterized by white felsic schist, micaceous quartzite, chloritic or actinolitic greenschist, greenstone, and marble. [Aleinikoff and others, 1984; Aleinikoff and Nokleberg, 1989; Chapman and others, 1971; Foster and others, 1987; Frost and Stanley, 1991; Nokleberg and others, 1989; Péwé and others, 1966; Weber, 1989; Weber and others, 1992]

Yukon-Tanana terrane south of Tanana River

MDt **Totatlanika Schist (Early Mississippian to Middle Devonian)**—Metavolcanic and metavolcaniclastic rocks (schist and gneiss), both felsic and mafic, and subordinate amounts of intercalated metasedimentary rocks, such as black (carbonaceous) pelitic schist and phyllite and, at one locality, a thin interbed of fossiliferous marble. Interpreted to represent continental margin deposits by Csejtey and others (1986). Metamorphic mineral assemblages suggest recrystallization in the greenschist metamorphic facies. Maximum preserved cumulative thickness is over 5,700 m, but, in any one area, the thickness of the rocks may be considerably less. Depositional age span inadequately known because fossils were found only at one locality within a thin marble interbed; however, these fossils indicate a Middle Devonian to Early Mississippian age. Unit MDt crops out at T. 8-16 S., R. 1 E.-R. 15 W. In the Kantishna Hills (T. 12-16 S., R. 15-19 W.), unit MDt may include rocks correlative with part of unit Pzkp (Yukon-Tanana terrane south of Tanana River). These rocks were mapped as unit Pzts by Csejtey and others (1986) and as unit DSt by Péwé and others (1966). [Bundtzen, 1981; Csejtey and others, 1992, 1986; Péwé and others, 1966]

Dms **Metasedimentary rocks (Late or Middle Devonian)**—Schist, phyllite, quartzite, metachert, and marble; thin bedded with a well-developed foliation that parallels bedding. Metamorphic grade is lower greenschist facies; metamorphism probably occurred during mid-Cretaceous time. Poorly preserved fossils in marble interbeds indicate a Middle or Late Devonian age. These rocks are exposed in discontinuous outcrops just north of the Hines Creek Fault (T. 13 S., R. 1 E.-R. 1 W. and T. 14-15 S., R. 11-13 W.). Unit Dms appears to be closely associated spatially with unit MDt; the contact between the two units may be a thrust fault. Along the Wood River (T. 13 S., R. 1 E.-R. 1 W.), unit Dms is very similar to unit Dy (McKinley and Pingston terranes, undivided) in lithology, metamorphic grade and level of recrystallization, deformation style, and apparent age and depositional environment. These rocks were mapped as unit Pzms by Csejtey and others (1986). [Csejtey and others, 1992, 1986]

Dmg **Metagabbro (Late Devonian?)**—Dark greenish gray; fine to medium grained and foliated; greenschist facies metamorphism. Exposed only as two small intrusive bodies within unit Pzp€s (T. 12 S., R. 1 W. and T. 13 S., R. 5 W.). Age is uncertain, but these rocks may be the intrusive equivalent of Late Devonian metabasalts and related metasedimentary rocks included in unit MDt. Alternatively, they may correlate with Jurassic to Early Cretaceous gabbroic intrusives north of the Hines Creek Fault within units Dy and Ŧcs (McKinley and Pingston terranes, undivided). These rocks were mapped as unit Pzmg by Csejtey and others (1986). [Csejtey and others, 1992, 1986; Wahrhaftig, 1970b, 1970c]

Pzkp **Keevy Peak Formation (early Paleozoic)**—Sequence of quartz-sericite and (or) muscovite schist, black quartzite, black carbonaceous pelitic schist and phyllite, pebble conglomerate, greenish-gray and purple schist and slate, and a few thin marble interbeds. Rests unconformably on unit Pzp€s and is overlain in fault contact by unit MDt. Thickness is unknown, but preserved section ranges from 700 to 1,200 m in thickness. No fossils have been found; age is based on stratigraphic relations with the underlying unit Pzp€s, which is early Paleozoic in part (Csejtey and others, 1992). These rocks are exposed at T. 11-12 S., R. 1 E.-R. 5 W. Mapped as unit Pzk by Csejtey and others (1992), as unit kp by Csejtey and others (1986), and as part of unit bc by Péwé and others (1966). [Csejtey and others, 1992, 1986; Péwé and others, 1966; Wahrhaftig, 1968]

Pzp€s **Pelitic and quartzose schist (early Paleozoic and (or) Precambrian)**—Pelitic schist, quartzite, phyllite, and a few marble interbeds; intensely deformed; lower greenschist facies metamorphism. Contact with the overlying Keevy Peak Formation (unit Pzkp) is thought to be a depositional unconformity (Csejtey and others, 1992). Base is not exposed, therefore, thickness is not known; however, thickness measured perpendicular to the axial plane of cleavage is at least 3,000 m. Fossils from a marble interbed indicate possibly an Ordovician or younger age (Csejtey and others, 1992, 1986, p. 82, no. 171); isotopic ages range from 1,170 Ma to 120 Ma (Péwé and others, 1966), but are considered unreliable. Part of the Birch Creek Schist of former usage. Unit Pzpes crops out in the Kantishna Hills (T. 12-16 S., R. 15-19 W.) where it may, in part, include part of unit Pzkp (Yukon-Tanana terrane south of Tanana River), in the Alaska Range (T. 11-14 S., R. 1 E.-R. 12 W.), east of Clear Creek (T. 6 S., R. 1 E.), and at Clear Creek Butte (T. 3 S., R. 1 W.). According to F.R. Weber (written commun., 1992), the rocks at Clear Creek Butte (T. 3 S., R. 1 W.) are probably part of the Fairbanks schist unit (unit Zf, White Mountains terrane, Wickersham terrane, and Yukon-Tanana terrane north of Tanana River, undivided). Robinson and others (1990) map the rocks at Clear Creek Butte as part of the Birch Hill sequence (unit M€bh, White Mountains terrane, Wickersham terrane, and Yukon-Tanana terrane north of Tanana River, undivided). Rocks of unit Pzp€s were mapped as unit Pzp€p by Csejtey and others (1992), as unit pqs by Csejtey and others (1986), as unit bc by Péwé and others (1966), and as unit p€bc by Reed (1961). [Bundtzen, 1981; Csejtey and others, 1992, 1986; Péwé and others, 1966; Reed, 1961]

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