```
/* ------------------------ CODESET -------------------------- */
```

Title: Bedrock geologic map of the Liberty Bell area, Fairbanks A-4 Quadrangle, Bonnifield mining district, Alaska
Publication: RI 2006-2
URL: http://www.dggs.dnr.state.ak.us/pubs/pubs?reqtype=citation&ID=15026

```
/* ---------------------------------------------------------- */
```

UNIT DESCRIPTIONS

TERTIARY SEDIMENTARY ROCKS

Tn NENANA GRAVEL (Pliocene): Light brown to orange-brown, poorly consolidated, clast-supported pebble conglomerate and sandstone. Conglomerate layers are commonly 1-60 cm thick but range up to 5 m thick. Gravel is well rounded to subrounded, averaging 5-30 mm in diameter with clasts up to 45 cm in diameter. Composition of gravel and larger clasts is 20-50 percent quartz and quartzite, 10-30 percent black and other chert, 10-80 percent plutonic (granite, gabbro, diorite), <20 percent volcanic (basalt, latite, diabase, andesite, porphyry), <20 percent metamorphic (phyllite, schist, orthogneiss), and <10 percent sedimentary (Cantwell Formation conglomerate, siltstone, mudstone, sandstone; not including chert). Gravel layers are commonly cemented with iron oxides forming ferricretes. Sites rich in gabbro cobbles and boulders, located in the northwest corner of the map area, possibly correlate with the upper 305 m of the Nenana Gravel section (Wahrhaftig, 1987) or the gabbro could be glacially transported (De Anne Stevens, oral commun., 2006). Gravel layers are interbedded with gray to pale brown to orange-brown, locally silty and clayey, very fine- to coarse-grained sand layers 5-20 cm thick, but up to 10 m thick. Sand is composed of quartz grains and sedimentary lithic fragments with significant but lesser amounts of feldspar grains and metamorphic, volcanic, and plutonic fragments (table 2). Clay fraction of the sand is composed of a small to moderate amount of kaolinite and montmorillonite, and possible zeolite and chlorite (table 3). Unit also contains thin, gray to orange clay layers, clay concretions up to 10 cm in diameter, and thin lignite layers with occasional plant remains (one log 10 cm in diameter). Magnetic susceptibility is low to moderate (0.00-1.34 averaging 0.22 x 10-3 SI [Systeme International]). Visual observations and measurements of cross-bedding generally indicate a northeastward paleocurrent direction (fig. 4). Possibly conformable on the Lignite Creek Formation in the southwestern corner of the map, but unconformable on a variety of units elsewhere in the map area. The intervening Grubstake Formation was not recognized in this map area. Wahrhaftig and others (1969) pinch the Grubstake Formation out along Elsie Creek, which crosses the southern boundary of the map area. Age from palynological and paleobotanical data (Wolfe and Tanai, 1980; Leopold and Liu, 1994). Maximum measured thickness is approximately 1,040 m in the headwaters of Suntrana Creek, located 15 km south of the map area (Wahrhaftig, 1987). Interpreted as coalescing alluvial fans shed during uplift of the Alaska Range (Wahrhaftig, 1987).

Tlc LIGNITE CREEK FORMATION (Late Miocene) : Very fine- to medium-grained sandstone and gravel. Sandstone is white, light gray, cream, and orange, well sorted, well rounded, and rarely coarse-grained with <2 percent granules. The sand fraction is composed primarily of quartz grains and metamorphic lithic fragments, and lesser feldspar grains, sedimentary lithic fragments, and volcanic lithic fragments. Plutonic lithic fragments are rare (table 2). Beds are occasionally micaceous, contain clay concretions, and the silt content varies widely. The clay fraction of the sandstone is composed of low to moderate amounts of kaolinite, moderate to no amounts of montmorillonite (occasionally higher amounts), and possible zeolite and chlorite (table

3). Sandstone beds 3-4.5 m thick are commonly interbedded with light brown to orange-brown, poorly sorted conglomerate layers 1-4 cm thick to less commonly 30.5-60 cm thick. Cross-bedding is infrequently observed in outcrop. Outcrops are generally composed of <5 percent, but up to 30 percent, conglomerate. Pebbles and cobbles in the conglomerate are well rounded to subangular and 0.5-8 cm in diameter (averaging 1 cm in diameter; rare cobbles up to 25 cm in diameter). Composition of clasts is 10-50 percent quartz, 35-50 percent metamorphic (black quartzite, other quartzite, quartz schist, slate, gneiss, greenstone), 20-50 percent chert (10-40 percent black chert, 0-5 percent red chert), 10-40 percent plutonic (gabbro, diorite, granite, clinopyroxenite?), 5-20 percent volcanic (basalt, rhyolite, hornblende andesite, dacite?), and 0-5 percent sedimentary (Cantwell Formation conglomerate, argillite, sandstone, limestone). Locally iron cemented, forming ferricrete and occasionally contains iron concretions 2-15 cm in diameter. Unit also contains platy- to blocky-parting, light gray to brown shale <57 cm thick and friable coal <0.7 m thick (apparent coal rank is Lignite A; table F1). Magnetic susceptibility is low to moderate (0.00-3.44, averaging 0.22 x 10exp-3 SI; one sandstone sample registered 20.5 x 10exp-3 SI). Visual observations and measurements of cross-bedding generally indicate a southward or westward paleocurrent direction (fig. 4). Conformably overlies the Suntrana Formation. (Wahrhaftig and others, 1969). Age from paleobotanical data (Wolfe and Tanai, 1980). Thickest measured section is 244 m in the Wood River coal basin, located 45 km east of the map area (Wahrhaftig and others, 1969). Interpreted as point bar deposits, gravelly and sandy braided stream deposits, and lesser overbank deposits (Buffler and Triplehorn, 1976; Stanley and others, 1992).

Tsn SUNTRANA FORMATION (Middle Miocene): Fine- to medium-grained with minor very fine- to coarse-grained, "salt and pepper" sandstone and conglomerate. Sandstone has an overall gray to light yellow-brown color. Rarely beds are iron-oxide stained. Sandstone is well-sorted, rarely clayey (kaolinite > montmorillonite) or silty and is composed primarily of quartz, minor feldspar grains, and lesser sedimentary and metamorphic lithic fragments; volcanic and plutonic lithic fragments are rare (table 2). Conglomerate beds 10-70 cm thick occur in about 5-50 percent of the outcrops. Conglomerate is composed of 25-80 percent white quartz, 15-50 percent black chert, 20-25 percent white and black quartzite, 5-60 percent metamorphic clasts (schist, phyllite), <10 percent red and green chert, <5 percent granitic rocks and minor conglomerate, diabase, and porphyritic igneous rocks. Gravel averages 1-2 cm in diameter (ranges 3 mm to 10 cm). Outcrops contain fining-upward sequences and cross-bedding. Unit also contains glassy, conchoidally fracturing coal up to 6 m thick (apparent coal rank is Lignite A and B and High-volatile Subbituminous C; table F1) and gray to chocolate brown, platy, friable shale. Magnetic susceptibility is variable (0.0-13.0, averaging 1.32 x 10exp-3 SI; coal had magnetic susceptibilities up to 43.4 x 10exp-3 SI). Cross-bedding in the Suntrana Formation throughout the Nenana coal basin generally indicates a south- or westward paleoflow (Wahrhaftig and others, 1969; Ridgway and others, 1999). Unit is almost entirely burnt in the Rex Dome area, and local, small pockets of clinker occur south of hill VABM Coal. In the field area, Suntrana Formation may conformably overlie Healy Creek Formation without the intervening Sanctuary Formation. Sanctuary Formation as described by Wahrhaftig and others (1969) and Wahrhaftig (1987) was not recognized in the field area. Assigned stratigraphic age from paleobotanical data (Wolfe and Tanai, 1980). Thickest section of unit is 393 m on Coal Creek, tributary of Healy Creek, 13.5 km south of the map area (Wahrhaftig and others, 1969). Interpreted as high-energy fluvial channels filled by gravel and sand bars (Buffler and Triplehorn, 1976; Wahrhaftig, 1987; Stanley and others, 1992).

Thc HEALY CREEK FORMATION (Early Miocene-Early Oligocene/Late Eocene?): Interbedded, poorly sorted pebbly sandstone, siltstone, claystone, conglomerate, and coal. Sandstone is white to light gray, very fine- to fine-grained, with lesser medium- and coarse-grained sandstone; it contains about 60-80 percent sand, 5-40 percent pebbles, and 5 percent cobbles. Sand is composed of quartz grains, metamorphic rock fragments, feldspar grains, minor sedimentary rock fragments, and rare plutonic or volcanic rock fragments. Brown to gray, platy, micaceous siltstone and claystone (primarily kaolinite) weathers bright white, locally exhibits varves, and frequently contains subangular to angular, 2-3 mm quartz and chert granules. White to light brown conglomerate contains well rounded to subangular gravel 1-3 cm in diameter (up to 40 cm in diameter) in a sandy + silty + clayey matrix. Gravel is composed of 30-92 percent quartz, 20-45 percent locally derived metamorphic clasts, 5-45 percent chert, 5 percent red chert, and rare quartzite and granite. Platy, friable, locally resinous coal beds are 8 cm to 2.5 m thick (apparent coal rank is Lignite A and B and High-volatile Subbituminous C; table F1). On the northern edge of the map, one outcrop contains at least 14 fining-upward sequences of pebbles to 8-cm-thick coal beds. Magnetic susceptibility is moderate (0.0-1.49, averaging 0.43 x 10exp-3 SI); coal exhibits magnetic susceptibilities up to 11.5 x 10exp-3 SI. Unit is commonly burnt north of hill VABM Coal. Cross-bedding in the Healy Creek Formation throughout the Nenana coal basin indicates a variety of paleocurrent directions (Wahrhaftig and others, 1969; Ridgway and others, 1999). Unit was deposited on an irregular surface, infilling valleys (Wahrhaftig and others, 1969); significant thickness changes over short distances and unit's composition was heavily influenced by surrounding bedrock. Assigned stratigraphic age from palynological and paleobotanical data (Wolfe and Tanai, 1987; Leopold and Liu, 1994). Thickness of unit in the map area is unknown; unit is 350 m thick at the eastern edge of the Healy Creek coal basin, 13 km south of the map area (Wahrhaftig and others, 1969). Interpreted as sand and gravel bars in shallow, low-sinuosity channels of high-energy, braided streams and fine-grained sediment deposited in abandoned, quiet-water stream channels (Buffler and Triplehorn, 1976; Wahrhaftig, 1987; Stanley and others, 1992).

TERTIARY-CRETACEOUS IGNEOUS ROCKS

Td DACITE FLOWS (Tertiary): Fine-grained, massive, jointed (columnar?), porphyritic flows crop out in the southeastern map area. Unit is at least 200 m thick. Light- to dark-green colored, with varying proportions of hornblende, biotite, pyroxene, plagioclase, and (or) quartz phenocrysts up to 6 mm in length in an aphanitic groundmass. Modal composition is 62 percent plagioclase, 10 percent hornblende, 20 percent quartz, 3 percent pyroxene, 3 percent biotite, and 2 percent opaque minerals (both magnetite and ilmenite? based on shapes). Secondary chlorite partially to completely replaces mafic minerals. Major- and minor-oxide and trace-element analyses indicate the dacite flows are calc-alkalic and likely to be subduction related (fig. 7). Magnetic susceptibility is high (1.00-10.00, averaging 3.78 x 10exp-3 SI). Unit corresponds to a pronounced magnetic high in airborne geophysical data (Burns and others, 2002). 40Ar/39Ar biotite plateau age of 37.4 +/- 0.3 Ma (map location A1; table 5). This unit is not related to the Jumbo Dome intrusive center, located 3 km south of the map border. Jumbo Dome is a much younger system (40Ar/39Ar hornblende weighted average age of 1.026 +/- 0.057 Ma) and compositionally an Adakite (Sr:Y ratio approximately 1,000:1; C.J. Nye, written commun., 2006), while the Sr:Y ratio of this unit is 7:1. The closest, dated, volcanic rock of that approximate age is from Sugar Loaf Mountain, a fossilized volcanic vent located 24 km to the south (K-Ar ages of 32.4 +/- 1.0 to 35.2 +/- 1.0 Ma; Albanese and Turner, 1980). Unit is offset by a late, north-northeast-trending, high-angle fault.

Kg GRANITE DIKES AND STOCKS (Cretaceous): Fine- to very fine-grained, porphyritic-textured, lesser equigranular-textured, and rarely pegmatitic-textured, hypabyssal granite dikes (up to 10 m wide; average less than 3 m wide) and stocks (at least 1.2 km long and 0.3 km wide) are present throughout the map area. Orange to light yellow-brown weathering, white to light gray colored. Porphyritic intrusions contain widely varying proportions of quartz, feldspar, and biotite phenocrysts (10-42 percent; average 21 percent) in an aphanitic to finely granular matrix. Modal composition ranges from 2-38 percent quartz (average 13 percent), 4-65 percent feldspar (average 16 percent), 0-7 percent biotite, 0-2 percent primary(?) tourmaline, and accessory sphene, zircon, rutile, and apatite. Freeman and others (1987) reported the presence of small, pink to red, clear, glassy euhedral garnets. Dikes that intrude graphitic phyllite (unit Dgq) north of Cody Creek in the western map area contain up to 3 percent graphite, and 70 percent perthite. Weight percent CIPW normative compositions were assigned to igneous rocks using the methodology of Irvine and Baragar (1971). The granite intrusions are locally intensely sericitized, silicified, and tourmalinized with occasional chlorite, epidote, and clinozoisite alteration. Associated mineralization includes arsenopyrite, scorodite, and stibiconite. Major- and minor-oxide and trace-element analyses indicate the granite intrusions are subduction-related and formed in an island-arc tectonic setting (fig. 7). Magnetic susceptibility is low (0.00-0.31, averaging 0.05 x 10exp-3 SI). Age estimated to be 93 Ma based on a 93.0 +/- 0.95 Ma K-Ar age of sericite from a quartz-sericite-tourmaline-sulfide alteration zone associated with a cross-cutting felsic dike in the Liberty Bell Mine area (Yesilyurt, 1996) and spatial association with, and trace-element-indicated tectonic setting similarity to, unit Kgd.

Kgd GRANODIORITE DIKES AND STOCK (Cretaceous): Fine- to medium-grained, porphyritic to equigranular granodiorite dikes (average 3 m wide) and stocks (at least 1.2 km long and 80 m wide) are present along Moose Creek, Little Moose Creek, and on the southern flank of hill VABM Coal. Brown weathering; white, light yellow-brown, and gray-green colored. Porphyritic intrusions contain highly variable proportions of quartz, feldspar, +/- biotite, and +/- hornblende phenocrysts (up to 65 percent; average 29 percent) in an aphanitic to finely granular matrix. Modal composition ranges from 0-15 percent quartz, 16-35 percent plagioclase, 16-30 percent K-feldspar, 0-30 percent hornblende, 0-28 percent biotite, and accessory apatite, zircon, rutile, and opaque minerals. Rock names were assigned from weight percent CIPW normative calculations; one sample from lower Moose Creek is a tonalite and may represent a more mafic phase of the pluton. Intrusions contain chlorite, epidote, +/- actinolite altered from hornblende and biotite, and are locally silicified and sericitized. Mineralization includes gold (panned from a crushed rock sample from Little Moose Creek; Timothy Ruppert, oral commun., 2005), pyrite, arsenopyrite, and scorodite. Major- and minor-oxide and trace-element analyses indicate the granite intrusions are subduction-related and formed in an island-arc tectonic setting (fig. 7). Magnetic susceptibility is low (0.00-0.31, averaging 0.05 x 10exp-3 SI). 40Ar/39Ar ages of 92-93 Ma (hornblende plateau age of 91.6 +/- 0.5 Ma [map location A2]; biotite plateau age of 92.9 +/- 0.5 Ma [map location A4]; table 5). Unit Kgd is possibly a more mafic, marginal phase of a larger, subsurface granitic(?) pluton.

Kb GABBRO DIKES (Cretaceous): Fine-grained, blocky to spheroidally weathering, equigranular to porphyritic gabbro dikes up to 3 m in width are present on hill VABM Coal in the eastern map area. Medium-brown weathering, dark-green colored, with rare quartz- and calcite-filled amygdules up to 5 mm in diameter. Porphyritic dikes contain plagioclase phenocrysts up to 1 cm in length. Modal composition ranges from 55 to 58 percent plagioclase, 0-38 percent hornblende, 3-25 percent biotite, 0-15 percent olivine, 0-5 percent opaque minerals, and accessory apatite. Secondary minerals include talc, chlorite, calcite, quartz, and (or) white mica. Major- and minor-oxide and trace-element analyses indicate the gabbro dikes are subduction-related and formed in an island-arc tectonic setting (fig. 7). Magnetic susceptibility is moderate to high (0.30-1.95, averaging 2.57 x 10exp-3 SI). 40Ar/39Ar biotite plateau age of 95.6 +/- 0.5 Ma (map location A5; table 5). Unit Kb is about 3 million years older than unit Kgd; the two igneous units may not be genetically related.

PALEOZOIC UNITS

Dg METAGRANITE (Devonian): Megacrystic to lesser fine-grained, equigranular to porphyritic metagranite. Orange weathered; white, light green, and light gray colored. Foliated outcrops break in semi-massive blocks to schistose sheets. Modal composition is 10-40 percent relict quartz phenocrysts (average 22 percent) and 10-65 relict feldspar phenocrysts (average 34 percent). Metagranite is defined as having relict quartz + feldspar phenocrysts > 60 percent based on typical textures exhibited by extrusive volcanic and hypabyssal rocks (K.F. Bull, oral commun., 2006). Megacrystic samples from Rex Dome and other similar bodies in the northern map area, which contain relict feldspar phenocrysts 1.5-3.0 cm (average 1.6 cm) and relict quartz phenocrysts 1-10 mm (average 4.3 mm), artificially generate low modal compositions because not every small sample or thin section contains the correct ratio of megacryst to matrix. Megacrystic samples are assumed to be metagranite instead of metarhyolite. Porphyritic samples with high crystal contents may represent a continuous increase in relict phenocrysts from metarhyolite, unit Dr. Conversely, groundmass composed of white mica and very fine-grained quartz and feldspar may have been seriate-textured before metamorphic recrystallization. Relict phenocrysts are commonly euhedral and sub-euhedral to less commonly spindle-shaped and sheared along foliation. Also contains biotite, chlorite (from biotite), rutile, epidote, clinozoisite, zircon, sphene, and opaque minerals. Rarely contains inclusions of unit Dgq. Weight percent CIPW normative composition is granite. Both varieties typically have Nb + Y > 50 ppm and TiO2 < 0.3 ppm. Metagranite is locally hornfelsed and mineralized by arsenopyrite, pyrite, and pyrrhotite as disseminated crystals and in cross-cutting quartz +/- tourmaline veins. Feldspars commonly, partially to wholly replaced by sericite and quartz. Magnetic susceptibility is low (0.0-0.6, averaging 0.09 x 10exp-3 SI); hornfelsed samples containing pyrrhotite have magnetic susceptibilities up to 6.0 x 10exp-3 SI. Major- and minor-oxide and trace-element analyses indicate the metagranite formed in a within-plate, extensional tectonic setting (fig. 7). Represents metamorphosed plugs, dikes, and (or) sills at least 3.4 km long and 0.6 km thick (probably stretched and thinned within foliation, respectively) emplaced within units Daw and Dgq. Where spatial extent is unknown, locations are marked with a symbol (see "Map Symbols," sheet RI 2006-2). Equivalent to augen gneiss in the California Creek Member of the Totatlanika Schist and comprises a portion of the area mapped as the Moose Creek Member of the Totatlanika Schist on Wahrhaftig's map (1970c) of the Fairbanks A-4 Quadrangle. Zircons from California Creek Member augen gneiss located about 37.5 km southeast of the map area and dated by SHRIMP U-Pb exhibit an age of 373 +/- 3 Ma (fig. 5; Dusel-Bacon and others, 2004).

Dr METARHYOLITE (Devonian): Very fine- to medium-grained, porphyritic metarhyolite. Orange and brown weathered; white, gray, and light green colored and possibly flow banded. Forms massive, blocky outcrops with poorly formed foliation to well-foliated outcrops with strong cleavage. Modal composition is 1-40 percent relict feldspar phenocrysts (average 18 percent), 1-20 percent relict quartz phenocrysts (average 10 percent), and accessory apatite, zircon, and rutile. Feldspar crysts are 1-15 mm in diameter (average 2.3 mm) and quartz crysts are 0.5-4 mm in diameter (average 1.8 mm). Relict quartz (frequently embayed) and feldspar phenocrysts are euhedral to rarely subrounded, and frequently shattered and sheared in foliation. Groundmass is composed of very fine-grained (<0.02 mm), granular quartz, feldspar, and white mica. No tuffaceous textures are present. Metarhyolite is defined as having relict quartz + feldspar crystals < 60 percent based on typical textures in extrusive volcanic and hypabyssal rocks (K.F. Bull, oral commun., 2006). Weight percent CIPW normative composition is primarily granite (rhyolitic texture); a few samples from the mine area are dacitic (SiO_2 < 68 percent). Metarhyolite typically has Nb + Y > 50 ppm and TiO_2 < 0.3 ppm. Where hornfelsed, metarhyolite contains biotite and (or) phlogophite, and is locally cross-cut and brecciated by quartz + sericite + tourmaline + arsenopyrite +/- pyrrhotite +/- pyrite(?) veins. Frequently samples have iron oxide pseudomorphs after pyrite(?) and feldspar is altered to sericite and quartz. Other alteration products include epidote, chlorite, and carbonate. Magnetic susceptibility is low (0-0.8, averaging 0.12 x 10exp-3 SI); hornfelsed samples have magnetic susceptibilities up to 3.07 x 10exp-3 SI. Major- and minor-oxide and trace-element analyses indicate the metarhyolite formed in a within-plate, extensional tectonic setting (fig. 7). Represents flows or hypabyssal intrusions at least 5 km long and 0.4 km wide (probably stretched and thinned within foliation, respectively) that intrude units Daw, Dgq, and Dqw. Where spatial extent is unknown, locations are marked with a symbol (see "Map Symbols," sheet RI 2006-2). Equivalent to "Dacite crystal tuff" in Liberty Bell Mine sequence (Freeman and others, 1987) and comprises most of the area mapped as the Moose Creek Member of the Totatlanika Schist on Wahrhaftig's map (1970c) of the Fairbanks A-4 Quadrangle. Zircons from "Moose Creek Member" metarhyolite located about 39 km southeast of the map area and dated by SHRIMP U-Pb exhibit an age of 365 +/- 5 Ma (fig. 5; Dusel-Bacon and others, 2004).

Dar APHYRIC METARHYOLITE (Devonian): Aphyric, finely laminated, metamorphosed rhyolite flow or sill located at the head of Cody and Spruce creeks and one metamorphosed dike(?) located between Spruce and California creeks. White- to light gray- to light yellow-brown-weathering, with pale gray to pale greenish-gray color laminations (possible flow banding). Typically forms rounded hills of loose, fissile chips, but near the head of Spruce Creek, forms prominent outcrops that exhibit isoclinal folding of laminations. In thin section, composed of an aphanitic to finely granular mixture of quartz and feldspar, some of which may exhibit relict spherulitic texture. Phenocrysts of quartz are very rare. Weight percent CIPW normative composition is granite (rhyolitic texture). Typically has Nb + Y > 50 ppm and TiO_2 < 0.3 ppm. Major- and minor-oxide and trace-element analyses indicate the aphyric metarhyolite formed in a within-plate, extensional tectonic setting (fig. 7). Also contains rare, blocky, laminated pieces of bright red- and white-colored, banded, hematite-bearing, granular quartzite (jasperoid). Magnetic susceptibility is low (0.00-0.11, averaging 0.04 x 10exp-3 SI). Topographically overlies units Daw and interfoliated Dgq. Age is based on a trace-element-indicated tectonic setting similar to, and loose spatial association with, units Dg and Dr.

Db METABASITE (Devonian): Carbonate-altered, metamorphosed mafic flows, sills, dikes, and (or) tuff. Primarily gray and green colored, but also brown and black. Metabasite is aphanitic to medium-grained (rarely coarse-grained), locally banded and laminated, and foliated. Outcrops are platy-breaking to massive. Primary igneous textures are erased by recrystallization and alteration.

Mineral composition varies widely, but chemical composition suggests a mafic parent (high TiO_2 and MgO). Where metamorphosed but not carbonate-altered, major element composition is clearly basaltic; mineralogy is 30-50 percent chlorite, 20-30 percent albite, 10-20 percent clinozoisite, <10 percent carbonate, <10 percent quartz, and 1-2 percent rutile + sphene + magnetite. Where carbonate-altered but not metasomatized, composition is 15-55 percent carbonate, <35 percent chlorite, <30 percent albite, <25 percent white mica, <15 percent quartz, and accessory rutile, ilmenite, magnetite, and other opaque minerals. Due to its high carbonate content, metabasite is the preferred ore host at the Liberty Bell Mine. Where variably metasomatized and hornfelsed in the general mine area, composition is <95 percent tremolite, <70 percent biotite/phlogopite, <67 percent calcite, <60 percent black to dark green chlorite, <60 percent white mica, <60 percent pyrophyllite, <45 percent actinolite, <40 percent plagioclase, <40 percent quartz, <30 percent clinopyroxene (diopside?), <25 tourmaline (brown- and green-gray-zoned), lesser epidote, clinozoisite, and accessory rutile, sphene, zircon, monazite, magnetite, ilmenite, and other opaque minerals. Ore minerals include arsenopyrite, pyrite, chalcopyrite, and pyrrhotite. Locally contains pyrrhotite-arsenopyrite-actinolite-calcite veins that cross-cut and subparallel foliation. Unit is rarely carbonaceous; a portion of the calcareous material may originally have had a sedimentary, instead of a mafic igneous, protolith. Magnetic susceptibility is moderate to high (0.0-5.92, averaging 0.63 x 10exp-3 SI), primarily reflecting the pyrrhotite content. Major- and minor-oxide and trace-element analyses indicate the metabasite is alkalic and formed in a within-plate, extensional tectonic setting (fig. 7). Equivalent to the "Eva Creek phyllite" (Freeman and others, 1987) and possibly the chloritic schist of the Moose Creek Member of the Totatlanika Schist (Wahrhaftig, 1968). In the map area, the longest, continuous metabasite body is 2.5 km and the thickest is at least 300 m. Spatially associated and interfoliated with units Dgq, Dq, Dr, and Dg such that the group forms a laterally extensive E-W subunit, suggesting stratigraphic significance. This grouping is essentially the Liberty Bell Mine sequence (Freeman and others, 1987). Metabasite is found within these units and unit Daw, and is the mafic portion of the bimodal suite of alkalic, igneous rocks. Where spatial extent is unknown, locations are marked with a symbol (see "Map Symbols," sheet RI 2006-2). Age is based on a trace-element-indicated tectonic setting similar to, and spatial association with, units Dg and Dr.

Daw ARKOSIC METAWACKE (Devonian): Fine- to medium-grained with minor very fine- and coarse-grained, metamorphosed arkosic wacke and lesser feldspathic wacke. Also contains rare metamorphosed quartz wacke and fine-grained quartzite. Forms light green, gray, and white colored, commonly iron-stained, well-foliated and schistose outcrops; less commonly forms massive outcrops. Modal composition is 5-85 percent feldspar porphyroclasts (average 32 percent; average 2.2 mm in diameter), <80 percent clear, white, and smoky quartz porphyroclasts (average 17 percent; average 2 mm in diameter), and <5 percent lithics in very fine-grained (<0.02 mm) sericite +/- chlorite +/- biotite + quartz + feldspar matrix. Matrix is interpreted to be recrystallized mud. Accessory minerals include zircon, apatite, sphene, opaque minerals, and monazite. Metamorphosed lithic fragments include carbonaceous slate (mud rip-up clasts?), polycrystalline quartz, chert, quartz-feldspar amalgams, and rare scheelite and garnet. Exhibits crystal sorting (bedding?). Although a large percentage of the porphyroclasts are rounded, shattered, and (or) sheared along foliation, occasional euhedral to sub-euhedral porphyroclasts, quartz embayments, and a homogeneous quartz + feldspar clast composition suggest the sediments are derived from felsic igneous rocks. Typically has Y + Nb < 50 ppm (fig. 6) and TiO_2 >0.3 ppm. Locally contains disseminated arsenopyrite and pyrite, scorodite and stibiconite staining, and quartz +/- tourmaline veins up to 5 cm thick. Magnetic susceptibility is low (0.0-0.92, averaging 0.10 x 10exp-3 SI); higher values are from hornfelsed samples. Except for the megacrystic variety of Dg, interfoliated units Db, Dg, Dq, Dr, Dar, and Dgq decrease in abundance to the north toward the topographic top of the unit. Unit is at least 900 m thick in Last Chance Creek, located 18 km southeast of the map area (Wahrhaftig, 1968). Equivalent to the "Lower tuffite sequence" in the Liberty Bell Mine sequence (Freeman and others, 1987) and quartz-orthoclase-sericite schist from the California Creek Member of the Totatlanika Schist (Wahrhaftig, 1970c). Age is assumed to be Devonian; unit is intruded by Devonian-aged meta-igneous units Dg and Dr and stratigraphically(?) overlain by the Devonian Chute Creek Member of the Totatlanika Schist (fig. 5; Dusel-Bacon and others, 2004).

Dq QUARTZITE AND METAPELITE (Devonian): Very fine- to fine-grained, sucrosic quartzite and metapelite. Orange-weathered, white-colored outcrops are either platy-breaking or hard and massive depending on the mica content of the rock. Modal composition is 50-97 percent quartz (grains up to 0.1 mm in diameter), 3-50 percent white mica, 5(?) percent feldspar, and 2 percent calcite. Commonly contains <2 percent disseminated pyrrhotite, <5 percent pyrite, and lesser tourmaline, arsenopyrite, and phlogopite/biotite in wispy bands and laminations. This unit only appears in the hornfelsed zone. Magnetic susceptibility is moderate to high (0.0-4.0, averaging 0.45 x 10exp-3 SI), and variable due to the amount of unoxidized pyrrhotite in the rock. In Little Moose Creek, unit is at least 350 m thick. Equivalent to the "Hangingwall slatey phyllite" in the Liberty Bell Mine sequence (Freeman and others, 1987) and slate within the California Creek and Moose Creek(?) members of the Totatlanika Schist (Wahrhaftig, 1968). Quartzite and metapelite is found interfoliated with units Dgq, Daw, Dr, Dg, and Db. Age is based on spatial association with these Devonian units.

Dgq GRAPHITIC QUARTZITE (Devonian): Very fine- to fine-grained, sucrosic, foliated graphitic quartzite. Gray- to black-colored outcrops are fissile to blocky-breaking. Composition is <90 percent quartz, <36 percent white mica, <10 percent graphite, with accessory apatite, zircon, and opaque minerals. Graphite occurs disseminated throughout rock, in lenses, sooty partings, and rare nodules. Locally hornfelsed and bleached to light gray and white, and commonly iron-oxide stained. Hornfels contains up to 30 percent pyrrhotite and occasionally quartz-tourmaline-biotite/phlogopite veins. Intense mineralization is expressed as brecciated quartz veins with iron oxide, scorodite, and arsenopyrite cement. Magnetic susceptibility is generally low (0.0-1.0, averaging 0.1 x 10exp-3 SI); hornfelsed samples containing pyrrhotite have magnetic susceptibilities up to 2.53 x 10exp-3 SI. In the map area, unit ranges from 3-m-thick lenses to approximately 700-m-thick sections, and decreases in thickness topographically (and stratigraphically?) up-section. Unit found interfoliated with all of the Devonian units in the map area, and age of unit is also assumed to be Devonian. Equivalent to "Graphitic (Footwall) phyllite" of the mine sequence (Freeman and others, 1987) and graphitic quartzite and schist in the California Creek and Moose Creek Members of the Totatlanika Schist and the Keevy Peak Formation (Wahrhaftig, 1968).

Dqw QUARTZ METAWACKE AND META-ARENITE (Devonian): Very fine- to medium-grained, rarely coarse-grained, metamorphosed quartz wacke and arenite, and minor feldspathic wacke. Light gray and light gray-green colored, hard and massive to platy-breaking, and foliated in outcrop. Modal composition is 14-80 percent quartz porphyroclasts (mono- and polycrystalline), 0-25 percent feldspar porphyroclasts (varying amounts of K-feldspar and plagioclase/albite), 0-10 percent chert or chalcedony grains, and a matrix of 5-50 percent white mica, 0-25 percent chlorite, and 20-35 percent very fine-grained quartz (<0.02 mm). Accessory minerals include tourmaline, rutile, ilmenite, graphite, pyrite, and zircon. Subangular to rounded, 0.2-3.0 mm grains are common. Magnetic susceptibility is low (0.0-0.5, averaging 0.09 x 10exp-3 SI). In the map area, unit is at least ~600 m thick. Topographically underlies California Creek Member and units Dg and Dr, mapped as the Moose Creek Member of the Totatlanika Schist (Wahrhaftig, 1970c). Equivalent to "arkosic gritlike schist" of Keevy Peak Formation (Wahrhaftig, 1970c). Age is presumed to be Devonian; unit is intruded by meta-igneous unit Dr, stratigraphically(?) overlain by unit Daw, and stratigraphically(?) underlain by Devonian(?) Healy Schist (Birch Creek Schist of former usage; Wahrhaftig, 1968; Newberry and others, 1997; Dusel-Bacon and others, 2004) (fig. 5).

REFERENCES CITED

Albanese, M.D., and Turner, D.L., 1980, 40K-40Ar ages from rhyolite of Sugar Loaf Mountain, central Alaska Range: Implications for offset along the Hines Creek strand of the Denali Fault system, in DGGS Staff, Short Notes on Alaskan Geology, 1979-1980: Alaska Division of Geological & Geophysical Surveys Geologic Report 63B, p. 7-10.

Athey, J.E., Werdon, M.B., Newberry, R.J., Szumigala, D.J., Freeman, L.K., and Lessard, R.R., 2005, Major-oxide, minor-oxide, and trace-element geochemical data from rocks collected in the Liberty Bell area, Fairbanks A-4 Quadrangle, Alaska in 2005: Alaska Division of Geological & Geophysical Surveys Raw Data File 2005-5, 29 p.

Bemis, S.P., 2004, Neotectonic framework of the north-central Alaska Range foothills: Fairbanks, University of Alaska, Master of Science thesis, 142 p.

Bidwell, Gerry, 1994, 1994 Exploration Program, Liberty Bell Property, Bonnifield Mining District, Fairbanks A-4 Quadrangle, T10S R6-7W, Alaska, USA: Noranda Exploration Company, 17 p., appendices I-III.

Buffler, R.T., and Triplehorn, D.M., 1976, Depositional environments of the Tertiary coal-bearing group, central Alaska, in Miller, T.P., ed., Recent and ancient sedimentary environments in Alaska, Proceedings of Symposium, April 2-4, Anchorage: Anchorage, Alaska Geological Society, p. H1-H10.

Bundtzen, T.K., 1986, Prospect examination of a gold-tungsten placer deposit at Alder Creek, Vinasale Mountain area, western Alaska: Alaska Division of Geological & Geophysical Surveys Public Data File 86-15, 10 p.

Burns, L.E., Fugro Airborne Surveys, and Stevens Exploration Management Corp., 2002, Plot files of the airborne geophysical survey data of the Liberty Bell area, western Bonnifield mining district, central Alaska: Alaska Division of Geological & Geophysical Surveys, Geophysical Report (GPR) 2002-06, 1 CD-ROM.

Capps, S.R., 1912, The Bonnifield region, Alaska: U.S. Geological Survey Bulletin 501, 64 p.

Davis, J.C., 1986, Statistics and data analysis in geology, 2nd ed.: John Wiley and Sons, Inc., 646 p.

Decker, J.E., 1985, Sandstone model analysis procedure: Alaska Division of Geological & Geophysical Surveys Public Data File 85-3, 38 p.

DGGS, 1994, Unpublished geologic mapping of Liberty Bell Mine area (Reifenstuhl, R.R., Werdon, M.B., and Wiltse, M.A.).

Dickinson, W.R., Beard, L.S., Brakenridge, G.R., Erjavec, J.L., Ferguson, R.C., Inman, K.F., Knepp, R.A., Lindberg, F.A., and Ryberg, P.T., 1983, Provenance of North American Phanerozoic sandstones in relation to tectonic setting: Geological Society of America Bulletin, v. 94, no. 2, p. 222-235.

Dusel-Bacon, Cynthia, Wooden, J.L., and Hopkins, M.J., 2004, U-Pb zircon and geochemical evidence for bimodal mid-Paleozoic magmatism and syngenetic base-metal mineralization in the Yukon-Tanana terrane, Alaska: Geological Society of America Bulletin, v. 116, no. 7, p. 989-1,015.

Ellis, William, Hawley, C.C., and Dashevsky, Samuel, 2004, Alaska Resource Data File, Mount Hayes Quadrangle, Alaska: U.S. Geological Survey Open-File Report 2004-1266.

Freeman, C.J., and Schaefer, Janet, 2001, Alaska Resource Data File, Fairbanks Quadrangle: U.S. Geological Survey Open-File Report 01-0426, 355 p.

Freeman, L.K., Hanneman, N.L., and Flanders, R.W., 1987, Liberty Bell Joint Venture Report of 1987 Exploration: Resource Associates of Alaska, Inc., v. I, II, and IV.

Galey, J.T., Jr., Hahn, Raimundo, and Duncan, W.M., 1993, 1991 Exploration Program, Liberty Bell Project, Bonnifield mining district, Nenana recording district, Alaska: AMAX Gold , Inc., 39 p., appendices A-E.

Gilbert, W.G., and Bundtzen, T.K., 1979, Mid-Paleozoic tectonics, volcanism, and mineralization in the north-central Alaska Range: Geological Society of Alaska Symposium 1977, p. F1-F22.

Ingersoll, R.V., Bullard, T.F., Ford, R.L., Grimm, J.P., Pickle, J.D., and Sares, S.W., 1984, The effect of grain size on detrital modes: A test of the Gazzi-Dickinson point-counting method: Journal of Sedimentary Petrology, v. 54, p. 103-116.

Irvine, T.N., and Baragar, W.R.A., 1971, A guide to the chemical classification of the common volcanic rocks: Canadian Journal of Earth Sciences, v. 8, p. 523-548.

Lanphere, M.A., and Dalrymple, G.B., 2000, First-principles calibration of 38Ar tracers: Implications for the ages of 40Ar/39Ar fluence monitors: U.S. Geological Survey Professional Paper 1621, 10 p.

Layer, P.W., 2000, 40Argon/39Argon age of the El-gygytgyn impact event, Chukotka, Russia: Meteoritics and Planetary Science, v. 35, p. 591-599.

Layer, P.W., Hall, C.M., and York, Derek, 1987, The derivation of 40Ar/39Ar age spectra of single grains of hornblende and biotite by laser step heating: Geophysical Research Letters, v. 14, p. 757-760.

Leopold, E.B., and Liu, Gengwu, 1994, A long pollen sequence of Neogene age, Alaska Range: Quaternary International, v. 22/23, p. 103-140.

McCoy, D., Newberry, R.J., Layer, P.W., DiMarchi, J.J., Bakke, A., Masterman, J.S., and Minehanne, D.L., 1997, Plutonic-related gold deposits of Interior Alaska, in Goldfarb, R.J., and Miller, L.D., eds., Mineral deposits of Alaska: Economic Geology Monograph 9, p. 191-241.

McDougall, Ian and Harrison, T.M., 1999, Geochronology and Thermochronology by the 40Ar/39Ar method, 2nd ed., Oxford University Press: New York, 269 p.

Meschede, Martin, 1986, A method of discriminating between different types of mid-ocean ridge basalts and continental tholeiites with the Nb-Zr-Y diagram: Chemical Geology, v. 56, p. 207-218.

Newberry, R.J., Crafford, T.C., Newkirk, S.R., Young, L.E., Nelson, S.W., and Duke, N.A., 1997, Volcanogenic massive sulfide deposits of Alaska: Economic Geology Monograph 9, p. 120-150.

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.

Pettijohn, F.J., Potter, P.E., and Siever, Raymond, 1987, Sand and sandstone, 2nd ed.: New York, Springer-Verlag, 553 p.

Plafker, George, Naeser, C.W., Zimmermann, R.A., Lull, J.S., and Hudson, Travis, 1992, Cenozoic uplift history of the Mount McKinley area in the central Alaska Range based on fission-track dating: U.S. Geological Survey Bulletin 2041, p. 202-212.

Puchner, C.C., and Freeman, L.K., 1988, Summary of Liberty Bell area prospects and recommendations for future exploration: NERCO Exploration Company internal correspondence.

Ridgway, K.D., Trop, J.M., and Jones, D.E., 1999, Petrology and provenance of the Neogene Usibelli Group and Nenana Gravel: Implications for the denudation history of the central Alaska Range: Journal of Sedimentary Research, v. 69, no. 6, p. 1,262-1,275.

Ridgway, K.D., Trop, J.M., Nokleberg, W.J., Davidson, C.M., and Eastham, K.R., 2002, Mesozoic and Cenozoic tectonics of the eastern and central Alaska Range: Progressive basin development and deformation in a suture zone: Geological Society of America Bulletin, v. 114, no. 12, p. 1480-1504.

Samson, S.D., and Alexander, E.C., 1987, Calibration of the interlaboratory 40Ar/39Ar dating standard, MMhb1: Chemical Geology, v. 66, p. 27-34.

Stanley, R.G., Flores, R.M., and Wiley, T.J., 1992, Fluvial facies architecture in the Tertiary Usibelli Group of Suntrana, central Alaska, in Bradley, D.C., and Ford, A.B., eds., Geologic studies in Alaska by the U.S. Geological Survey, 1990: U.S. Geological Survey Bulletin 1999, p. 204-211.

Steiger, R.H., and Jaeger, Emilie, 1977, Subcommission on geochronology: Convention on the use of decay constants in geo and cosmochronology: Earth and Planet Science Letters, v. 36, p. 359-362.

Szumigala, D.J., and Hughes, R.A., 2005, Alaska's Mineral Industry 2004: Alaska Division of Geological & Geophysical Surveys, Special Report 59, 75 p.

Thoms, E.E., 2000, Late Cenozoic unroofing sequence and foreland basin development of the central Alaska Range: Implications from the Nenana Gravel: Fairbanks, University of Alaska, Master of Science thesis, 215 p.

Triplehorn, D.M., 1976, Clay mineralogy and petrology of the coal-bearing group near Healy: Alaska Division of Geological & Geophysical Surveys Geologic Report 52, 14 p.

Van Der Plas, L., and Tobi, A.C., 1965, A chart for judging the reliability of point counting results: American Journal of Science, v. 263, p. 87-90.

Wahrhaftig, Clyde, 1968, Schists of the central Alaska Range: U.S. Geological Survey Bulletin 1254-E, 22 p.

Wahrhaftig, Clyde, 1970a, Geologic map of the Fairbanks A-2 quadrangle, Alaska: U.S. Geological Survey Geologic Quadrangle Map GQ-808, 1 sheet, scale 1:63,360.

Wahrhaftig, Clyde, 1970b, Geologic map of the Fairbanks A-3 quadrangle, Alaska: U.S. Geological Survey Geologic Quadrangle Map GQ-809, 1 sheet, scale 1:63,360.

Wahrhaftig, Clyde, 1970c, Geologic Map of the Fairbanks A-4 quadrangle, Alaska: U.S. Geological Survey Geologic Quadrangle Map GQ-810, 1 sheet, scale 1:63,360.

Wahrhaftig, Clyde, 1970d, Geologic map of the Healy D-2 quadrangle, Alaska: U.S. Geological Survey Geologic Quadrangle Map GQ-804, 1 sheet, scale 1:63,360.

Wahrhaftig, Clyde, 1970e, Geologic map of the Healy D-3 quadrangle, Alaska: U.S. Geological Survey Geologic Quadrangle Map GQ-805, 1 sheet, scale 1:63,360.

Wahrhaftig, Clyde, 1970f, Geologic Map of the Healy D-4 quadrangle, Alaska: U.S. Geological Survey Geologic Quadrangle Map GQ-806, 1 sheet, scale 1:63,360.

Wahrhaftig, Clyde, 1987, The Cenozoic section at Suntrana Creek, in Hill, M.L., ed., Geological Society of America, Cordilleran Section, Centennial Field Guide, v. 1, p. 445-450.

Wahrhaftig, Clyde, Wolfe, J.A., Leopold, E.B., and Lanphere, M.A., 1969, The coal-bearing group in the Nenana Coal Field, Alaska: U.S. Geological Survey Bulletin 1274-D, p. D1-D30.

Williams, Howel, Turner, F.J., and Gilbert, C.M., 1982, Petrography, an introduction to rocks in thin section, 2nd ed.: San Francisco, CA, W.H. Freeman and Company, 626 p.

Wolfe, J.A., and Tanai, Toshimasa, 1980, The Miocene Seldovia Point flora from the Kenai Group, Alaska: U.S. Geological Survey Professional Paper 1105, 52-p.

Wolfe, J.A., and Tanai, Toshimasa, 1987, Systematics, phylogeny, and distribution of Acer (Maples) in
the Cenozoic of western North America: Hokkaido University Faculty of Science Journal, ser. 4, v. 22, p. 1-246.

Wood, G.H., Kehn, T.M., Carter, M.D., and Culbertson, W.C., 1983, Coal resource classification system of the U.S. Geological Survey: U.S. Geological Survey Circular 891, 65 p.

Yesilyurt, Suleyman, 1994, Geology, geochemistry, and mineralization of the Liberty Bell gold mine area, Alaska: Oregon State University, unpublished Master of Science thesis, 189 p., 1 plate.

Yesilyurt, Suleyman, 1996, Geology, geochemistry, and mineralization of the Liberty Bell gold mine area, Alaska, in Coyner, A.R., and Fahey, P.L., eds., Geology and Ore Deposits of the American Cordillera: Symposium Proceedings, Reno/Sparks, Nevada, April 1995, p. 1,281-1,316.

York, Derek, Hall, C.M., Yanase, Yotaro, Hanes, J.A., and Kenyon, W.J., 1981, 40Ar/39Ar dating of terrestrial minerals with a continuous laser: Geophysical Research Letters, v. 8, p. 1,136-1,138.