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PRELIMINARY GEOLOGIC MAP OF THE FAIRBANKS MINING DISTRICT, ALASKA

by

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with contributions by
K.H. Clautice, R.A. Combellick, T. Douglas, G.M. Laird, S.A. Liss,
D.S. Pinney, R.R. Reifenstuhl, and D.N. Solie

In cooperation with Department of Geology and Geophysics
University of Alaska Fairbanks

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PRELIMINARY GEOLOGIC MAP OF THE FAIRBANKS MINING DISTRICT, ALASKA

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INTRODUCTION

Geologic mapping in the Fairbanks mining district was undertaken in 1995 and 1996 as part of the Alaska Division of Geological & Geophysical Surveys (DGGS) airborne geophysical/geological mapping program and was partially supported by a federal grant awarded to DGGS as part of the National Geologic Mapping Act - State Map program administered by the U.S. Geological Survey. The purpose of the effort was to produce an updated surficial and bedrock geologic map at 1:63,360 scale that depicts construction material availability, geologic hazards, mineral potential, and new geologic information. The Fairbanks Mining district was mapped by DGGS nearly 15 years ago by Metz (1982), Robinson (1982), and Bundtzen (1982) at the request of the Fairbanks North Star Borough. A final map product was eventually published (Robinson and others, 1990). This earlier work did not include surficial geologic coverage. Additionally, due to extensive cover, the bedrock geology was based on only a few percent rock exposure, and significant geologic questions remained unresolved.

This study has benefited from the availability of state-of-the-art laboratory facilities at the University of Alaska-Fairbanks including Ar-Ar isotopic age dating techniques, determination of temperature and pressure metamorphic conditions through microprobe analyses of metamorphic minerals, and trace element analyses of igneous and metamorphic rocks. Detailed petrographic studies were performed by staff. Dr. James Mortenson fom the University of British Columbia provided two U-Pb zircon ages. In addition, the study area was recently surveyed with modern airborne geophysical methods (Dighem Surveying and Processing, 1995), which provides important new subsurface information that has been used to resolve previous geologic problems.

Hence this updated geologic map is built on the work of Robinson and others (1990), as well as the efforts of Metz (1991), Forbes (1982), Forbes and Weber (1982), Péwé, and others (1961, 1976a, 1976b, 1976c, 1976d, 1976e), Williams and others, (1959), Mertie (1937), and Prindle and Katz (1913).

GEOLOGIC SETTING

Bedrock Geology

The Fairbanks mining district is located in the western portion of the Yukon-Tanana Terrane, a displaced portion of the North American continental margin. The Yukon-Tanana Terrane consists of polydeformed and polymetamorphosed Upper Paleozoic and older metasedimentary, metavolcanic, and metaplutonic rocks that crop out from southeastern Alaska and western Canada to western Alaska, a distance of over 2,000 kilometers.

In Alaska, these rocks were once collectively referred to as the Birch Creek Schist, after exposures on Birch Creek in the Circle mining district northeast of Fairbanks (Mertie, 1937). We have recognized and mapped four, structurally juxtaposed, metamorphic sequences in the study area. From oldest to youngest, they are: (1) the amphibolite facies metasedimentary and metavolcanic rocks of the Proterozoic Fairbanks Schist; (2) the Ordovician(?) to upper Devonian low grade metamorphic phyllites of the Birch Hill Sequence; (3) the amphibolite facies metavolcanic and metasedimentary rocks of the Muskox Sequence, which contains Upper Devonian U-Pb zircon ages; and (4) the eclogite facies Chatanika Terrane, which contains protoliths of Devonian-Mississippian age. In addition, Mississippian granodiorite gneiss intrudes the Proterozoic Fairbanks Schist (table 1).

The structurally highest Chatanika Terrane contains calcareous sediment-dominated rocks metamorphosed to the eclogite facies. Microprobe analyses of garnets, micas, and pyroxenes indicate a non-skarn origin and metamorphic conditions of approximately 600° C and 14 kilobars of pressure (Brown and

TABLE 1: PROVISIONAL CORRELATION DIAGRAM FOR REGIONALLY METAMORPHOSED ROCKS OF THE YUKON-TANANA TERRANE, EASTERN INTERIOR ALASKA

Alaska Range-Healy	Alaska Range-Tok	Kantishna Hills	Fairbanks District	Upper Chena River area	INFERRED AGE
(Wahrhaftig, 1968; Gilbert & Bundtzen, 1979)	(Nokleberg et al., 1992; Lange et al., 1993)	(Bundtzen, 1981; Cooper, 1995)	(Forbes and Weber, 1982; Robinson et al., 1990; Weber et al., 1992; this study)	(Smith et al., 1994)	
Totatlanika Schist Missipian fossils VMS prospects	not presently recognized	**Totatlanika Schist** U-Pb (zircon) 338 Ma metarhyolite; (R. Tosdal, writt. writt. comm., 1994)	not presently recognized	**Totatlanika Schist** overlies Late Devonian rocks	**lower Mississippian**
not presently recognized	**Jarvis Creek Terrane** 364-372 Ma (U-Pb, zircon) metarhyolite; lower Amphibolite facies VMS deposits	**Spruce Creek Sequence** 367-369 Ma (U-Pb, J. Aleinikoff, writ. comm., 1993): lower Amphibolite facies VMS prospects	**Muskox Sequence** 369 Ma (U-Pb; Aleinikoff & Nokleberg, 1989); lower Amphibolite facies	**Blackshell Unit** 356 Ma (U-Pb) Greenschist or Amphibolite facies VMS prospects	**upper Devonian**
Keavy Peak Formation Middle Devonian fossils; Greenschist facies	**Macomb Terrane** Middle Devonian or older; Greenschist facies	**Keavy Peak Formation** Greenschist facies	**Birch Hill Sequence** Greenschist facies	**Dan Creek Unit** Greenschist facies	**Middle to Upper Devonian**
Healy or Mt Lathrop Schist pre-Devonian (underlies Keavy Peak Formation); Amphibolite and Greenschist facies	**Lake George Terrane** Amphibolite facies; intruded by 360 Ma granodiorite; contains Proterozoic detrital zircons	**Birch Creek Schist** Amphibolite facies; (500° C, 5kb); intruded by 370 Ma granodiorite (R. Tosdal, writ. comm, 1991); contains Proterozoic detrital zircons	**Fairbanks Schist** Amphibolite facies; (500° C, 5kb); intruded by 350 Ma granodiorite (J. Mortensen writ. comm., 1996); contains Proterozoic detrital zircons	**Chena River Sequence** Amphibolite facies; intruded by 340 Ma and 671 Ma granitic bodies	**Proterozoic**

Forbes, 1984; this study). K-Ar and Ar-Ar ages are up to 475 Ma for high P/T metamorphism and 130-to-110 Ma for retrograde metamorphism (Forbes, 1982; sheet 2, table 2).

Structurally below the Chatanika Terrane is the heterogeneous assemblege of the Fairbanks Schist, which underlie nearly 75 percent of the study area. Robinson and others (1990) included in the original Fairbanks Schist a package of bimodal metavolcanic and metasedimentary rocks that was named the Cleary Sequence. We do not recognize the Cleary Sequence as originally defined and do not depict it on the geologic map. Minor metarhyolite and intermediate metavolcanic rock mapped during this study as the Muskox Sequence were included in the Cleary Sequence by Robinson and others (1990). The Fairbanks Schist as defined here includes rocks of the Chena River Sequence (Robinson and others, 1990). Microprobe and major oxide compositions indicate that that both rock units underwent identical P/T metamorphic conditions and are chemically indistinquishable (fig. 1; table 3). Hence we have included the Chena River Sequence with the Fairbanks Schist. Amphibolites in the Fairbanks Schist yield K-Ar and Ar-Ar prograde metamorphic ages of up to 250 Ma, and evidence of a retrograde greenschist facies event at 110-to-120 Ma. We believe the protoliths of the Fairbanks Schist are Proterozoic in age because: (1) a 671 Ma orthogneiss intrudes rocks equivalent to the Chena River Sequence east of the study area (Smith and others, 1994); (2) early to mid-Proterozoic detrital zircons typically found in Proterozoic metasediments of the North American miogeocline are found in quartz-rich metasediments of the Fairbanks Schist (Aleinikoff and others, 1981, 1989); and (3) many metasedimentary rocks of the Fairbanks Schist are similar to Middle to Late Proterozoic Sequences described immediately north of the Fairbanks district (Weber and others, 1992).

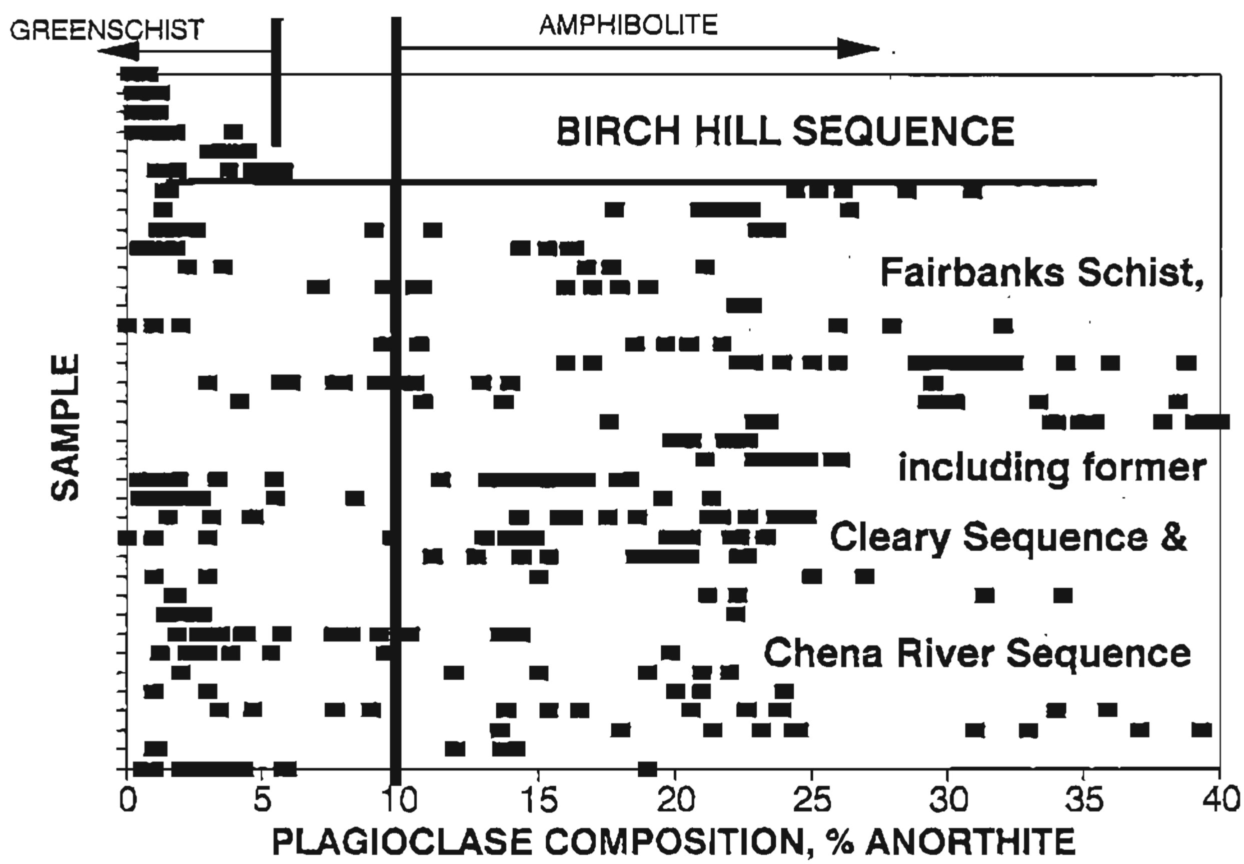

Figure 1. *Microprobe plagioclase compositions, Fairbanks mining district.*

TABLE 3: NEW CALCULATED PRESSURE-TEMPERATURE DATA FOR METAMORPHIC ROCKS OF THE FAIRBANKS MINING DISTRICT

gar-hbl-plag				gar-bio-plag-musc			garnet-pyroxene			sphl-po-pyrite		
Sample no.		T (°C)	P (kb)	Sample no.	P (kb)	T (°C)	Sample no.	P (kb)	T (°C)	Sample no.	P (kb)	T (°C)
		FARIBANKS SCHIST										
PM5	h2-g2	480	4.3	81PM5	4.3	524						
PM5	h1-g1	494	4.6									
KC124	h3-g3	479	4.0									
KC124	h2-g2	492	4.4									
KC100	h1-g1	452	4.1									
DNS12	h2-g2	520	4.3									
DNS12	h1-g1	485	4.6									
BT36	g2-h2	485	4.0									
BT36	g3-h3	494	4.1									
BT36	g1-h1	501	4.2									
BT73E	g1-h1	446	3.5									
BT73E	g2-h2	464	4.6									
BT73E	g3-h3	468	4.1									
				KC51	3.9	484						
				RN206	3.7	451						
				RN206	4.2	515						
		retrograde		RN352	2.9	356						
		prograde		RN352	4.1	501						
				RN204	3.8	514						
				RN204	4.3	534						
				FM10	3.7	511						
		ECLOGITE-BEARING SEQUENCE (Chatanika Terrane)										
				KC64	>11	583	KC64	13	580			
				RN400	11.8	643						
				RN400	11.7	645						
				RN347	11.6	590						
							MH80	14	590			
							CC-E	12	620			
							BF2	15	600			
							BF3	15	600			
							BF4	15	600			
							AWr108	13.5	600			
										81MIRL4	>11	620

g, gar=garnet; h, hbl=hornblende; bio= biotite; plag= plagioclase; musc= muscovite; sphl=sphalerite; po= pyrrhotite.
Data and computational techniques given in Joy and others (1996).

Distinctive metarhyolite and intermediate metavolcanic rocks of the Muskox Sequence occur as structural klippen over the Fairbanks Schist in the southern part of the map area (fig. 2). The metarhyolites yielded U-Pb primary igneous zircon ages of Upper Devonian age (Aleinikoff and Nokleberg, 1989), which dates volcanic activity in the Yukon-Tanana Terrane.

The structurally lowest metamorphic rocks are the phyllite, quartzite, slate and calcareous schists of the Birch Hill Sequence. These have been complexly isoclinally folded, exhibit cleaveges not seen in other higher metamorphic rank rocks, and yield Ar-Ar ages of 105-to-115 Ma. The Birch Hill Sequence is similar to the Devonian Keevy Peak Formation in the Central Alaska Range (Wahrhaftig, 1968; Gilbert and Bundtzen, 1979).

Granitic rocks underlie Gilmore, Pedro, and Ester Domes and other elevated upland areas throughout the study area. Isotopic ages indicate that these non-metamorphosed plutonic rocks intruded in two pulses: a quartz-poor intrusive event at 110 Ma; and a quartz-rich intrusive event at 88-to-94 Ma (fig. 3). Isotopic and trace element data indicates that the quartz-rich plutonic suite are fractionated products derived from a common magmatic source.

Tholeiitic basalts, with Ar-Ar ages of 50-55 Ma, erupted onto the landscape in both subaerial and subaqueous (lacustrine) environments. Sediments from ancestral river systems also of early Tertiary age are preserved on Fourth of July Hill in the Fairbanks Creek drainage. The river system eroded a terrane distal from the study area, as no clasts of local derivation have been recognized, evidently implying that the presently exposed rock lithologies were buried. Basalt and associated sedimentary rocks are now preserved in structural troughs in the northeastern and southeastern portions of the study area.

Surficial Geology

The study area has never been glaciated. The accordant rounded ridges have been blanketed with eolian loess, which in turn has been recycled into thick slopewash and alluvial aprons. The broad valleys are filled with thick alluvial deposits, which are frequently overlain by silt and peat deposits. The area is in a zone of discontinuous permafrost, where many geotechnical hazards have been encountered during road and building construction projects in and near Fairbanks (Péwé, 1982). Frost heave and thermokarst settling continue to be serious problems for roads and improperly built structures.

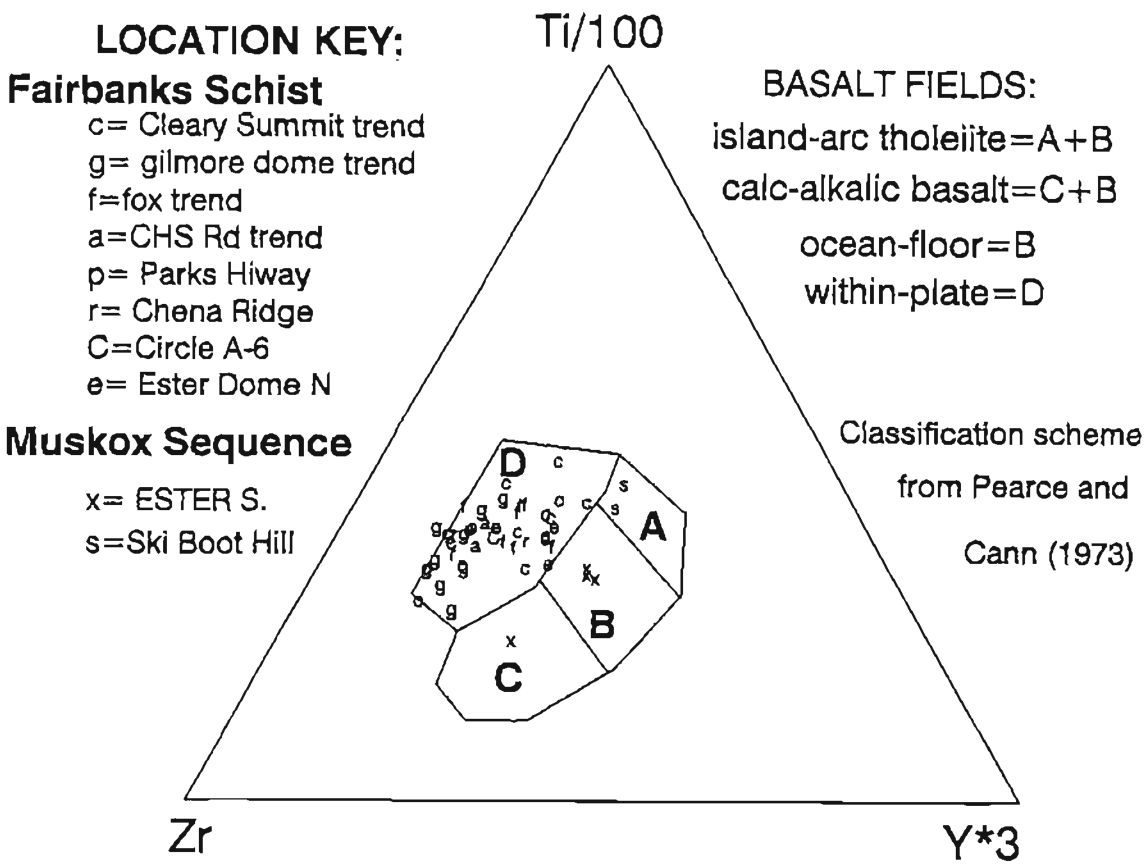

Figure 2. *Tectonic classification of amphibolites, Fairbanks mining district.*

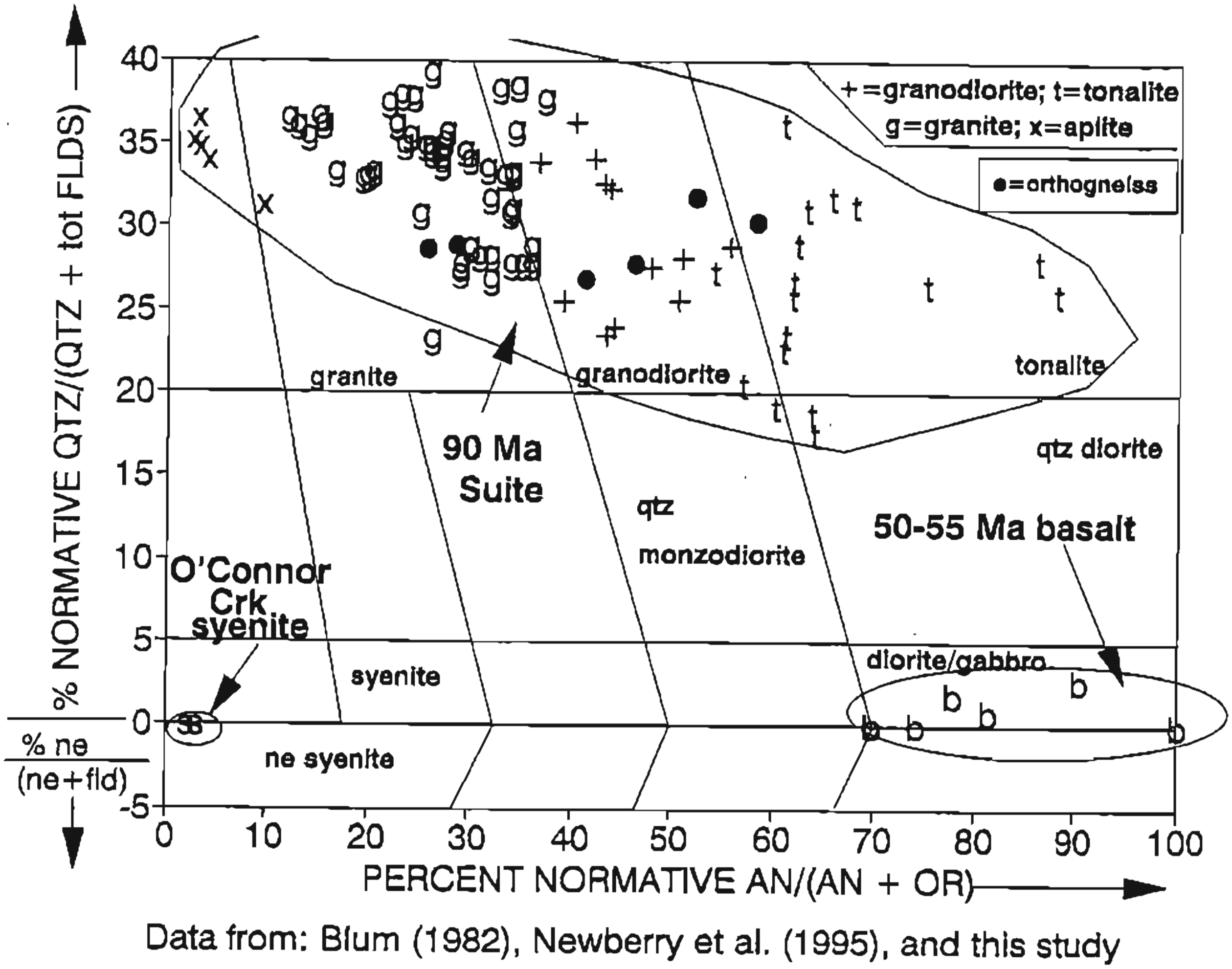

Figure 3. *Normative compositions of igneous rocks after Streckheisen and LaMaitre (1979), Fairbanks mining district.*

Structural Geology and Earthquake Potential

The study area has been deformed by northwest verging, isoclinal folds, and later by northeast verging open to soclinal folds with amplitudes ranging from meters to 15 kilometers (Hall, 1985). Folds with north-vergent axial planes and northeast trending axes transect the older northwest verging fold episode at about a 60° angle. The earlier and later isoclinal fold episodes are believed to correlate with two or more episodes of regional dynamothermal metamorphism recognized in the metamorphic rock sequences.

Seismic studies (Page and others, 1995) and detailed airborne geophysical maps (Dighem Surveys and Processing, 1995) indicate NE-trending, high angle faults pervasively cut the bedrock units of the study area. We have mapped many of these faults, all with dips of 60° northwest to 60° southeast, and with slickensides that plunge from 20 to 50°. Apparant horizontal displacements of several kilometers to several meters are typical, and we infer vertical displacements of up to one kilometer. Faults juxtaposing Tertiary basalt against phyllite of the Birch Hill Sequence are well exposed, and clearly indicate left-lateral normal movement.

We interpret stair-stepped contacts in the Pedro Dome and Gilmore Dome plutons as the result of normal fault offsets, and interpret similar stair-stepped contacts between the Chatanika Terrane and Fairbanks Schist as normal fault offsets.

Other high angle faults are manifested in zones of mass slumping along the Steese Highway, and as terminations or offsets of WNW-trending veins in the Cleary Hill area and elsewhere.

Major fault blocks, 3-to-5 km wide and up to 30 km long, have consistent vertical offsets as indicated by the systematic presence of Tertiary basalt and/or Chatanika Terrane in down-dropped blocks versus major exposures of granitic rocks and other metamorphic units in uplifted blocks.

West-northwest oriented faults, veins and shears are also common throughout the study area, but typically show little or no offset of the northeast high angle structures. There are probably many more west-northwest trending faults than are presently shown on the geologic map—especially in the eastern portion of the map area. Ar-Ar dating of some northeasterly shears indicate ages as old as 90 Ma; recent seismicity suggests Holocene movement as well.

Numerous moderate magnitude earthquakes have occurred in Interior Alaska, including a magnitude 7.3 earthquake 45 km southeast of Fairbanks in 1937 (Bramhill, 1938), and a magnitude 6.0 earthquake 15 km east of Fairbanks in 1967 (Gedney and Berg, 1967). The latter earthquake was previously believed to be related to a line of epicenters defining the 'Badger Road fault,' which was not reproduced by recent studies (Page and others, 1995).

ECONOMIC GEOLOGY

From 1902 to 1995, the Fairbanks mining district has produced 8,022,434 ounces (249.4 tonnes) of placer gold and 304,548 ounces (9.5 tonnes) of lode gold, equal to 26 percent of all the gold mined in Alaska (Bundtzen, 1996). The principal metallic mineral deposits occur as epigenetic veins, stockworks, and vein breccias hosted in both metamorphic and intrusive rocks, and as sulfide and scheelite-bearing skarns. Prior to 1985 up to 100 individual sulfide-quartz veins in the Ester Dome, Pedro Dome, Gilmore Dome and Cleary Hill areas were mined for gold, silver, and antimony (Chapman and Foster, 1969; Metz, 1991). Skarn deposits adjacent to the Gilmore Dome pluton were mined for tungsten and gold during World War Two, the Korean War and in the early 1980s (Byers, 1957; Allegro, 1987).

Currently the giant Fort Knox gold-bismuth porphyry deposit (Bakke, 1995), which contains about 4.1 million ounces (129 tonnes) gold, is being developed as Alaska's largest gold mine. Other mineralized areas such as the Ryan Lode, True North, and Cleary Hill gold-polymetallic deposits, show promise of future mineral production.

K-Ar and Ar-Ar dating of of vein, shear zone, breccia, stockwork, pegmatite, and skarn mineralization in the Fairbanks district indicates consistant 88-90 Ma ages and an early Tertiary resetting episode. Given the modest exposures of Tertiary basalt in the district and the widespread thermal resetting, either the Fairbanks area was largely covered by an extensive volcanic field, or is intruded by hidden Tertiary plutons.

Present day exposures of mineralization reflect post-ore faulting. Plutonic-hosted gold mineralization such as the Fort Knox deposit are present in blocks receiving the greatest uplift. Stratiform low temperature replacement deposits such as those at the True North property are in structurally down-dropped blocks. Major vein deposits with some plutonic hosted mineralization such as the Ester Dome area occupy structural blocks of intermediate vertical displacement.

The highly productive gold-heavy mineral placer deposits of the Fairbanks district are found in streams that drain: (1) Ester Dome, (2) Cleary-Pedro Dome, and (3) Gilmore Dome mineralized areas (Metz, 1991). Nearly all placers consist of buried ancestral channels to Cleary, Goldstream, Fairbanks, Engineer, Dome, Eldorado, Little Eldorado, Ester, Cripple, and Smallwood Creeks. The Goldstream paystreak was nearly 2 km wide, 20 km long, and produced at least 1,994,000 ounces (62 tonnes) gold from 1902 to 1995. The smaller Cleary paystreak produced about 1,750,000 ounces (57.5 tonnes) gold during the same time period. Other large producers include Fairbanks, Cripple, Ester, and Dome Creeks. Most of the placer deposits are buried by thick sections of wind blown and retransported loess ranging from 5 to 70 meters thick. Recent stratigraphic studies of the loess deposits indicate many of the ancestral gold-bearing deposits are Pliocene or older in age. Over 30 heavy minerals have been identified including stibnite, scheelite, bismuthinite, native bismuth, arsenopyrite, cassiterite, and galena. Gold fineness ranges from about 830 to 940 and averages about 875. The gold and associated heavy minerals were derived from mineralized systems as summarized by Chapman and Foster (1969).

Industrial mineral deposits have been important components of the local Fairbanks mineral industry. Sand and gravel are extracted from floodplain alluvium and from formerly processed placer mine tailings. Tertiary basalt has proven to be excellent for D-1 road metal, crushed aggregate, and riprap applications. Local silt and peat deposits have made excellent material for agricultural and lawn and garden applications, and is used extensively by local area residents.

DESCRIPTION OF BEDROCK UNITS

Tertiary Sedimentary and Volcanic Rocks

Subaerial and subaqueous basalt and associated volcaniclastic sedimentary rocks crop out in the Fourth of July, Lakloey, Birch, Sage, and Brown's Hill in the eastern and southeastern portion of the study area. The basalts are chemically transitional between tholeiites and alkalai basalts (Furst, 1968). Although columnar jointing is well recognized on Browns Hill, pillows and palagonite breccias were recognized by Forbes and Weber (1982) in exposures on Birch and Sage Hills, which indicate subaqueous depositional environments—probably in a Tertiary age lake. Abundant *Metasequoia* and Ar-Ar isotopic data indicate an early Tertiary age for the eruption of the basaltic magmas.

Tb Tertiary Basalt: Dark Gray, maroon weathered, very fine grained to aphanitic, columnar jointed, olivine basalt and minor mudflow deposits. Locally contains leaf and plant stems including *Metasequoia* that indicate either Late Cretaceous or early Tertiary age, and samples from Browns Hill, Lakloey Hill, Fourth of July Hill, Birch Hill and Junniper Creek yield K-Ar and Ar-Ar whole rock isotopic ages of 50 to 56 Ma (Roe and Stone, 1993; this study). Moderatedly resistant where exposed.

Tbc Concealed Tertiary Basalt: Subaerial basalt as in Tb unit that is covered by thick colluvial and alluvial deposits. Determined mainly by airborne aeromagnetic anomalies in southeastern portion of study area (DGGS, 1973).

Ts Tertiary Conglomerate and Sandstone: Greenish gray, generally poorly consolidated, moderately well sorted, pebble conglomerate, and volcaniclastic sandstone mainly exposed on Fourth of July Hill in Fairbanks Creek drainage. Pebbles of greenstone, maroon phyllite, and black radiolarian chert indicate a provenance not of local origin, but rather a source area accessed when present drainage patterns in the study area were not developed. Association with Tb unit and presence of *Metasequoia* suggests Tertiary age. Nonresistant and poorly exposed.

Cretaceous Plutonic Rocks and Related Alteration

Isotopic ages from Ar-Ar, K-Ar, U-Pb, and Rb-Sr techniques indicate that nonmetamorphosed, plutonic rocks intruded in two pulses: quartz-poor intrusions at 110 Ma; and quartz-rich intrusions at 88-94 Ma. Trace element and Sr isotopic data by Blum (1983) and from this study indicate that the quartz-rich plutonic rocks in the study area are fractionated products derived from a common, crustally contaminated, subduction-related, magmatic source.

Ki Altered Dikes: Tan to gray, usually ferricrete stained, altered quartz porphyry, tonalite, granodiorite and undiffrentiated mafic dikes. Compositional estimates, where made, are based mainly on limited trace element and major oxide chemistry. Unit is generally nonresistant, due to ubiqutous alteration.

Kgd Granodiorite: Medium to light gray, medium to coarse grained, equigranular to porphyritic, hornblende biotite granodiorite; CI ranges from 18 to 35. Plutonic rocks in Gilmore and Pedro Dome areas yield ages ranging from 89 to 94 Ma from Rb-Sr, Ar-Ar, and K-Ar methods (Blum, 1983; Allegro, 1987; this study). Unit is resistant and underlies or forms prominant upland "domes" in the Gilmore, Pedro and Ester areas.

Kg Granite: Light gray, tan weathered, medium to coarse grained, typically porphyritic, biotite granite. Contains significant gold mineralization in valley of Monte Cristo Creek, where silicification has resulted in resistant blocky bedrock exposures. Ar-Ar ages range from 88 to 93 Ma in Lincoln Creek and Gilmore Dome bodies (Blum, 1983; Allegro, 1987; this study).

Ktn Tonalite and Quartz Diorite: Medium gray fine to medium grained, equigranular, biotite, pyroxene, hornblende tonalite and quartz diorite. Very resistant and forms rugged rubble outcrops in Pedro Dome region. Yields 92 Ma K-Ar, and Rb-Sr isotopic ages (Blum, 1983; this study)

Ksy Nepheline Syenite: Medium gray, distinctively brownish-red altered, subfoliated, fine grained phaneritic, K-feldspar rich, nepheline syenite exposed in O'Conner Creek valley. Contains abundant megascopic zircon. Feldspar-nepheline grains up to 6 mm in long dimension oriented along foliation structure. Subfoliated texture may be from primary crystallization or the result of the mid-Cretaceous retrograde regional metamorphism that affected the metamorphic rocks throughout the study area. Entire pluton contains anomalous thorium, uranium, zirconium, and niobium. The O'Conner Creek pluton yielded a U-Pb zircon age of 110 Ma (J. Mortenson, written commun., 1996). Forms resistant blocky rubble in O'Conner Creek valley.

Khsk Hornfels and Skarn: Variably colored, massive to coarsely crystalline, biotite rich schistose hornfels and garnet-hedenbergite-amphibole skarn mainly recognized in Gilmore Dome region. Locally contains massive sulfides and gold-scheelite mineralization, and is temporally and spatially associated with 90 Ma granitic bodies (Allegro, 1987). Generally nonresistant due to alteration and mineralization. Hornblende hornfels facies rocks derived from Birch Hill Sequence is present near the 90 Ma Curlew stock on Ester Dome.

Regionally Metamorphosed Rocks

Regionally metamorphosed rocks of the Fairbanks mining district are part of the Yukon-Tanana Terrane (Foster and others, 1994), and have been subdivided into four major groups on the basis of regional metamorphic history, lithology, and age. They include: (1) the eclogite bearing Chatanika Terrane of calcareous eclogite white mica schist, amphibolite, and quartzite; (2) the Muskox Sequence, an amphibolite facies metasedimentary and metavolcanic schist package that contains Upper Devonian U-Pb zircon ages; (3) the Fairbanks Schist, a heterogeneous package of schist, quartzite, and amphibolite that has undergone prograde amphibolite and retrograde greenschist facies metamorphism; and (4) the Birch Hill sequence, which consist of slate, metarhyolite tuff, calc-phyllite, and phyllite that were subjected to greenschist facies conditions. All four major metamorphic rock packages are in tectonic contact with each other. The regionally metamorphosed rocks in the study area range in age from Proterozoic to Upper Paleozoic, and have been correlated with rocks exposed elsewhere in the Yukon-Tanana Terrane (see table 1).

Chatanika Terrane

The Chatanika Terrane was defined by Robinson and others (1990) as a high grade metamorphic rock sequence containing type-C eclogites (Coleman and others, 1965). The unit includes garnet-bearing biotite muscovite schist, impure marble, black quartzite, and amphibolite (Swainbank, 1970; Swainbank and Forbes, 1975; Brown and Forbes, 1986). Microprobe analyses conducted during this study show P/T conditions of 11 kilobars and 600-to-700° C or clearly forming within eclogite facies conditions (table 3). Ar-Ar, K-Ar, and Pb-Pb studies (Forbes, 1982; Metz, 1991; Foster and others, 1994; this study) indicate that the eclogite bearing Chatanika Terrane may contain Devonian-Mississippian protoliths that have been subjected to more than one period of regional metamorphism. The Chatanika Terrane is always in thrust contact with the underlying Fairbanks Schist.

PDe Eclogite Bearing Schist, Amphibolite, and Quartzite: Variably colored, light gray to dark green, fine to coarse grained metapelite, metabasalt, metamarl, metasandstone, and marble metamorphosed to eclogite facies conditions. Includes: (1) garnet clinopyroxene rocks (eclogite) with distinctive pale-pink garnet and olive green omphacitic pyroxene; (2) garnet clinopyroxene amphibole rocks with zoned garnet and pleochroic amphibole; (3) garnet amphibolite difficult to distinquish from similar units in the Fairbanks schist; (4) light brown coarse grained calcareous muscovite schist; (5) dark gray garnet feldspar muscovite schist; (6) dark gray muscovite quartzite; and (7) nearly black, impure micaceous marble with minor clinopyroxene, phlogopite, and epidote. PDe unit is generally nonresistant, and forms subdued slopes in the northern portion of the map area. e=eclogite locality, M=marble locality.

Metamorphosed Granitic Rocks

Mog Orthogneiss: Light gray, distincly tan weathered, coarse grained, subfoliated, blasto-porphyritic, K-feldspar, biotite, muscovite granodiorite gneiss exposed in two, narrow, northeast trending belts that intrude the Fairbanks Schist in the eastern portion of the study area. U-Pb zircon age of 350 Ma (J. Mortenson, written commun., 1996) determined from a sample on Pedro Creek. Very similar to Augen Gneiss (Pzra) unit in Upper Chena River area (Smith and others, 1994) that intrudes "Chena River Sequence," which we regard as part of the Fairbanks Schist. Mog unit is moderately resistant, and forms coarse rubble whenever exposed.

Muskox Sequence

The Muskox Sequence (Dmr, Dma, Dms) is herein named after exposures in the Muskox Subdivision area, and consists of metamorphosed andesite, basalt, rhyolite, and sandstone that have been subjected to amphibolite facies conditions (P=5 kilobars; T≈500° C) and retrograded to greenschist facies conditions. Metarhyolite yielded a U-Pb zircon age of 369 Ma (Aleinikoff and Nokleberg, 1989). Metabasalt has a low TiO2 content and a calc-alkaline, island arc trace element signature. The Muskox sequence was originally mapped as part of the Cleary Sequence by Robinson and others (1990). The unit is correlative with the Spruce Creek Sequence in the Kantishna Hills (Bundtzen, 1981), the Blackshell unit in the Upper Chena River Area (Smith and others, 1994), and the Delta Schist in the Tok mining district (Lange and others, 1993). In the Fairbanks district the Muskox Sequence is in fault contact with the Fairbanks Schist in the Muskox Subdivision and Ester Dome areas.

Dmr Metarhyolite: Light gray, tan weathered, medium to coarse grained, muscovite rich, blasto-porphyritic, metarhyolite schist. Unit is poorly exposed in an abandoned radio tower area on the top of Muskox ridge.

Dma Amphibolite: Medium to dark green, medium grained, hornblende schist and amphibolite. Contains prograde hornblende, oligoclase, biotite, and quartz and retrograde actinolite, albite, chlorite, and epidote. Amphibolite contains low TiO_2 values that differ somewhat from megascopically similar units in the Fairbanks Schist. Unit is generally nonresistant.

Dms Biotite Schist: Medium to dark gray, distinctly brown weathered, medium grained highly schistose, quartz bearing, chlorite, biotite, mafic schist. Forms a distinctive linear band that tracks with amphibolite (Dma) along the southeastern flank of Ester Dome. Moderately resistant and forms stable outcrops in road cuts.

Birch Hill Sequence

The Birch Hill Sequence was defined by Robinson and others (1990), and consists of black slate, phyllite, minor metarhyolite tuff, and quartzite (Dbs) and calcareous chlorite schist and impure marble (Dbcs). The type sections lie in well exposed quarry cuts and in natural outcrops that form the southern edge of Birch Hill on Fort Wainwright. Microprobe analyses of plagioclase (fig. 1) and white mica indicate that units of the Birch Hill sequence underwent a single metamorphic event that reached greenschist facies conditions. The Birch Hill Sequence is correlative with the Keevy Peak Formation in the Central Alaska Range and Kantishna Hills (Wahrhaftig, 1968; Gilbert and Bundtzen, 1979) and the Dan Creek Unit in the Upper Chena River area (Smith and others, 1994).

Dbs Slate, Phyllite Tuff, and Quartzite: Dark gray, locally bleached, fine grained, sub schistose, quartzite phyllite, and slate, which locally contains thin (< 1 meter) layers of light gray feldspathic tuff that contains desseminated barite in Birch Hill area. Mineral assemblage includes chlorite, albite, illite and kaolinite. Can be moderately resistant due to high quartz content in interbedded quartzite beds.

Dbcs Calcareous Schist and Impure Marble: Light gray, tan weathered, coarse grained schistose, calcite chlorite schist and impure marble. Best exposed along flanks of Ester Dome and in University Hill area. Generally nonresistant due to high carbonate content.

Fairbanks Schist

The Fairbanks Schist as defined by Robinson and others (1990) comprizes the dominant rock type in the Fairbanks mining district. The Fairbanks Schist includes a wide variety of metamorphic rocks including quartz muscovite schist, quartzite, quartzite grit, marble, chlorite schist, amphibolite, and a distinctive magnetitie-rich biotite schist. Nearly 90 percent of the Fairbanks schist is composed of quartzite and quartz muscovite schist. As originally defined, the Fairbanks Schist was described as a sequence of metamorphosed sedimentary and volcanic rocks that was subjected to greenschist facies metamorphism. Also included in the original Fairbanks Schist package was a bimodal metavolcanic and metavolcaniclastic assemblege of rocks known as the Cleary Sequence. During our studies, we have not recognized the Cleary sequence as originally defined and do not depict it on the geologic map. Metarhyolite and intermediate metatuff mapped in the Muskox Sequence during this study was originally included in the Cleary Sequence (Robinson and others, 1990). The Fairbanks Schist as defined here includes rock types of the Chena River Sequence as described by Robinson and others (1990). The distinction between the Chena River Sequence and Fairbanks Schist was based on the belief that the former was metamorphosed under amphibolite facies conditions whereas the latter was subjected only to greenschist facies conditions. Detailed microprobe work conducted during this study (Joy and others, 1996; table 3) show that rocks of the Fairbanks Schist and those formerly mapped as Chena River Sequence have undergone identical T/P regional metamorphism (P=5 kilobars; T= 500° C). In addition the amphibolites in the Chena River Sequence and Fairbanks Schist are chemically indistinquishable (fig. 2). Hence we have included the Chena River Sequence of Robinson and others (1990) into the Fairbanks Schist package. Although the Fairbanks Schist occurs structurally above the Devonian (?) Birch Hill Sequence, we correlate the Fairbanks Schist with similar poly-deformed, amphibolite facies lithoIigies mapped in the Alaska Range (Gilbert and Bundtzen, 1979), the Upper Chena River Area (Smith and others, 1994) and the Livengood Quadrangle (Weber and others, 1993), which are regarded as pre-Devonian—probably Proterozoic—in age.

Zf Quartz Muscovite Schist, Quartzite, and Chlorite Quartzose Schist: Light to medium gray, fine to coarse grained, quartzite, quartz muscovite schist, and garnet biotite quartz muscovite schist. Rocks have been subjected to a prograde amphibolite facies event and a retrograde greenschist facies event. Early Proterozoic, detrital zircons are identified in many quartzite localities (Aleinikoff and Nokleberg, 1989). Unit is moderately resistant due to its relatively high quartz content.

Zfa Amphibolite, Magnetite-Rich Biotite Schist, Quartzose Schist, and Marble: Heterogeneous unit of variably colored, gray to green, fine to coarse grained, garnet hornblende amphibolite, magnetite bearing biotite schist, coarsely crystalline marble, and light gray, mica-rich quartzite or "white schist." Zfa as shown on the geologic map was originally mapped by Robinson and others (1990) as part of both the Chena River and Cleary Sequences. Amphibolites contain prograde hornblende, oligoclase, biotite, and garnet and retrograde chlorite, albite, actinolite, and sphene. Amphibolites contain high TiO_2 and exhibit major oxide and trace element signatures typical of tholeiitic, 'within plate' basalt (Pearce and Cann, 1973). Zfa unit appears as linear magnetic anomaly on an aeromagnetic survey (Dighem Surveys and Processing, 1995) due to magnetite content of biotite schist. Hydrothermally altered marble in Fox area juxtaposed against a high angle fault zone contains numerous euhedral tremolite veins. Bleached, light gray muscovite quartzose "white schists" were originally regarded by Robinson and others (1990) as rhyolite tuff or exhalite; major oxide chemistry and trace element data collected during this study do not support this interpretation. Rather, presence of detrital zircons in these "white schists" (Aleinikoff and Nokleberg, 1989) indicate a metasedimentary parentage. Zfa is generally resistant and forms subdued rubble crop throughout map area.

Zfm Marble: Light gray, medium to coarsely crystalline, muscovite rich marble. Where Zfm is in the vicinity of a 90 Ma pluton, small idocrase-garnet-hedenbergite-hornblende scheelite skarns have formed. Generally nonresistant.

Zfc Metaconglomerate: Light gray coarse grained, quartz rich, porphyroclastic metaconglomerate that contains stretched pebbles of chert and shale in a well defined, 100 meter-thick bed that can be traced for about 10 kilometers in the Murphy Dome area. Very resistant and forms blocky rubble and outcrops.

Zfg Metasandstone Grit: Light to medium gray, quartz-rich, porphyroclasic muscovite, biotite metasandstone "grit" usually found in association with Zfc unit. Probably originally a quartz rich sedimentary rock deposited in continental margin environment. Similar to "grits" in Livengood Quadrangle (Weber and others, 1992) and in Upper Chena River area (Smith and others, 1994), which are regarded as Late Proterozoic quartzofeldspathic metasandstones. Very resistant and underlies the Murphy Dome upland in northwestern portion of map area.

Zfw Bleached Feldspathic Quartzose Schist: Light gray, bleached, muscovite and biotite bearing, feldspathic schist. The Zfw unit is mapped in a linear belt across the summit of Ester Dome that has been offset along high angle fault. Occasional thin interbedded amphibolite layers found with the feldspathic Zfw schists. Petrographic studies and major oxide and trace element chemistry suggests that the feldspars are relict detrital grains from an arkosic metasedimentary rock rather than metavolcanic in origin. Some patchy areas underlain by the Zfw unit (for example, Murphy Dome, Parks Highway and Cleary Hill areas) may be hydrothermal alteration of quartzose schists related to nearby plutonism. Moderately resistant and forms blocky rubble in road cuts.

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