STATE OF ALASKA

DEPARTMENT OF NATURAL RESOURCES

DIVISION OF GEOLOGICAL & GEOPHYSICAL SURVEYS

Tony Knowles, *Governor*

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GEOLOGIC MAP OF THE TANANA B-1 QUADRANGLE, CENTRAL ALASKA

by
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GEOLOGIC BACKGROUND

The Tanana B-1 Quadrangle is part of the Yukon Tanana uplands. Mertie (1937) originally mapped this area, and more recently Chapman and others (1982) mapped the Tanana Quadrangle at 1:250,000 scale. Rock units trend northeast into areas mapped by Weber and others (1992) in the Livengood Quadrangle. Previous mapping in the area by Dover (1994 unpublished data), D.M. Hopkins and Bond Taber (1959 unpublished data; written comm., 1996), and detailed prospect mapping on Elephant Mountain (Harry Noyes, written comm., 1996) have been useful in our mapping. Numerous topical studies also apply to area geology (Jones and others, 1984; Loney and Himmelberg, 1985 and 1988). Regional geologic compilations, which include the Tanana B-1, have been published by Dover (1994), Dusel-Bacon (1994), Nokleberg and others (1994), Silberling and others (1994). Plafker and others (1994) discussed faulting, and Barnes and others (1994) reported on gravity.

Structural relationships between major rock units were largely ignored by some authors (Chapman and others, 1982 and Silberling and others, 1994.) Other authors bound units by thrust faulting from the south (Weber and others, 1992) or north (Dover, 1994; Dusel-Bacon, 1994; Nokleberg and others, 1994). Major right-lateral strike-slip faults, variously called the Kaltag fault, Victoria Creek fault, or the Tozitna fault, are placed south of the Rampart Group by Nokleberg and others (1994), within the Rampart Group by Dusel-Bacon (1994) and Chapman and others (1982), within and south of the Rampart Group by Dover (1994), or north and south of the Rampart Group by Weber (written commun., 1996), or not recognized (Silberling and others, 1994).

Airborne geophysics for the Tanana B-1 Quadrangle and surrounding area (Burns, 1996; 1997) was highly influential in our lithologic and structural mapping, especially in areas of poor exposure. Trace element geochemistry, rock geochemistry and, in particular, chert geochemistry, were also important in lithologic affinity and regional correlations. Reports on the Rampart area by the Alaska Division of Geological and Geophysical Surveys (DGGS) include airborne magnetics and electromagnetics (Burns, 1996; 1997), rock geochemistry (Liss and others, 1997), $^{40}Ar/^{39}Ar$ geochronology (Reifenstuhl and others, 1997), chert geochemistry (Haug and others, 1997), igneous rock trace element studies (Newberry and Haug, 1997), and gold geochemistry (Newberry and Clautice, in press).

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DESCRIPTION OF MAP UNITS

UNCONSOLIDATED DEPOSITS

Alluvial Deposits

Qaf Alluvial fan deposits—Fan-shaped, heterogeneous mixtures of gravel with some sand and silt and few to numerous, subangular to rounded boulders, especially in proximal areas; may include debris-flow deposits; thick to thin bedded; surface smooth, except for numerous shallow, interconnected channels.

Qal Alluvium in modern stream channels—Elongate deposits of stratified gravel and sand with few to numerous boulders beneath modern floodplains and associated low terraces; well sorted and medium to thick bedded, locally crossbedded.

Qat2 Younger alluvial terrace deposits of lower Hunter, Hoosier, and Minook Creeks—Stratified pebble-cobble gravel and coarse sand forming elevated benches bordering modern floodplains with a maximum tread elevation of approximately 30 m above the modern streams; surface smooth, except for local low scarps; capped by up to 10 m primary and reworked eolian silt containing Pleistocene mammalian remains, including mammoth, sheep, horse and bison in the Hunter Creek area; plant remains and freshwater mollusk shells present in thin peat layers in the silt cap; radiocarbon dating of wood preserved in the gravel and overlying silt indicates the upper alluvial gravels were deposited between 10,960 ± 200 yr. B.P. (GX-22411) and 8,800 ± 160 yr. B.P. (GX-22410); bench gravels are auriferous and are mined in Hunter Creek drainage

Qat1 Older alluvial terrace deposits of lower Minook Creek—Stratified pebble-cobble gravel and medium sand forming elevated benches bordering east side of lower Minook Creek with a maximum tread elevation of approximately 150 m above the present stream; surface smooth; capped by approximately 50 cm primary and reworked eolian silt.

Qfo Old fan deposits of lower Chapman Creek—Fan-shaped, heterogeneous mixture of coarse gravel with some sand and silt and numerous rounded cobbles up to 40 cm in diameter; up to 6 m thick at distal parts and graded to a base level several meters higher than the present stream level; surface thickly vegetated and mostly smooth with some relict stream channels and prominent ridges of cobble-gravel bar deposits aligned parallel to paleochannels.

Qfp Floodplain alluvium bordering modern streams—Elongate deposits of stratified pebble-cobble gravel and medium sand with few to numerous boulders forming modern floodplains and associated low (<3 m) terraces; lower surfaces may be flooded during periods of maximum stream discharge; surface smooth except for local low scarps.

Qof Outwash fan deposits—Fan-shaped, heterogeneous mixtures of washed pebble-cobble gravel with some sand and silt and numerous subangular to rounded boulders deposited by meltwater streams draining the margins of former glaciers; thin to thick bedded, locally crossbedded and contain imbricate clasts; surface generally smooth and gently sloping, except for local low scarps and perched, abandoned paleodrainage channels.

QTg High-level bench gravel—Stratified gravel, sand and silt, possibly of glaciofluvial origin, forming elevated benches in the northeastern part of the map area with a maximum tread elevation of approximately 430 m above the present streams; moderately to well sorted and medium to thick bedded, locally crossbedded; clasts are well rounded and include boulders up to 2 m in diameter; commonly characterized by distinctive bright orange silt and clay filling interstices of tightly packed gravel and granule-pebble matrix; perennially frozen and up to at least 30 m thick (Mertie, 1937); thickly mantled by primary and redeposited eolian silt; surface generally smooth and heavily vegetated; bench gravels are auriferous and extensively prospected, but are not currently being mined.

Colluvial Deposits

Qac Undifferentiated alluvial and colluvial valley-fill deposits—Fan-shaped and elongate heterogeneous mixtures of subangular rock fragments and gravel with some silt and sand deposited in upper stream courses primarily by brief, intense summer stream flow, debris flows, and gelifluction; surface smooth, except for local low scarps and shallow, steep-sided channels. In the lower northwestern part of the map area the unit includes a considerable amount of reworked loess.

Qc Undifferentiated colluvium—Irregular, heterogeneous blankets, aprons, and fans of angular to subrounded rock fragments, gravel, sand and silt that are left on slopes, slope bases, or high-level surfaces by residual weathering and complex mass-movement processes, including rolling, sliding, flowing, gelifluction, and frost creep; probably perennially frozen; locally washed by meltwater and slope runoff; surface generally reflects configuration of underlying bedrock surface.

Qca Colluvial apron and fan deposits—Apron- and fan-shaped, heterogeneous mixtures of angular rock fragments with trace to some gravel, sand and silt deposited at the bases of steep walls of modern stream valleys; may include or be capped by a considerable amount of redeposited eolian silt; locally washed by meltwater and slope runoff; surface steep to gently sloping.

Qcs Solifluction deposits—Irregular drapes of poorly sorted mixtures of angular rock fragments of local origin, with trace to some sand and silt deposited on the upper slopes of Elephant Mountain primarily by solifluction and gelifluction; probably pernnially frozen; surface gently to moderately sloping with prominent scallop-shaped ridges and lobes oriented approximately perpendicular to slope.

Qct Talus deposits—Apron- and cone-shaped heterogeneous mixtures of angular rock fragments and trace to some gravel, sand, and silt deposited on steep slopes by snow avalanches, free fall, tumbling, rolling, and sliding; surface steep, slightly irregular, and covered with numerous angular rock fragments.

Qls Landslide deposits—Oval to tongue-shaped heterogeneous mixtures of fractured bedrock and pebble-cobble gravel with trace to some sand and silt, deposited by near-surface to deep flowing and sliding due to slope failures in bedrock and unconsolidated surficial deposits; surface slightly irregular.

Eolian Deposits

Qer Primary and reworked upland silt—Heterogeneous blankets of silt and organic silt originally laid down by eolian processes and subsequently extensively reworked by fluvial and colluvial processes; primary loess deposits occur as blankets of massive silt up to 20 m thick; reworked deposits probably perennially frozen and ice rich; primary deposits dry and generally ice free, but probably perennially frozen; surface smooth to locally gullied.

Qes Dune sand deposits—Homogeneous blankets of medium to fine sand in longitudinal dunes deposited by wind along the banks of the Yukon River; surface is partially stabilized by vegetation and forms prominent elongate ridges up to 10 m high parallel to prevailing wind direction.

Glacial Deposits

Qd Modified drift—Heterogeneous blankets of non-stratified pebble-cobble gravel with some sand and silt and few to numerous subangular to subrounded boulders deposited directly from glacial ice and modified by mass movement; weathering rinds of monzonite clasts up to 3 cm thick; surface smooth and rounded to gently hummocky with scattered rounded monzonite erratics up to 2.5 m in diameter; may be thickly mantled by angular colluvial debris, especially on lower valley walls.

Lacustrine Deposits

Ql Undifferentiated lacustrine deposits—Arcuate or semicircular deposits of silt, sand and organic silt along margins of local small lakes and filling basins of shallow lakes; generally of thermokarst origin; saturated and locally frozen, locally ice rich; surface horizontal and smooth.

Manmade Deposits

Qh Mine tailings—Water-washed pebble-cobble gravel with trace to some sand reworked by placer mining operations; moderate to well sorted; surface irregular or forming symmetrical ridges and cones.

BEDROCK UNITS

Tertiary volcanic, and sedimentary rocks

Early Tertiary bimodal volcanic rocks and minor sedimentary rocks unconformably overlie Rampart Group rocks. Chemical analyses show that the rocks are entirely rhyolite and basalt, with no intermediate types. Massive and columnar basalt apparently occurs both stratigraphically below and above rhyolite. Two $^{40}Ar/^{39}Ar$ age dates (one each on basalt and rhyolite) establish the early Tertiary age, ranging from 56 to 62 Ma (table 1; Reifenstuhl and others, 1997). The bimodal basalt-rhyolite suite (Liss and others, 1997) is geochemically similar to other 55 to 60 Ma volcanic rocks in the Fairbanks and Fortymile districts of Interior Alaska (Dusel-Bacon and others, 1989; Newberry and others, 1995) and in the Ross River area of central Yukon Territory, Canada (Christie and others, 1992). This bimodal volcanism is typical of extensional igneous activity, and may be related to the transtensional stress related to the Tintina strike-slip fault. Airborne geophysics (Burns 1996; 1997) and rock geochemistry (Liss and others, 1997) were locally important for unit distribution and structural relationships in poorly exposed areas.

Ts **Sedimentary rocks undivided (Weber and others, 1992; Eocene)**—Light yellowish brown, yellowish gray, and yellowish to reddish brown-weathering sandstone, siltstone and shale. Rocks are generally poorly consolidated, calcite cemented, and commonly contain plant fossils and debris. Better exposures crop out 3 km northeast of the Tanana B-1 Quadrangle on the Yukon River. Local coal beds to 30 cm thick and rare amber indicate a fluvial, non-marine depositional environment. In the Livengood Quadrangle, the sedimentary section is about 1,500 m thick (Weber and others, 1992) and contains minor chert, pebble- to boulder-conglomerate, and plant fossils of probable Eocene age (T.A. Ager, written commun., 1989, in Weber and others, 1992).

Tr **Rhyolite (early Eocene)**—White and pink, purple and white, light-orange and pink, glassy-aphanitic to very fine grained, flow-banded rhyolite, rhyolite tuff breccia, ignimbrite, and potassium feldspar-porphyritic rhyolite. The rock types present suggest that the rhyolites were emplaced as flows, domes, tuffs, breccia, and rare obsidian, and suggest extrusion over a significant period of time. Felsic volcanic rocks locally weather to pastel-colored "badland" topography. Compositions range from 66 to 80 percent silica and 150 to 300 ppm zirconium (Liss and others, 1997; Newberry and Haug, 1997) and show a well-defined bimodal relationship with the associated Tertiary basalt (Tb). The rhyolite is mostly high-silica and unusually enriched in incompatible elements and rare earth elements (Newberry and Haug, 1997). Geochemistry plots of the Tertiary rhyolite lie in the "within-plate" field of Pearce and others (1984). One geochemical sample of altered rhyolite yielded 260 ppb gold. One $^{40}Ar/^{39}Ar$ age date on rhyolite is 56 Ma (table 1). The unit is commonly poorly exposed, but estimated thickness is >100 m.

Tb **Basalt (Paleocene)**—Very dark greenish gray, dark greenish brown-weathering, amygdaloidal, locally columnar jointed basalt. Locally copper stained, and locally contains minor sulfides including pyrite, chalcopyrite and arsenopyrite. Lack of extensive pillows suggests the basalts were primarily extruded in a subareal environment. Early Tertiary basalt ranges from 43 to 55 percent silica and

150 to 375 ppm zirconium and is tholeiitic and slightly alkalic, as indicated by alkali-silica data (Liss and others, 1997; Newberry and Haug, 1997). The basalt is enriched in incompatible elements and rare earth elements, and plots in the "within-plate basalt" field of Pearce and Cann (1973). Basalt is poorly exposed, and total thickness is estimated at greater than 100 m. Basalt apparently both underlies and overlies Tertiary rhyolite and suggests a prolonged extrusive history (perhaps several million years). One $^{40}Ar/^{39}Ar$ age date on basalt is 60 Ma (table 1).

Tdm **Mafic dikes (Paleocene)**—Very dark gray and greenish very dark gray, very fine grained hypabyssal dikes. Composition is alkalic gabbro to monzodiorite, based on chemical analyses. Major minerals include biotite, clinopyroxene, and plagioclase. Thickness is typically less than 3 m. These mafic dikes are similar in major and minor element abundances to the Tertiary basalt (Liss and others, 1997; Newberry and Haug, 1997). Two $^{40}Ar/^{39}Ar$ whole-rock, age dates are 58 and 59 Ma (table 1; Reifenstuhl and others, 1997).

Tsy **Quartz syenite dikes (Paleocene)**—Medium gray to greenish gray, very fine grained equigranular to porphyritic, with 1 cm potassium feldspar tablets in a fine-grained groundmass, in which quartz, feldspar, and biotite predominate. Chemical analyses indicate these dikes range in composition from quartz syenite to syenogranite (Liss and others, 1997). These are hypabyssal dikes up to 2 m thick. Two $^{40}Ar/^{39}Ar$ age dates are 57.2 Ma (biotite) and 57.8 Ma (whole-rock) (table 1; Reifenstuhl and others, 1997).

TKq **Quartz veins (Paleocene to Cretaceous)**—Light gray to white, very fine grained, gold-bearing quartz veins with variable pyrite and chalcopyrite or arsenopyrite and rare muscovite selvages. The observed veins range from several centimeters to nearly 1 m thick. Quartz veins cross-cut several older units (described below) including the Rampart Group rocks, amphibolite facies metamorphic rocks, Cretaceous and Jurassic sedimentary rocks, and Cretaceous plutonic rocks. Two $^{40}Ar/^{39}Ar$ age dates (white mica) are 61 Ma and 72 Ma (table 1; Reifenstuhl and others, 1997).

Tertiary amphibolite-grade metamorphic belt

Lithologies of this metamorphic belt include amphibolite grade garnet-mica pelitic schist, marble, mafic metavolcanic rocks, and quartzite. This northeast-trending belt of amphibolite-grade metamorphic rocks with pre-Tertiary protoliths crops out adjacent to, and predominantly southeast of, the Rampart Group (described below) on the north side of the Victoria Creek fault zone. Airborne geophysics (Burns, 1996; 1997) and outcrop patterns indicate a steep northwest contact and suggest a moderate southeast-dipping southeast contact. This belt of enigmatic origin and affinity was previously assigned to the Ruby terrane in regional compilations (Silberling and others, 1994). Dusel-Bacon (1994) describes a pressure-temperature condition of greater than 3.8 kb and 500°C (based on the presence of kyanite and sillimanite). Dusel-Bacon (1994) assigned a metamorphic age bracketed between an assumed middle Paleozoic protolith age and an assumed Early Cretaceous age for structural emplacement of the adjacent allochthonous Rampart Group. Our preliminary work (Joy, in press) indicates moderate pressure, amphibolite-facies metamorphism and no evidence for a greenschist overprint. $^{40}Ar/^{39}Ar$ geochronology on white mica (62 Ma) and hornblende (57 Ma) from a white mica-garnet-biotite-hornblende schist indicates an early Tertiary metamorphic age (table 1; Reifenstuhl and others, 1997). This metamorphic belt is here assigned a "pre-Tertiary" age designation based on these early Tertiary age-data and the lack of definitive protolith age and affinity.

Earlier workers (Dusel-Bacon and others, 1989; Dover, 1994) noted that these rocks grossly resemble metamorphic rocks in the Yukon-Tanana and Ruby terranes. This unit is, however, different from known metamorphic rocks in interior Alaska by virtue of its early Tertiary metamorphic age and metamorphic history. Nearby metamorphic rocks of the Ruby Terrane have Middle Jurassic to Early Cretaceous K-Ar ages and are cut and hornfelsed by early Cretaceous granites (Dusel-Bacon and others, 1989; Roeske and others, 1995). Metamorphic rocks north of the Yukon River have greenschist to blueschist facies mineral assemblages (Roeske and others, 1995), whereas those farther north (Ray Mountains) exhibit early lower amphibolite facies and later greenschist facies conditions (Dusel-Bacon and others, 1989). The amphibolite metamorphic belt has a high-angle fault contact on the north and is bounded on the south by a low angle fault and the Victoria Creek fault. Given the amphibolite facies belt contacts with the surrounding lower greenschist facies pelitic and metavolcanic rocks, its unusual metamorphic age, its distinctive metamorphic P-T conditions, and its location as a "lozenge" along a strand of the Tintina-Kaltag fault system, it is unclear from where this unit was originally derived and the age and character of the protoliths. Available evidence suggests that it represents a deeply-buried fragment of Ruby or Yukon-Tanana terrane basement, rapidly exhumed during early Tertiary extension, and subsequently moved laterally along strike-slip faults.

pTam **Marble**—White to light gray, medium- to coarse-grained, thin- to medium-bedded, typically finely laminated marble. Saccharoidal texture commonly developed. Locally includes diopside-bearing, coarsely recrystallized marble and yellowish brown to orange-weathering dolomitic marble. Locally contains disseminated quartz clasts, thin quartzite interbeds, and broken quartz veins. Apparent thickness ranges from several meters to 35 m, but the unit has been structurally thickened and its true thickness is unknown.

pTas **Medium- to coarse-grained schist and amphibolite**—Gray to brown, red brown-weathering, medium- to coarse-crystalline, locally garnetiferous and staurolite-bearing, schist and green-black hornblende amphibolite. Diagnostic assemblages include garnet-staurolite-biotite-muscovite-quartz-calcic plagioclase-sillimanite-kyanite in pelitic rocks and hornblende-calcic plagioclase-quartz-magnetite in amphibolites. Garnets up to 1 cm in diameter characterize the metapelitic rocks in hand specimen. Preservation of earlier foliation in rotated garnets and distinctive compositional zonation in garnets indicates multiple periods of amphibolite-facies metamorphism. Because the origins of apparently rotated inclusion trails in garnets are now widely debated (Bell and others, 1992; Passchier and others, 1992; Johnson, 1993) the significance of multiple orientations in the pelitic schist is unclear. Lack of hornfelsic textures and retrograde mineral assemblages (except for local chlorite) indicates rapid cooling and the absence of contact metamorphism. Peak metamorphic conditions were approximately 6 kb and 600ºC and final metamorphic conditions were approximately 4 kb and 500°C; both based on preliminary microprobe data for coexisting garnet, biotite, and calcic plagioclase (Joy, in press). $^{40}Ar/^{39}Ar$ dating of muscovite and hornblende from this unit yields plateau ages of 58 to 65 Ma. Lack of "old" Ar fractions in the hornblende, and agreement between muscovite and hornblende ages indicates the rocks were heated at temperatures above 450°C for an extended period of time and then rapidly cooled in early Tertiary time. Detailed petrographic analysis of garnetiferous rocks suggests at least two phases of foliation development (S1 and S2) and possibly up to four or more phases of crystallization (M1-M4). An initial synkinematic foliation developed (S1, M1) followed by static growth of helicitic garnet and calcic plagioclase poikiloblasts (M2) that include deformed S1 foliation. A second synkinematic phase produced the main schistosity (S2, M3). During this main schistosity development the M2 garnets and plagioclase developed pressure shadows. Garnets may have undergone minor rotation. Finally, a post- kinematics phase resulted in static poikiloblastic biotite and staurolite growth, and chlorite (M4). Calc-silicate schist, containing diopside, actinolite, and epidote group minerals occurs locally. The epidote-hornblende-plagioclase-actinolite-chlorite schist is derived from mafic volcanic or volcaniclastic protolith.

pTaq **Quartzite**—Light gray to medium gray, fine-grained, recrystallized sucrosic-textured, hard, dense, cryptically-layered quartzarenite interbedded with the pelitic schist unit. Exposures are rare and typically consist of blocky, black lichen-covered talus. Bedding is rarely seen and is about 10 cm thick. A black opaque mineral comprises up to 3 percent of the quartzite. Quartzite unit is uncommon and differentiated where possible.

Cretaceous and Jurassic rocks

Clastic rocks in the southeastern part of the map area are part of a Cretaceous and Jurassic age flysch basin, variously called the Beaver Creek sequence (Dover, 1994) or Manley terrane (Silberling and others, 1994; Nokleberg and others, 1994; Dusel-Bacon, 1994), that is intruded by 90 Ma alkalic plutons. The Elephant Mountain pluton is one of these plutons. Clastic rocks include the Early Cretaceous to Jurassic

Wolverine quartzite unit (Weber and others, 1992), which is probably in part correlative with the Keenan Quartzite of the Kandik basin, and the Early Cretaceous (Albian) Wilber Creek unit (Weber and others, 1992) composed of graywacke sandstone, conglomerate, and shale.

Kwc **Wilber Creek unit (Albian)**—Black to dark greenish gray sandstone, conglomerate, shale and siltstone containing laminae and thin interbeds of impure quartzwacke. Hornfels near intrusions commonly produce disoriented crystals or rosettes of muscovite and biotite. Contains abundant disseminated opaque material and accessory detrital tourmaline. Present only in small area overlying Elephant Mountain pluton in southeastern corner of map area.

Khs **Hornfelsed sedimentary rocks**—Very dark gray to black, very fine- to fine-grained, hard, dense, hornfelsed sandstone and shale on the flank of Elephant Mountain pluton in the southeastern corner of map area. Commonly has disoriented crystals or rosettes of muscovite and biotite, and locally fine-grained andalusite.

KJwq **Wolverine quartzite unit (Early Cretaceous and (or) Jurassic)**—Light gray to tan, white-weathering, moderately well-sorted, subrounded, fine- to medium-grained quartzarenite. Contains 2 to 5 percent altered chert clasts and light blue quartz clasts, 2 to 5 percent limonite spots, and forms resistant outcrops and blocky, typically black lichen-covered, talus. Bedding is rarely discernible, and quartzite appears massive (bioturbated?) in outcrops up to 30 m thick with local argillaceous partings. Sedimentary structures include local load casts and feeding traces (*Nereites*?). No fossils were found. Sandstone clast estimates are greater than 90 percent quartz, two to five percent chert, and trace amounts of feldspar. Matrix is siliceous, with no trace of carbonate. Thickness about 200 m.

KJws **Sandstone and shale undivided**—Medium gray to light gray, locally black lichen-covered, quartz-rich sandstone and interbedded shale. Sandstone is tightly silica-cemented quartzarenite but lacks the prominent outcrop pattern and continuity of the quartzite unit (KJws). Sandstone is petrographically similar to the Wolverine quartzite unit: moderately well-sorted, subrounded, and with minor chert clasts.

Elephant Mountain pluton

The Elephant Mountain pluton is one of several 90 Ma alkalic plutons that crop out in the eastern Tanana, central Livengood, and western Circle quadrangles, radiometrically dated at about 90 Ma. For example, Elephant Mountain, 89 ± 1 Ma; Sawtooth Mountain, 88 ± 2 Ma; Wolverine Mountain, 89 ± 1 Ma; Huron Creek stock, 88 ± 1 Ma (N. Shew, written commun., 1989, in Weber and others, 1992); Roughtop Mountain, 92±5 Ma and 90 ± 10 Ma (Chapman and others, 1982); O'Brien Creek, 87 ± 4 to 90 ± 1 Ma; Bear Creek and Hope-Homestake Creek, 89 ± 4 Ma (Burton, 1981; Smith and others, 1987). These plutons are part of the "90 Ma alkalic-quartz alkalic suite" of Interior Alaska (Newberry and others, 1995). Locally, contacts of the Elephant Mountain pluton indicate that it is a large, northeast-trending, dike-like, plutonic body 1 to 2 km wide and 8 km long, cut off by high-angle faults at the northeastern and southwestern ends.

Pluton compositions range widely, from diorite to granite, as indicated by modal and normative analyses (Light and Rinehart, 1988; Newberry and Haug, 1997), and show some compositional zoning. The pluton locally has a mafic margin on its northwestern side, consisting of subequigranular, quartz-free diorite, monzodiorite, and monzonite. The presence of a mafic margin on the southeastern side of the pluton is unknown due to cover. The bulk of the pluton ranges in composition from trachytoidal, quartz-free syenite to subequigranular quartz syenite; a core zone, generally altered, consists of equigranular quartz syenite, granite, and granite pegmatite. All of the contacts between these broad units are gradational.

Biotite is the only mafic mineral in the quartz syenite-granite unit. The other units show a consistent mafic content of early clinopyroxene (mantled by deuteric hornblende) with younger, primary biotite and hornblende. The alkalic units have various proportions of alkalic feldspar to plagioclase and little or no quartz, but also no feldspathoid minerals. Accessory minerals in all the units include apatite, zircon, allanite, sphene, and ilmenite. None of the units contain primary magnetite.

Despite the wide range in compositions, the zonal character of the Elephant Mountain pluton suggests that it was fractionally crystallized from a single magma that did not become water-saturated until late in its crystallization history. Geochemical analyses (Newberry and Haug, 1997) show that all the units plot on or near the border between the volcanic arc field and the within-plate granite field of Pearce and others (1987). The quartz syenite-granite and quartz-syenite units possess essentially identical initial strontium (Sr) isotopic ratios of 0.7100 $\pm$ 0.0004 (this study)—values similar to those seen in other mid-Cretaceous calc-alkaline granitic plutons of Interior Alaska (McCoy and others, 1997). The pluton is located about 30 km northwest of the main belt of 90 to 105 Ma calc-alkalic, subduction-related plutons in Interior Alaska. Its location, alkalic composition (but arc-type trace element signature), and elongation parallel to the trend of the belt suggests that it represents back-arc magmatism formed behind a mid-Cretaceous magmatic arc (McCoy and others, 1997; Newberry and others, in press).

Kgs **Quartz syenite, granite, and granite pegmatite**—Buff to light gray, medium- to coarse-grained, subequigranular holocrystalline rock. The rock exhibits varying degrees of hydrothermal alteration, with much of the feldspar and biotite converted to white mica. Alteration makes petrographic distinction between plagioclase and alkali feldspar impossible, but quartz versus quartz + total feldspar ratios vary from 10 to 30 percent, and the vast bulk of the feldspar appears to have been potassium-feldspar. Altered granite/quartz syenite is yellowish green with a light- to bright-orange weathering rind and complete alteration of feldspar and biotite to white mica. Pyrite is disseminated as 1 to 2 percent fine-grained crystals, especially in former feldspar sites. Fine-grained, secondary rutile and arsenopyrite are common in the highly altered rock. H. Noyes (Doyon Ltd., personal commun., 1996) reports values up to 1,740 ppb Au and several thousand ppm As on drill-core analyses.

Kms **Monzonite, syenite, and quartz syenite**—Black- and white-peppered, coarse- to medium-grained, locally foliated, subequigranular to trachytoid, monzonite, syenite, and quartz syenite. With the exception of euhedral, megacrystic, alkali feldspar, the minerals are typically subhedral and anhedral. This unit contains 60 to 70 percent total feldspar, with alkali to plagioclase feldspar ratios of 1:1 to 2:1 and quartz content typically between zero and 5 percent, rarely to 10 percent. Hornblende and biotite are commonly present in subequal amounts; pyroxene abundance varies from approximately as much as hornblende to three times that of hornblende. Average abundances of the major minerals are: quartz, 2 percent; hornblende, 10 percent; biotite, 10 percent; plagioclase, 20 percent; pyroxene, 25 percent; and alkali feldspar, 40 percent. The plagioclase (andesine) is a fine- to medium-grained, anhedral, twinned and zoned, matrix material; alteration is typically minor. Potassium feldspar occurs typically as phenocrysts in the coarse trachytoid rocks, and also as interstitial crystals, and anhedral poikilitic crystals that enclose other minerals. Quartz, if present, occurs as minor late interstitial fillings. Clinopyroxene occurs as equant, pale grayish tan to pale green, equant anhedral poikilitic crystals with ragged edges. Hornblende occurs as rims encasing augitic pyroxene and as texturally primary crystals. Biotite occurs as subhedral to anhedral, fine- to medium-grained elongate shreds that are deep reddish brown and locally black.

Kmzd **Monzodiorite, diorite, and monzonite**—Black- and white-peppered, medium grained, subequigranular, alkalic plutonic rock lacking quartz and with more plagioclase than alkali feldspar. Mafic minerals (clinopyroxene>biotite>hornblende) commonly make up more than 50 percent of the rock. Hornblende in this rock is entirely deuteric, replacing early-formed clinopyroxene. Plagioclase exhibits a dusting of sericite; the other minerals are usually unaltered. Mapped only along the central northwest contact of the Elephant Mountain pluton with hornfels. Mafic dikes locally occur and are essentially identical in mineralogy, composition, and texture to the mafic border unit of the Elephant Mountain pluton (Liss and others, 1997; Newberry and Haug, 1997). Dikes up to 20 m wide are locally identified in the vicinity of the Elephant Mountain pluton.

Kf **Felsic dikes**—Light gray to greenish light gray, fine- to very fine-grained to aphanitic felsic, quartz-poor dikes up to 3 m thick. Dikes are typically altered and weathered to light greenish light gray, buff, and light orange buff, and contain abundant fine-grained white mica or clay minerals. No mafic minerals are present; ghost textures suggest that biotite and clinopyroxene were originally present but converted to white mica, rutile, pyrite, and carbonate. Low quartz and abundant altered feldspar suggest that these dikes were originally syenitic or monzonitic in composition. These dikes are notably present northwest of the Elephant Mountain pluton.

Triassic to Permian succession

The Triassic to Permian succession comprises siliciclastic rocks with characteristic subphyllitic to phyllitic texture, minor limestone, and rare tuff. Chapman and others (1982) previously mapped these rocks in the Tanana B-1 Quadrangle, and Weber and others (1992) mapped their extension into the Livengood Quadrangle. Previous fossil age determinations on this succession are included below to differentiate previous from current age determinations. Fossils from exposures northeast of Minook Creek in the Livengood B-6 Quadrangle were originally considered to be of Devonian age (Kindle, in Prindle, 1908) and were later reassigned to the Mississippian age, as were additional new collections from this unit (Mertie, 1937). These collections were re-examined by J.T. Dutro, Jr. in 1970 and assigned an Early Permian (?) age in Weber and others (1994). One new collection made by R.M. Chapman in 1973 (73ACh59) yielded Permian foraminifera and conodonts (identified by A.K. Armstrong and A.G. Harris, respectively, in Weber and others, 1992). In the Tanana B-1 Quadrangle coarse-grained limestone debris flows and sandy turbiditic flows contain crinoid ossicles and bryozoans. Conodonts recovered from 1996 DGGS limestone collections indicate an Early Permian age, with some species extending into the Triassic (N.M. Savage, written communication, 1997). The Triassic to Permian rock succession is separated by low- to moderate-angle thrust contacts from sequences above and below. Thickness is estimated to be greater than 2,000 m but internal structure is poorly defined.

TrPs **Sandstone and shale**—Dark brownish gray to dark gray, fine- to medium-grained, locally carbonate-cemented lithic sandstone, and sandy to silty shale. Sandstone is thinly laminated to thin bedded, and has generally uniform grain size, and rare graded bedding and cross bedding. Rare sedimentary structures include load casts, burrows and bioturbation. The unit is interbedded with argillite and argillaceous sandstone. Sandstone and shale are gun-metal gray, dark gray to black on fresh surfaces, and locally have a dusty white, slightly calcareous coating. Rocks are commonly phyllitic, with pencil cleavage, and contain calcite veins 1 to 2 mm thick. Pyrite is rare.

TrPa **Argillite**—Dark gray to black, orange-weathering siliceous and locally carbonaceous argillite. Generally harder, more competent, and with a stronger fabric than the shale of the "sandstone and shale" unit above. Locally thinly laminated and fissile, and locally more massive or phyllitic. Rare zones with pyrite cubes to 2 mm. Locally contains chert layers; mapped separately where possible.

TrPv **Tuff**—Pale green to medium greenish gray, and light greenish gray, very fine-grained to aphanitic, siliceous, limonite-stained, with reddish-brown leached pyrite pits, and rare malachite, chalcopyrite, and bornite. Occurs with cherty argillite as zones up to 10 m thick within layers of argillite and shales on ridges that flank Chapman Creek west of Elephant Mountain, where it is locally layered with a green andesitic sill. Some zones brecciated. One whole-rock $^{40}Ar/^{39}Ar$ date (table 1; Reifenstuhl and others, 1997) yields an integrated age of 113.2 Ma, no plateau, and a minimum age of approximately 180 Ma. The complex spectra yields ages from 43 to 186 Ma, and based on regional geologic relations, an approximately 120 Ma reset may be the age of thrusting and reset at about 50 Ma may be due to regional magmatism or tectonism associated with high-angle faulting.

TrPl **Limestone (Early Permian to Triassic)**—Reddish brown to brick red to yellowish brown, highly calcareous to limestone beds less than 1 m thick. Occurs in zones up to 60 m thick. Fossil and lithic fragments and rounded pebbles stand out in relief on weathered surfaces. Contains fragments of shells of bryozoans, corals, crinoids, pelecypods, and brachiopods. Locally sheared and has pencil cleavage. Coarse-grained limestone debris flows and sandy turbiditic flows contain crinoid ossicles and bryozoans. Early Permian to Triassic age (N.M. Savage, written commun., 1997).

TrPc **Chert**—Medium gray to light greenish gray, unfossiliferous, opalescent chert with concoidal fracture in poorly defined beds up to 10 cm thick. Contains no radiolarian ghosts and is undated. Chert is less than one percent of the total Triassic-Permian section, and is spatially associated with siliceous argillite. Geochemistry of chert (Haug and others, 1997) is distinctive relative to other chert units in the map area, and includes only minor overlap with the Rampart Group chert.

TrPp **Pebble conglomerate**—Very dark gray, subrounded pebble- to cobble, clast-supported conglomerate. Clasts are 80 percent black, red, green, and dark-gray chert with minor quartzite, 10 to 15 percent light gray to white quartz, and 5 to 10 percent very dark gray argillite. Matrix is very dark gray argillite to very fine sand. Locally the conglomerate has a pronounced tectonically-induced stretch-pebble fabric. Conglomerate forms prominent outcrops but is less than one percent of the total section and occurs as poorly defined 3-cm- to 1-m-thick interbeds with other clastic units.

Trd **Gabbro dike (Triassic)**—Dark greenish dark gray, medium-grained, dark green-weathering gabbro dikes or sills, commonly covered by bright orange lichen. Gabbro crops out at one locality in the easternmost central map area. Thickness is about 15 m. The steeply-dipping west contact with the argillite unit is mylonitic and siliceous, and may be a faulted synclinal structure or a simple fault.

Rampart Group (Triassic to Mississippian)

The Rampart Group was originally described as a volcanic and sedimentary rock sequence (Mertie, 1937; Brosgé and others, 1969). In the Tanana B-1 Quadrangle, plutonic gabbro sills are intimately mixed with the basaltic flows, associated volcanic rocks, and sedimentary rocks, and here informally included in the Rampart Group. Regionally, Rampart Group distribution and lithologies have been described by Chapman and others (1982), Jones and others (1984), and Rinehart (unpublished manuscript). Permian bryozoans and pelecypod prisms were recovered from a location on the Yukon River just east of the study area (Chapman and others, 1982; Jones and others, 1984). In the Tanana B-1 Quadrangle, sedimentary rocks include argillite, phyllitic argillite, volcaniclastic rocks, chert, and impure limestone, and are assigned a Mississippian to Permian age range based on radiolarian cherts within the project area. The sedimentary rocks of the Rampart Group are similar in lithology and age to the Permian to Triassic succession (discussed above) south of the Victoria Creek fault. Limestone in the Rampart Group and Permian to Triassic succession contain similar Permian fossil assemblages (Brosgé and others, 1969; this study). These two map units may represent a regional facies change within an originally correlative unit. Post-depositional offset along the Tintina-Kaltag-Victoria fault systems has displaced the regional stratigraphy, and rocks on the north side of the Victoria Creek fault include abundant gabbroic sills relative to those to the south.

Mafic and intermediate igneous rocks were assigned a latest Triassic age based on a K-Ar date of 210 $\pm$ 6 Ma from gabbro on the Yukon River, 20 km north of the Tanana B-1 Quadrangle (Brosgé and others, 1969) and provided a slightly younger limit for the Rampart Group igneous rocks. Major and minor element compositional data (Liss and others, 1997; Newberry and Haug, 1997) indicate subalkaline tholeiitic character, but within-plate, not mid-ocean ridge affinities. Rampart basalts have generally subalkaline character and lower P_2O_5 contents (Liss and others, 1997) than adjacent early Tertiary basalts (discussed above).

Structurally, the Rampart Group rocks locally have penetrative deformation and contain pervasive zeolite to lowest greenschist facies assemblages. Locally in fault zones the rocks are highly fractured, sheared, and altered, and may have a mylonitic fabric. Rocks of the Rampart Group are in high-angle fault contact to the north, and low angle fault contact to the south with the amphibolite-facies metamorphic rocks (discussed above). Rampart Group rocks are both unconformably overlain by, and in high-angle fault contact with, early Tertiary volcanic rocks.

Several regional compilations assign Rampart Group rocks to the Mississippian to Jurassic Tozitna terrane (Nokleberg and others, 1994; Silberling and others, 1994; Dusel-Bacon, 1994). The undated gabbro sills present in Rampart Group rocks are probably the same age, and have the same major and minor element compositions as the gabbro sills south of the Victoria Creek fault (Liss and others, 1997; Newberry and Haug, 1997). Cherts within the Rampart Group have extremely variable compositions, suggesting possible structural mixing of several different units (Haug and others, 1997). The locally complex distribution of units within the Rampart Group package suggest that it is complicated by low- and high- angle faults.

TrMra **Argillite and chert**—Very dark gray to black, fissile to phyllitic, nonfossiliferous argillite with variable amounts of gray, greenish gray, red, and white chert and cherty argillite. Chemical analyses (Haug and others, 1997) show that most of the rock mapped as chert is actually cherty argillite. Chert and cherty argillite comprise less than 10 percent of this argillite and chert unit. Elsewhere in the Tanana Quadrangle, chert in the Rampart Group contains Late Mississippian to Early Pennsylvanian radiolaria (Chapman and others, 1982), but no radiolaria were found in our mapping.

TrMrl **Limestone**—Medium gray, impure limestone associated with gabbro or other Rampart Group lithologies; locally contains clastic component. Contains pelecypod shell prisms and bryozoan fragments of probable Permian age from nearby in the adjacent Livengood Quadrangle (Chapman and others, 1982). No fossils recovered in this study.

TrMrs **Sedimentary rocks undivided**—A diverse package of sedimentary and low-grade metasedimentary rocks including argillite, phyllite, chert, cherty argillite, graywacke, sandstone, and tuff(?), distinguished primarily by its proximity to Rampart Group gabbro. Argillite, phyllite, cherty argillite and graywacke are medium to dark gray to greenish gray. Cherts are light to dark gray, red, white, and greenish gray. Sandstone and tuff are light gray to white. All units are fine grained to cryptocrystalline and locally phyllitic. The sedimentary rocks are complexly interspersed with gabbro, probably due to low- and high-angle faulting. Thickness is unknown.

TrMb **Basalt**—Very dark gray and dark greenish dark gray, very fine-grained, generally massive, but locally amygdaloidal or pillowed basalt. Distinguished with difficulty from fine-grained diabase sills on the basis of grain size, chilled margins, or chemistry; much of the rock mapped as Rampart Group basalt may be diabase. Unit is pervasively altered to fine-grained mixtures of chlorite, calcite, epidote, quartz, rutile, magnetite, and zeolite(?), with local remnant plagioclase ghosts.

TrMrg **Gabbro**—Very dark gray and dark greenish dark gray, fine-grained hornblende-pyroxene gabbro and diabase which constitute the most abundant igneous rock in the Rampart Group. Hornblende occurs both as reaction rims surrounding clinopyroxene, and as isolated, interstitial (late magmatic?) grains. The characteristic texture is diabasic, with subhedral-altered pyroxenes and interstitial hornblende intergrown with subhedral to euhedral former plagioclase grains. No primary quartz has been noted, but 1-3 percent normative quartz is common. Greenschist alteration is pervasive. Clinopyroxene is commonly altered to a very fine-grained mixture of chlorite, actinolite, calcite, and quartz; plagioclase is altered to a very fine-grained mixture of epidote, calcite, sericite, and quartz; and ilmenite is altered to rutile. Rampart Group gabbro tends to have higher TiO_2 than Rampart Group basalts, but are otherwise indistinguishable in major and minor element composition from the basalts (Liss and others, 1997; Newberry and Haug, 1997).

TrMru **Rampart Group undivided**—Poorly exposed rocks of the Rampart Group; may include igneous and sedimentary rocks as discussed above.

Lower Paleozoic and Proterozoic rocks

Three lower Paleozoic and Proterozoic age rock packages are mapped southeast of the Victoria Creek fault and northwest of the Triassic and Permian succession. Previous workers have assigned these rocks to the Baldry terrane (Silberling and others, 1994; Dusel-Bacon, 1994) or Livengood terrane (Nokleberg and others, 1994) with an assumed lower Paleozoic age. These three rock successions are here mapped as Late Proterozoic to Early Paleozoic and are tentatively correlated with the Wickersham grit unit, Amy Creek unit and Livengood Dome Chert (Early to earliest Middle Ordovician) mapped by Weber and others (1992). This correlation is based on detailed field mapping, conodont- and megafossil analyses, chert geochemistry (Haug and others, 1997), detailed stratigraphy, lithologic associations, and regional stratigraphy.

Livengood Dome Chert (?) (Ordovician)—This rock succession is tentatively correlated with the Livengood Dome Chert unit. The Livengood Dome Chert was named for exposures in the adjacent Livengood Quadrangle where it contains Late Ordovician graptolites (Chapman and others, 1979; Weber and others, 1988).

and includes several other lithologies including multicolored chert, siliceous slate, rare greenstone, tuff, limestone, and shale. In the Tanana B-1 Quadrangle the Livengood Dome unit shows pervasive cataclasis, low-grade metamorphic recrystallization, and is in low- to moderate-angle thrust contact with successions above and below. Chert geochemistry is nearly identical to chert of the type Livengood Dome Chert (Haug and others, 1997). All conodont samples were barren (N.M. Savage, written commun., 1997). No megafossils were recovered from any field or laboratory samples (R.B. Blodgett, written commun., 1997).

Pzlca **Chert and cherty argillite**—Heterogeneous unit composed dominantly of light gray to gray, finely laminated, recrystallized sericitic chert and siliceous argillite, commonly with phyllitic argillite partings; cherty argillite typically has cherty or mylonitic aspect on weathered surfaces, but fine-grained clastic or recrystallized texture on fresh surfaces. In places is distinctive cream-colored to mottled light- gray, fine-grained, even-grained, typically microfractured recrystallized chert that crops out poorly, forms coarse talus blocks 1 to 3 ft or more across, and produces "sandy powder" on freshly broken surfaces. This variety is associated with black and white laminated variety of argillite containing several laminations per centimeter that are usually intricately crenulated or contorted. Chert unit contains subordinate interbeds of carbonaceous argillite, tuffaceous and volcaniclastic rocks, gritty quartz-plagioclase wacke, limestone, and minor basaltic rocks or greenstone. Some distinctive lithologic units are locally mappable. Blastomylonitic texture more or less pervasive but unevenly developed; more detailed mapping might show its distribution to be controlled by ductile thrusting. Chert samples yield "Livengood Dome Chert-type" geochemical signature based on 19 major and minor element analyses (Haug and others, 1997). This chert and cherty argillite unit crops out as a tectonic slice of Livengood Dome Chert unit (see Wickersham unit discussion below) incorporated along a thrust emplacing the grit unit in the lower part of the Wickersham unit onto the calcareous siltstone and sandstone unit in the upper Wickersham unit. This interpretation implies that the Livengood Dome Chert and Wickersham units were geographically associated and that the Livengood Dome Chert unit may have been in stratigraphic or structural contact on the Wickersham prior to their structural juxtaposition here.

Pzlg **Graywacke and gritty quartzite**—Dark gray, fine- to coarse-grained, poorly sorted to bimodal, subangular, quartz-plagioclase-chert graywacke. The quartz-plagioclase-chert ratio varies considerably, but quartz plus plagioclase is much greater than chert; contains rare grit-sized blue quartz "eyes," and numerous single-crystal sand-sized clasts in thin section. Contains minor detrital tourmaline, zircon, and sphene. Unit shows moderately strong cataclastic foliation and synkinematically recrystallized micas.

Pzlv **Volcanic unit**—Greenish-gray, chloritic and feldspathic rocks and greenstone derived from volcaniclastic, tuffaceous, and flow rocks of basaltic to intermediate composition; typically forms bold, jagged outcrops. Some rocks are diabasic and may be meta-intrusive rocks. The number of metavolcanic layers is uncertain, but some structural repetition by folding and ductile thrusting is interpreted from map patterns. Most samples are intensely sheared with extensive chlorite, epidote, zoisite, plagioclase(?), and calcite recrystallization

Pzll **Limestone**—Light to medium gray, tan to reddish brown-weathering, extensively recrystallized, thin- to medium-bedded, lime mudstone containing floating quartz grains and distinctive coated grains and ooids in places. Unit locally is well-laminated, but is generally massive with bedding poorly developed or obscured by shearing. Contains chert nodules and stringers, minor dolomitization, and extensive silicification in places. Typical platy character resulting from well-developed axial planar fracture cleavage. Locally may have one or more interbeds of chloritic metavolcanic or greenstone, or mylonitic siliceous argillite. The number of limestone beds is uncertain but limestone of generally similar character has two somewhat different occurrences. One 10 m thick or less makes bold, "towered" outcrops in most places and forms a key marker bed that is repeated by folding and faulting. The other limestone is a thicker (possibly structurally thickened), white and tan banded unit restricted to the area between Baldry Mountain and Boulder Creek. Both units have prominent Fe-staining in places. May correlate with Orum Limestone of Hopkins and Tabor (unpublished manuscript, 1975).

Amy Creek unit (?) (Proterozoic? to Early Cambrian?)—This rock succession has lithologic similarities to, and is tentatively correlated with, the lower Paleozoic? and (or) Upper Proterozoic? Amy Creek unit in the Livengood Quadrangle of Weber and others (1992). Lithologies in order of decreasing abundance are: (1) oolitic dolostone, (2) siliceous argillite, (3) basaltic greenstone, (4) nonfossiliferous limestone, and (5) dark gray, massive chert. Rocks show non-pervasive cataclasis and low grade recrystallization, and are in low- to moderate-angle thrust contact with successions above and below. Inferred "probable Proterozoic to possibly Early Cambrian" age is based on absence of megafossils and lithologic similarity to ooid-rich intervals in Proterozoic carbonate units elsewhere in Alaska, for example Katakturuk Dolomite (Dutro, 1970) of northeastern Alaska and Kuchaynik Dolostone (Babcock and others, 1994) of west-central Alaska. Conodont samples were barren (N.M. Savage, personal commun., 1997). Previously mapped as Livengood Dome Chert (Chapman and others, 1982). Included by Silberling and others (1994) in the polymetamorphic Baldry terrane of probable early to middle Paleozoic age.

PzPad **Dolostone**—White, generally massive-bedded to locally laminated, cherty dolostone; locally is slightly limy and contains coated ooids. Typically is extensively silicified and characterized by box-work silica; grades locally at top and bottom into medium gray limestone, and has subordinate interbeds of mylonitic siliceous argillite, greenstone, siltite, and minor dark gray chert. The northeastern end of outcrop belt along east edge of map contains two distinctive units. The first unit is a 2-m-thick bed of tan-weathering quartz-clast quartzite. The second is a 2-m-thick bed of chert-clast pebble conglomerate. Typically shattered and forms "chippy" soils more commonly than good outcrops, except forms coarse talus rubble where extensively silicified. May correlate with dolomite in Amy Creek unit of Weber and others (1988), inferred but not proved to be of Proterozoic age. Probably equivalent to Wolverine Limestone of Hopkins and Tabor (unpublished manuscript, 1975).

PzPag **Greenstone**—Dark greenish gray, massive to well-foliated, locally magnetic greenstone, amygdaloidal greenstone, and agglomeratic greenstone; basaltic to intermediate composition. Contains calcite amygdule fillings, locally abundant pyrite cubes, and slightly stretched volcanic and carbonate clasts up to cobble size. Is associated with or interlayered within the Cherty-argillite and chert unit, and contains limestone pods or lenses up to 1 m thick locally.

PzPac **Cherty-argillite and chert**—Heterogeneous unit of dominantly black to dark gray chert and siliceous to carbonaceous argillite with well-developed phyllitic to subphyllitic slaty cleavage, and containing one or more dark gray limestone layers or lenses. Yields geochemical signature typical of chert in the Amy Creek unit (based on 19-element discriminant analyses, Haug and others, 1997) of Weber and others (1988). Limestone up to 3 m thick locally crops out and is included in this unit.

Wickersham unit (?) (lower Paleozoic and Upper Proterozoic)—This succession consists of a calcareous siltstone and sandstone unit and a grit and quartzite unit, and is tentatively correlated with the lower Paleozoic and Upper Proterozoic Wickersham unit of Weber and others (1988). The Wickersham unit shows pervasive cataclasis and low-grade recrystallization. Rocks are structurally dismembered and rest in low-angle thrust contact on underlying sequence, and are truncated on the north by the Victoria Creek strike-slip fault zone. Locally includes a tectonic sliver of rocks here mapped as Livengood Dome Chert. This map unit assignment is based on the geochemical signature of the chert, which is the same as that of the Livengood Dome Chert (Haug and others, 1997); the basal Wickersham unit thrust would otherwise have been mapped as an intraformational thrust.

PzPws **Calcareous Siltstone and Sandstone**—Distinctive medium gray, tan-weathering, thin-bedded, fine-grained, well-sorted siltstone and sandstone with up to 30 percent calcite recrystallized from, or replacing, matrix. These rocks contain abundant black, non-calcareous, carbonaceous, phyllitic argillite interbeds and partings; sandy layers and laminae are poorly sorted quartz-plagioclase wacke. Petrographically this unit is similar to the grit and quartzite unit (described below), indicating a genetic association. Recessively weathering, forming sparse outcrop over broad areas; typically has two well-developed, close-spaced fracture cleavages. Lithologically and petrographically similar to rocks assigned to the upper part of the Wickersham unit in the Schwatka belt of the Livengood Quadrangle (Weber and others, 1992).

PzPwg Grit and quartzite—Quartz- and plagioclase-rich, poorly sorted to bimodal, subangular quartzite, gritty quartzite, and granule conglomerate containing sparse milky or blue quartz "eyes" and granules; light gray varieties have quartz-plagioclase-wacke matrix, and medium gray types are more argillaceous. For the coarsest fraction, quartz is generally much more abundant than plagioclase, and most quartz grains are single crystals; the matrix contains a relatively higher proportion of plagioclase and minor chert. Common but sparse accessory detrital minerals are tourmaline and zircon. Where minor to extensive calcite replacement of matrix occurs, this unit is petrographically gradational into the calcareous sandstone and siltstone unit. However, these two units are structurally discordant and commonly separated by cherty rocks lithologically and chemically like the Livengood Dome Chert unit. Outcrop is typically sparse; and most commonly forms coarse rubble piles.

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REFERENCES

*The references marked have not been cited in the text, but are considered helpful in understanding the geology of the area.

Babcock, L.E., Blodgett, R.B., and St. John, J., 1994, New Late (?) Proterozoic-age formations in the vicinity of Lone Mountain, McGrath Quadrangle, west-central Alaska, *in* Till, Alison B., and Moore, Thomas E., eds., Geologic Studies in Alaska by the U.S. Geological Survey 1993, Bulletin 2107, p. 143-156.

Barnes, David F., Mariano, John, Morin, Robert L., Roberts, Carter W., and Jachens, Robert C., 1994, Incomplete isostatic gravity map of Alaska, *in* Plafker, George, and Berg, Henry C., eds., The Geology of Alaska: The Geological Society of America, Boulder, Colorado, 1 sheet, scale 1:2,500,000.

*Bell, T.H., and Johnson, S.E., 1989, Porphyroblast inclusion trails: the key to orogenesis: Journal of Metamorphic Geology, v. 7, p. 279-310.

*Bell, T.H., and Johnson, S.E., 1992, Shear sense: a new approach that resolves conflicts between criteria in metamorphic rocks: Journal of Metamorphic Geology, v. 10, p. 99-124.

Bell, T.H., Johnson, S.E., Davis, B., Forde, A., Hayward, N., and Wilkins, C., 1992, Porphyroblast inclusion-trail orientation data: *eppure non son girate*! Journal of Metamorphic Geology, v. 10, p. 295-307.

*Bell, T.H., Forde, A., and Hayward, N., 1992, Do smoothly curving, spiral-shaped inclusion trails signify porphyroblast rotation?: Geology, v. 20, p. 59-62.

Brosgé, W.P., Lanphere, M.A., Reiser, H.N., and Chapman, R.M., 1969, Probable Permian age of the Rampart Group, central Alaska: U.S. Geological Survey Bulletin 1294-B, p. b1-b18.

Burns, L.E., 1996, Portfolio of aeromagnetic and resistivity maps of the Rampart-Manley mining district: Alaska Division of Geological & Geophysical Surveys Public-Data File 96-9, 14 p.

Burns, L.E., 1997, Portfolio of aeromagnetic and resistivity maps of the extended coverage of the Rampart-Manley mining district: Alaska Division of Geological & Geophysical Surveys Public-Data File 97-23, 13 p.

*Burns, L.E., Newberry, R.J., and Solie, D.N., 1991, Quartz normative plutonic rocks of interior Alaska and their favorability for association with gold: Alaska Division of Geological & Geophysical Surveys Report of Investigations 91-3, 71 p., 2 sheets.

Burton, P.J., 1981, Radioactive mineral occurrences, Mt. Prindle area, Yukon-Tanana uplands, Alaska: University of Alaska, M.S. Thesis, Fairbanks, Alaska, 72 p.

Chapman, R.M., Weber, F.R., Churkin, Michael, Jr., and Carter, Claire, 1979, The Livengood Dome chert, a new Ordovician formation in central Alaska, and its relevance to displacement on the Tintina fault: U.S. Geological Survey Professional Paper 1126-F, p. F1-F13.

Chapman, R.M., Yeend, Warren, Brosgé, W.P., and Reiser, H.N., 1982, Reconnaissance geologic map of the Tanana Quadrangle, Alaska: U.S. Geological Survey Open-File Report 82-734, 18 p., scale 1:250,000.

Christie, A.B., Duke, J.L., and Rushton, R., 1992, Grew Creek Epithermal gold-silver deposit, Tintina Trench, Yukon: Yukon Geology, v. 3, Exploration and Geological Services Division, Yukon, Indian and Northern Affairs Canada, p. 223-259.

*Churkin, Michael Jr, Foster, H.L., Chapman, R.M., and Weber, F.R., 1982, Terranes and suture zones in east-central Alaska: Journal of Geophysical Research, v. 87, no. 135, p. 3718-3730.

*Churkin, Michael, Jr., and Brabb, E.E., 1965, Occurrence and stratigraphic significance of Oldhamia, a Cambrian trace fossil in east-central Alaska, *in* Geological Survey Research 1965: U.S. Geological Survey Professional Paper 525-D, p. D120-D124.

*Dover, J.H., and Miyaoka, R.T., 1985, Major rock packages of the Ray Mountains, Tanana and Bettles Quadrangles: U.S. Geological Survey Circular 945, p. 32-36.

Dover, James H., 1994, Geology of part of east-central Alaska, *in* Plafker, George, and Berg, Henry C., eds., The Geology of Alaska: The Geological Society of America, Boulder, Colo-rado, p. 153-204.

*Dover, James H., and Miyaoka, Ronny T., 1983a, Major rock packages of the Ray Mountains, Tanana and Bettles Quadrangles, in Bartsch-Winkler, Susan, and Reed, Katherine M., eds., The U.S. Geological Survey in Alaska, accomplishments during 1983: U.S. Geological Survey Circular 945, p. 32-35.

*———1983b, Metamorphic rocks of the Ray Mountains—Preliminary structural analaysis and regional tectonic implications, *in* Bartsch-Winkler, Susan, and Reed, Katherine M., eds., The U.S. Geological Survey in Alaska, accomplishments during 1983: U.S. Geological Survey Circular 945, p. 36-37.

Dusel-Bacon, Cynthia, 1994, Map and table showing metamorphic rocks of Alaska, *in* Plafker, George, and Berg, Henry C., eds., The Geology of Alaska: The Geological Society of America, Boulder, Colorado, 2 sheets, scale 1:2,500,000.

Dusel-Bacon, Cynthia, Brosgé, W.P., Till, A.B., Doyle, E.O., Mayfield, C.F., Reiser, H.N., and Miller, T.P., 1989, Distribution, facies, ages and proposed tectonic associations of regionally metamorphosed rocks in northern Alaska: U.S. Geological Survey Professional Paper 1497-A, 44 p., 2 sheets, scale 1:1,000,000.

Dutro, J.T., Jr., 1970, Pre-carboniferous carbonate rocks, northeastern Alaska *in* Geological seminar of the North Slope of Alaska, Palo Alto, Calif., 1970, Proceedings, Los Angeles, California, American Association of Petroleum Geologists Pacific Section, p. M1-M7; discussion, p. M8.

*Hayward, N., 1990, Determination of early fold axis orientations in multiply deformed rocks using porphyroblast inclusion trails: Tectonophysics, v. 179, p. 353-369.

Haug, S.A., Newberry, R.J., Reifenstuhl, R.R., Clautice, K.H., Liss, S.A., Weber, F.R., 1997, Chert geochemistry discriminant analyses and K-means cluster analysis: Rampart project area, Tanana B-1 Quadrangle, east-central Alaska: Alaska Division of Geological & Geophysical Surveys Public-Data File 97-29F, 25 p.

Hopkins, D.M., and Taber, B., 1962, Stratigraphy of the pre-Quaternary bedded rocks of the Manley Hot Springs area, Alaska: Unpublished U.S. Geological Survey Bulletin, 131 p., scale 1:63,360.

Johnson, S.E., 1993, Testing models for the development of spiral-shaped inclusion trails in garnet porphyroblasts: To rotate or not to rotate, that is the question: Journal of Metamorphic Geology, v. 11, p. 635-659.

Jones, D.L., Silberling, N.J., Chapman, R.L., and Coney, Peter, 1984, New ages of radiolarian chert from the Rampart district, east-central Alaska, in Coonrad, W.L., and Elliott, R.L., eds., The United States Geological Survey in Alaska—Accomplishments during 1981: U.S. Geological Survey Circular 868, p. 39-43.

Joy, Brian, in press, Microprobe analyses and geobarometry (garnet-biotite-muscovite-plagioclase) and geothermometry for amphibolite grade metamorphic rocks, Tanana B-1 Quadrangle, central Alaska.

Light, Thomas D., and Rinehart, C. Dean, 1988, Molybdenite in the Huron Creek pluton, western Livengood Quadrangle, Alaska, in Dover, James H., and Galloway, John P., eds., Geologic studies in Alaska by the U.S. Geological Survey, 1988: U.S. Geological Survey Bulletin 1903, p. 54-61.

Liss, S.A., Reifenstuhl, R.R., Clautice, K.H., Bundtzen, T.K., Newberry, R.J., Dover, J.H., and Blodgett, R.B., 1997, Rock geochemistry from the Rampart mining district: Alaska Division of Geological & Geophysical Surveys Public-Data File 97-29G., 19 p., 1 disk.

Loney, Robert A., and Himmelberg, Glen R., 1985, Distribution and character of the peridotite-layered gabbro complex of the southeastern Yukon-Koyukuk ophiolite belt: U.S. Geological Survey Circular 945, p. 46-48

Loney, Robert A., and Himmelberg, Glen R., 1988, Ultramafic rocks of the Livengood terrane, *in* Galloway, John P., and Hamilton, Thomas D., eds., Geologic studies in Alaska by the U.S. Geological Survey during 1987: U.S. Geological Survey Circular 1016, p. 68-70.

McCoy, D., Newberry, R.J., Layer, P., DiMarchi, J.J., Bakke, A, Masterman, J.S. and Minehane, D.L., 1997, *in* press, Plutonic related gold deposits of Interior Alaska, *in* Goldfarb, R.J. and Miller, L.S., eds., Mineral Deposits of Alaska: Economic Geology, Monograph 9.

Mertie, J.B., Jr., 1937, The Yukon-Tanana Region, Alaska: U.S. Geological Survey Bulletin 872, 276 p.

Newberry, R.J., and Clautice, K.H., in press, Microprobe composition and inclusion mineralogy of placer gold grains from the Rampart, Eureka, and Tofty areas, Interior Alaska: Alaska Division of Geological & Geophysical Surveys Public-Data File.

Newberry, R.J. and Haug, S., 1997, Trace element, CIPW Norm, and Sr isotopic data for igneous rocks in the Tanana B-1 Quadrangle and vicinity: Alaska Division of Geological & Geophysical Surveys Public-Data File 97-__, __p.

Newberry, R.J., Layer, P.W., Burleigh, R.E., Solie, D.N., in press, New $^{40}Ar/^{39}Ar$ dates for intrusions and mineral prospects in the eastern Yukon-Tanana terrane, Alaska—regional patterns and significance: *in* Gray, J.E., and Riehle, J.R., eds., Geologic Studies in Alaska by the U.S. Geological Survey, U.S. Geological Survey Bulletin.

Newberry, R.J., Layer, P.W., Solie, D.N., and Burleigh, R.E., 1995, Mesozoic-Tertiary rocks of eastern Interior Alaska: Ages, compositions, and tectonic settings [abs]: Geological Society of America Abstracts with Program, v.27, no. 5, p.68.

Nokleberg, W.J., Bundtzen, T.K., Berg, H.C., Brew, D.A., Grybeck, Donald, Robinson, M.S., Smith, T.E., and Yeend, Warren, 1994, Metallogenic map of significant metalliferous lode deposits and placer districts in Alaska, *in* Plafker, George, and Berg, Henry C., eds., The Geology of Alaska: The Geological Society of America, Boulder, Colorado, 1 sheet, scale: 1:2,500,000.

Passchier, C.W., Trouw, R.A.J., Zwart, H.J., and Vissers, R.L.M., 1992, Porphyroblast rotation: *eppur si muove?* Journal of Metamorphic Geology, v. 10, p. 283-294.

*Patton, W.W., Jr., Tailleur, I.L., Brosgé, W.P., and Lanphere, M.A., 1977, Preliminary report on the ophiolites of northern and western Alaska, *in* Coleman, R.G., and Irwin, W.P., eds., North American Ophiolites: Oregon Department of Geology and Mineral Industries Bulletin 95, p. 183, 1 sheet.

Pearce, J.A. and Cann, J.R., 1973, Ophiolite origin investigated by discriminant analysis using Ti, Zr, and Y: Earth and Planetary Sci Letters, v. 12, p. 339-349.

Pearce, J.A., Harris, N.B.W., and Tindle, A.G., 1984, Trace element discrimination diagrams for the tectonic interpretation of granitic rocks: Journal of Petrology, v. 25, p. 956-983.

Plafker, George, Gilpin, Lou M., and Lahr, John C., 1994, Neotectonic map of Alaska, *in* Plafker, George, and Berg, Henry C., eds., The Geology of Alaska: The Geological Society of America, Boulder, Colorado, 1 sheet, scale 1:2,500,000.

Prindle, L.M., 1908, The Fairbanks and Rampart region, Alaska: U.S. Geological Survey Bulletin 337, 102 p.

Reifenstuhl, R.R., Layer, P.W., and Newberry, R.J., 1997, Geochronology ($^{40}Ar/^{39}Ar$) of 17 Rampart area rocks, Tanana and Livengood quadrangles, central Alaska: Alaska Division of Geological & Geophysical Surveys Public-Data File 97-29H, 22 p.

Rinehart, C. Dean, (unpublished), Major oxide data and petrographic descriptions from Sawtooth Mountain, Wolverine Mountain, Elephant Mountain, and Rampart Group rocks in the Livengood Quadrangle. Unpublished data prepared for the U.S. Geological Survey Livengood geologic map.

Roeske, S.M., Dusel-Bacon, C., Aleinikoff, J.N., Snee, L.W., and Lanphere, M.A., 1995, Metamorphic and structural history of continental crust at a Mesozoic collisional margin, the Ruby terrane, central Alaska: Journal of Metamorphic Geology, v. 13, no. 1, p. 25-40.

Silberling, Norman J., Jones, David L., Monger, James W.H, Coney, Peter J., Berg, Henry C., and Plafker, George, 1994, Lithotectonic terrane map of Alaska and adjacent parts of Canada, *in* Plafker, George, and Berg, Henry C., eds., The Geology of Alaska: The Geological Society of America, Boulder, Colorado, 1 sheet, scale 1:2,500,000.

*Smith, T.E., Pessel, G.H., and Wiltse, M..A., eds., 1987, Mineral assessment of the Lime Peak-Mt. Prindle area, Alaska: Alaska Division of Geological & Geophysical Surveys , 663 p.

Weber, F.R., Blodgett, R.B., Harris, A.G., and Dutro, J.T., Jr., 1994, Paleontology of the Livengood Quadrangle, Alaska: U.S. Geological Survey Open-File Report 94-215, 24 p., 1 sheet, scale 1:250,000.

Weber, F.R., McCammon, R.B., Rinehart, C.D., Light, T.D., and Wheeler, K.L., 1988, Geology and mineral resources of the White Mountains National Recreation Area, east-central Alaska: U.S. Geological Survey Open-File Report 88-284, 2 v., 33 plates, scales 1:250,000 and 1:63,360.

Weber, F.R., Wheeler, K.L., Rinehart, C.D., Chapman, R.M., and Blodgett, R.B., 1992, Geologic map of the Livengood Quadrangle, Alaska: U.S. Geological Survey Open-File Report 92-562, 20 p., 1 sheet, scale 1:250,000.

Table 1. *Geochronology ($^{40}Ar/^{39}Ar$) of 17 Rampart-area rocks, Tanana and Livengood Quadrangles, east-central Alaska*

Sample	Latitude	Longitude	Rock Type, Map Unit and Location (Tanana B-1 Quadrangle unless noted)	Mineral Phase[a]	Integrated Age (Ma)	Plateau Age (Ma)[b]	Plateau Fractions	Plateau % ^{39}Ar
96BT298b	65.48944	-150.000	Tertiary basalt (Tb)	WR	59.7±0.2	**60.0±0.2**	10	95
96BT313	65.46034	-150.387	Tertiary rhyolite (Tr)	WR	55.7±0.2	**56.0±0.3**	9	89
96RN103	65.43731	-150.172	Rampart Group gabbro (TRMrg)	HO	179.5±1.1	**185.2±1.4**	2	27
96RN110a	65.4249	-150.156	Biotite schist (pTas)	WM	61.2±0.2	**61.6±0.2**	13	97
96RN110b	65.4249	-150.156	Amphibolite (pTas)	HO	57.1±0.3	**57.1±0.3**	6	73
96RN110c	65.4249	-150.156	Mafic dike (Tdm)	WR	56.5±0.2	**57.8±0.3**	10	86
96RN111	65.44262	-150.154	Muscovite schist (pTas)	WM	62.7±0.2	**63.0±0.2**	12	98
96RN114b	65.43021	-150.17	Rampart Group Au?-quartz vein (TKq)	WM	72.6±0.3	**73.1±0.3**	10	97
96RN114c	65.43021	-150.17	Mafic dike (Tdm)	WR	58.4±0.3	**59.1±0.3**	10	93
96RN16	65.04347	-150.603	Manley Hot Springs granite - (not on map: Tanana A-2)	BI	58.1±0.2	**58.3±0.2**	9	95
96RN167	65.41301	-150.237	Rampart Group syenite dike (Tsy)	BI	60.0±4.9	**57.2±0.9**	3	66
96RN167	65.41301	-150.237	Rampart Group syenite dike (Tsy)	WR	57.2±0.2	**57.8±0.2**	10	88
96RN191	65.39279	-150.26	Cu-Au-quartz vein in (TKq) amphibolite grade metamorphic rocks	WM	61.8±0.3	**61.2±0.3**	10	85
96RN192a	65.43347	-150.048	Hoosier Creek Au-quartz vein (TKq)	WM	72.2±0.3	none	--	--
96RN243a	65.3272	-151.057	Yukon rapids granite– (not on map: Tanana B-3)	BI	59.9±0.2	**60.0±0.2**	11	98
96RN244	65.51861	-149.588	Victoria Creek fault zone granite– (not on map: Livengood C-6)	WM	83.4±0.4	**83.8±0.4**	7	90
96RR16a	65.2844	-150.129	Andesite (TrPt: from Triassic to Permian age tuff unit)	WR	113.2±0.4	none	--	--

[a]WR = whole rock, HO = hornblende, WM = white mica, BI = biotite. Samples run against standard Mmhb-1 with an age of 513.9 Ma and processed using the standards of Steiger and Jager (1977). All errors quoted to ± 1 σ.

[b]Bold numbers are interpreted ages (Geochronology Lab, Geophysical Institute, University of Alaska Fairbanks).