The Geology of North America
Vol. G-1, The Geology of Alaska
The Geological Society of America, 1994

Chapter 6

Geology of the Yukon-Tanana area of east-central Alaska

Helen L. Foster and Terry E. C. Keith
U.S. Geological Survey, 345 Middlefield Road, Menlo Park, California 94025
W. David Menzie
U.S. Geological Survey, Reston, Virginia 22092

INTRODUCTION

East-central Alaska as described in this volume (Fig. 1) is a physiographically diverse region that includes all or parts of the following physiographic divisions (Wahrhaftig, this volume): Northern Foothills (of the Alaska Range), Alaska Range (north of the northernmost strand of the Denali fault system), Tanana-Kuskokwim Lowland, Northway-Tanacross Lowland, and the Yukon-Tanana Upland. The Northern Foothills are largely rolling hills in Pleistocene glacial deposits and dissected Tertiary nonmarine sedimentary rocks. The included part of the Alaska Range is composed of highly dissected terranes of metamorphic rocks that have been intruded by Cretaceous and Tertiary igneous rocks. Mountain peaks reach altitudes as high as 4,000 m, and relief is commonly more than 1,000 m. Glaciers have carved a rugged topography. The Tanana-Kuskokwim Lowland is covered with thick glacial, alluvial, and wind-blown deposits. The Northway-Tanacross Lowland consists of three small basins mantled with outwash gravel, silt, sand, and morainal deposits. The Yukon-Tanana Upland, the largest of the physiographic divisions, consists of maturely dissected hills and mountains with altitudes as high as 1,994 m, and relief ranging from a few to hundreds of meters. Some of the highest areas supported small alpine glaciers during the Pleistocene, and rugged topography resulted locally.

With the exception of the Alaska Range, outcrops in east-central Alaska are commonly widely scattered and small, due to extensive surficial deposits and vegetation. The vegetation ranges from heavy spruce forests along large streams to tundra at elevations of approximately 1,000 m. The region is largely in the zone of discontinuous permafrost. Most of the low-lying areas, as well as the high mountain areas, are in the permafrost regime. Some areas, mostly intermediate in elevation, are permafrost free.

East-central Alaska is composed of a number of accreted terranes (Jones and others, 1984; Silberling and others, this volume) that have continental, oceanic, and possibly island-arc affinities. The largest terrane, the Yukon-Tanana, has mostly continental affinities. The small Seventymile terrane has oceanic affinities. The southern part of the Yukon-Tanana terrane, which includes the Lake George, Macomb, and Jarvis Creek Glacier terranes (or subterranes) of the Mount Hayes Quadrangle, may have island-arc affinities (Gilbert and Bundtzen, 1979; Nokleberg and Aleinikoff, 1985). The Hayes Glacier and Windy terranes in the Mount Hayes Quadrangle are also suggested to be tectonic slices of an island-arc or possibly of a submerged continental-margin arc (Nokleberg and Aleinikoff, 1985).

Terminology of igneous rocks used in this chapter follows that of Streckeisen (1976).

YUKON-TANANA TERRANE

The Yukon-Tanana terrane (YT) consists largely of the area lying between the Yukon and Tanana Rivers but, as defined by Silberling and others (this volume), it also includes some of the Alaska Range and its foothills north of the Denali fault system. Nokleberg and Aleinikoff (1985) describe the part of the Mount Hayes Quadrangle in the YT as the Lake George terrane, which lies north of the Tanana River, and the Macomb, Jarvis Creek Glacier, Hayes Glacier, and Windy terranes, which lie between the Tanana River and the Denali fault. For this chapter, we consider those terranes, with the exception of the Windy terrane, to be subterranes of the YT. In the Healy, Mount McKinley, and Kantishna Quadrangles, isolated, probably fault-bounded exposures of rocks are also included in the Yukon-Tanana terrane. For ease in discussing stratigraphy and structure, the Macomb, Jarvis Creek Glacier, Hayes Glacier, and Windy terranes and the areas to the southwest and southeast of them will be discussed separately from the part of the Yukon-Tanana terrane between the Yukon and Tanana Rivers. In this chapter, we refer to the part of the Yukon-Tanana terrane north of the Tanana River as the YTTN. The eastern YTTN also includes the small extension into Alaska of the Stikinia terrane (Silberling and others, this volume).

YUKON—TANANA TERRANE NORTH OF THE TANANA RIVER

The YTTN has been referred to as the "Yukon-Tanana region" (Mertie, 1937), the "Yukon-Tanana upland" (Foster and others, 1973), and the "Yukon Crystalline Terrane" (Tempelman-Kluit, 1976; Churkin and others, 1982). It is nearly coinci-

Foster, H. L., Keith, T.E.C., and Menzie, W. D., 1994, Geology of the Yukon–Tanana area of east-central Alaska, *in* Plafker, G., and Berg, H. C., eds., The Geology of Alaska: Boulder, Colorado, Geological Society of America, The Geology of North America, v. G-1.

dent with the previously described physiographic division called the Yukon-Tanana Upland (Wahrhaftig, this volume). The YTTN is primarily a terrane of quartzitic, pelitic, calcic, and mafic metasedimentary rocks with some mafic and felsic meta-igneous rocks that have been extensively intruded by Mesozoic and Cenozoic granitic rocks and minor amounts of intermediate and mafic rocks. Cretaceous and Cenozoic volcanic rocks are abundant in the eastern part. Late Cretaceous and Tertiary sedimentary rocks were deposited in small, widely separated nonmarine basins. The YTTN has been considered a composite terrane by Churkin and others (1982), and many problems related to its complex geologic history are as yet unresolved.

Metamorphic rocks

The geology of the YTTN was reported by Mertie (1937), who described the stratigraphy in some detail. Mertie included many of the metamorphic rocks in a formation called the Birch Creek Schist, of Precambrian age, and eventually most of the metamorphic rocks of east-central Alaska were included in this formation. Because usage of the name Birch Creek Schist became so broad, and because parts of the formation were found to be younger than Precambrian, the name lost usefulness. In 1973, Foster and others recommended that it be abandoned. In recent reconnaissance geologic mapping the metamorphic rocks have been divided into many units, but because of the lack of information on age and structural relations, few new formations have been formally named and described.

The metamorphic rocks within the YTTN vary in such aspects as composition and origin of protoliths, present lithology, structure, and metamorphic history. On the basis of these characteristics and other data, Churkin and others (1982) divided the YTTN into four subterranes (Y_1 to Y_4). Although structural

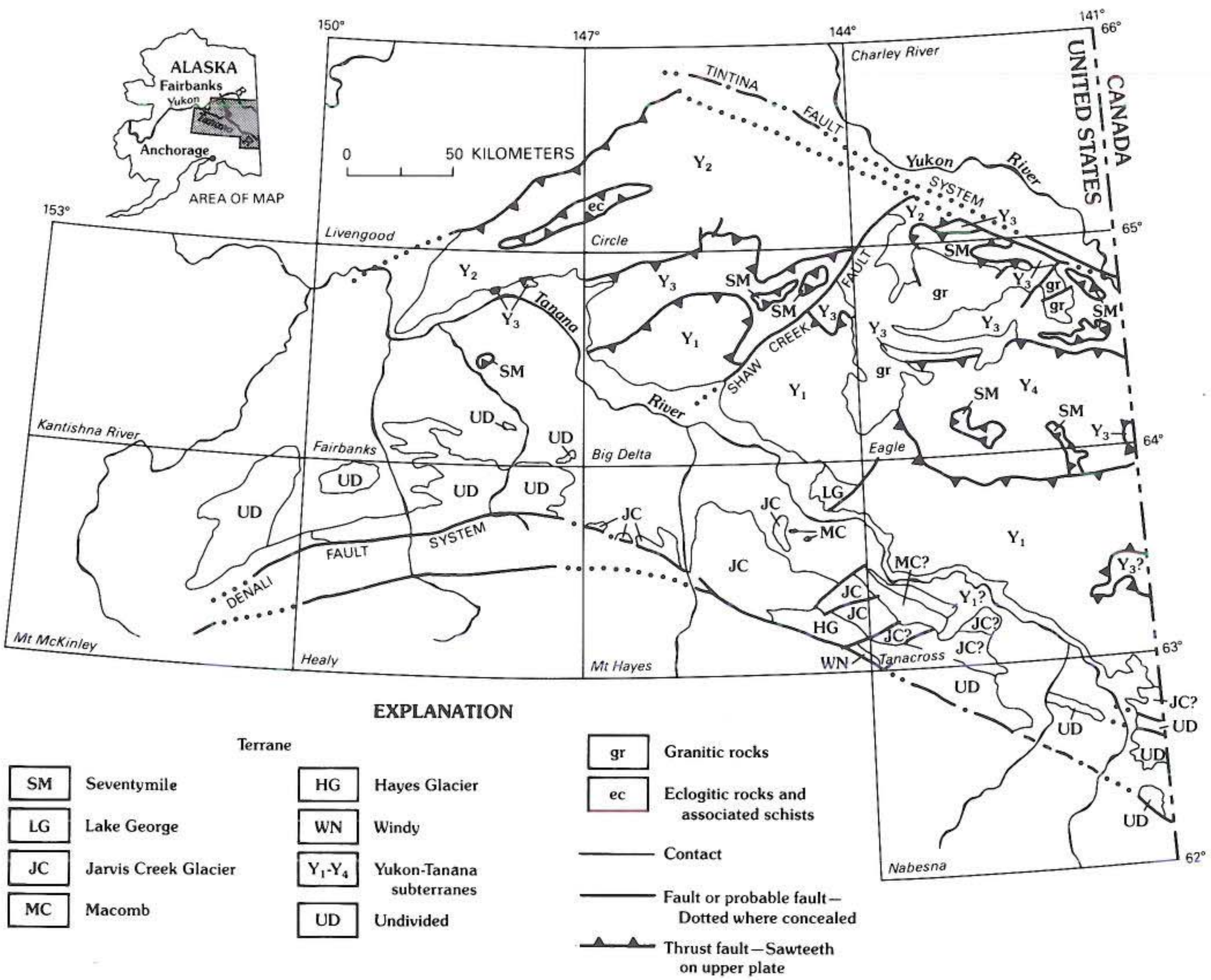

Figure 1. Map of east-central Alaska showing locations of quadrangles, terranes, and subterranes. Subterranes modified from Churkin and others (1982). Terranes of Mount Hayes Quadrangle from Nokleberg and Aleinikoff (1985).

details and stratigraphic relations are poorly known, these subdivisions are useful for descriptive purposes and for discussion of regional relations. We have used them, with minor modifications, as the framework for our discussion of the metamorphic rocks of the YTTN (Fig. 1; Table 1).

Subterrane Y_1 (northeastern Mount Hayes, southern Big Delta, southwestern Eagle and northern Tanacross Quadrangles). This is the largest and southernmost subterrane of the YTTN (Fig. 1). The part of this subterrane in the Mount Hayes Quadrangle has been termed the "Lake George terrane" (Nokleberg and others, 1983). The southern boundary of Y_1 in the Mount Hayes Quadrangle (the southern boundary of the Lake George terrane) is the largely concealed Tanana River fault (Nokleberg and Aleinikoff, 1985). An extension of this or adjoining faults probably forms the southern Y_1 boundary elsewhere. The northern boundary of Y_1 is probably a thrust fault. The rocks are all metamorphosed to the amphibolite facies, probably at intermediate pressures. Protoliths primarily were quartzitic and pelitic sedimentary rocks and felsic intrusive rocks with some intermediate and mafic intrusive and volcanic rocks. Calcareous rocks, rare to absent in the eastern part of Y_1, occur in very minor amounts in the western part of Y_1. Pelitic rocks are more abundant in the western part of Y_1, and quartzose rocks predominate in the eastern part of Y_1. The dominant rock types include quartz-biotite gneiss and schist, sillimanite gneiss, quartzite, amphibolite, and orthogneiss (unit ag, Fig. 2), including augen gneiss.

Augen gneiss, a widely distributed and characteristic rock type having a granitic composition and blastoporphyritic texture, occurs primarily east of a major high-angle fault, the Shaw Creek fault (Fig. 1; Dusel-Bacon and Aleinikoff, 1985). Large augen (megacrysts or porphyroblasts) of potassium feldspar range from 1 to 9 cm in longest dimension and have been modified into augen by mylonitization. These augen gneisses, occurring in the Big Delta, Eagle, Mount Hayes, and Tanacross Quadrangles, are considered to be a part of deformed and metamorphosed intrusions of porphyritic granite. Dusel-Bacon and Aleinikoff (1985) postulated that these and similar augen gneisses and other orthogneisses in the Yukon Territory are part of an intrusive belt that extends from the central part of the Big Delta Quadrangle in east-central Alaska into the Yukon Territory. Most of these augen gneisses were included in the Pelly Gneiss of McConnell (1905); Mertie (1937) used the term "Pelly Gneiss" for the augen gneisses in eastern Alaska but did not map them separately from the Birch Creek Schist. Other types of augen gneiss also occur in minor amounts in subterrane Y_1.

Sillimanite gneiss is a major rock type around the augen gneiss in the Big Delta Quadrangle and occurs in a large area that has been interpreted as a gneiss dome (Dusel-Bacon and Foster, 1983) on the northwest side of the Shaw Creek fault (Fig. 1). Metamorphic grade (second sillimanite isograd) is highest in the central part of the gneiss dome and decreases northward. Triple-point conditions for alumina silicate minerals are postulated for the schist on the north flank of the gneiss dome. The gneiss dome is mostly quartz-orthoclase-plagioclase-biotite-sillimanite ± muscovite gneiss. Cordierite occurs in some of the gneisses. To the north, muscovite gradually increases and K-feldspar decreases. North of the Salcha River, the pelitic rocks are interlayered with quartzitic schist, quartzite, marble, amphibole schist, and quartzo-feldspathic schist.

The rocks of subterrane Y_1 are well foliated, and foliation is folded at least once. Gneissic banding is well developed in the augen gneiss and is concordant with the foliation in the surrounding metamorphic rocks (Dusel-Bacon and Aleinikoff, 1985). Foliation is plastically folded in the gneiss dome and some other gneisses. Most of the rocks show varying degrees of mylonitization and post-mylonitization recrystallization. In the Lake George terrane (Mount Hayes Quadrangle), Aleinikoff and Nokleberg (1985a) described small-scale isoclinal folds in pelitic schist; axial planes parallel foliation and compositional layering but fold an older foliation. A lineation formed by the intersection of the axes of small tight folds with foliations occurs locally in augen gneiss in the Big Delta Quadrangle and is especially well developed in the northeastern Tanacross Quadrangle.

The only information on the age of the protoliths of the metamorphic rocks in subterrane Y_1 comes from U-Pb dating of zircon. U-Pb analyses of zircon from medium-grained schistose granitic rock from the Mount Hayes Quadrangle indicate a Devonian intrusive age, about 360 Ma (Aleinikoff and Nokleberg, 1985a). Detailed study of augen gneiss from the Big Delta Quadrangle indicates an intrusive age of Mississippian, about 345 Ma (Dusel-Bacon and Aleinikoff, 1985). U-Pb analyses of zircon from augen gneiss in the Tanacross Quadrangle (Aleinikoff and others, 1986) and also of augen gneiss in the southeastern Yukon Territory (Mortensen, 1983) indicate a Mississippian intrusive age. Dusel-Bacon and Aleinikoff (1985) interpret the paragneisses, schists, and quartzites of subterrane Y_1 as wall rocks of the orthogneisses; therefore they are Mississippian or older in the Big Delta, Eagle, and Tanacross Quadrangles and Devonian or older in parts of the Mount Hayes Quadrangle. An early Paleozoic age seems most likely for most of them, but a Precambrian age for at least some cannot be ruled out. Both the augen gneiss and some quartzites are shown by U-Pb analyses of zircons to have an inherited early Proterozoic component (2.1 to 2.3 b.y. old) (Aleinikoff and others, 1986). The origin of this Proterozoic material is unknown, but a high initial $^{87}Sr/^{86}Sr$ ratio in the augen gneiss supports petrologic indications of involvement of continental crustal material in the formation of these rocks (Dusel-Bacon and Aleinikoff, 1985).

Deformed and recrystallized ultramafic rocks in isolated outcrops (too small to show on Fig. 2) are infolded with gneisses and schists of subterrane Y_1; most are concentrated in the south-central and southeastern Big Delta and southwestern Eagle Quadrangles. Locally preserved textures indicate that some of the ultramafic rocks were originally peridotite (harzburgite). Intense recrystallization has formed elongate-oriented olivine crystals with pods of granular magnetite as long as 5 cm. Other metamorphic minerals include hornblende, actinolite, serpentine, chlorite, talc, anthophyllite, and magnesite. The ultramafic rocks probably

TABLE 1. SUBTERRANES OF THE YUKON–TANANA TERRANE NORTH OF THE TANANA RIVER (YTTN)

Subterrane	Included map units (Fig. 2)	Lithology	Metamorphic facies	Distinctive characteristics	Age of protolith
Y_1 (Includes Lake George terrane)	ag	Gneiss, schist, amphibolite, quartzite	Amphibolite (moderate pressure)	Augen gneiss common; marble and other calcareous rocks rare or absent	Mississippian and pre-Mississippian
Y_2	qq	Quartzite and quartzitic schist with small amounts of pelitic schist, calc-silicate rocks, mafic schist, and rare marble	Greenschist (moderate pressure)	Quartzite and quartzitic schists that are commonly recrystallized mylonites with megacrysts of quartz and/or feldspar	Unknown, may be early Paleozoic
	ps	Pelitic schist, quartzite, marble, and amphibolite	Amphibolite (moderate pressure)	Sillimanite and kyanite-bearing pelitic schists	Unknown, may be early or middle Paleozoic
	ec	Eclogite, amphibolite pelitic schist, and mafic glaucophane-bearing schist	Amphibolite (high pressure)	Occurrence of eclogite and of glaucophane in mafic schists	Unknown
Y_3	ms	Mylonitic schist, semischist, quartz-white mica chlorite schist, quartzite, and minor phyllite, marble, and greenstone	Greenschist (moderate pressure)	Light greenish gray color characteristic. Abundant mylonitic schists	Unknown, may be Carboniferous or middle Paleozoic
	cp	Calcareous phyllite, phyllite marble, quartzite, and argillite	Low greenschist	Calcareous phyllite with thin, crumbly layers. Weathers leaving a lag gravel of white quartz on surface. Gray and dark gray quartzite and argillite overlie calcareous phyllite	Unknown, may be early or middle Paleozoic
	sm	Greenschist, calcareous greenschist, quartz-chlorite white mica schist, marble, greenstone, quartzite	Greenschist	Abundant layers and lenses of marble; some schists contain megacrysts of quartz and/or feldspar	Paleozoic; partly Mississippian
	ws	Quartz-chlorite white mica schist with minor quartzite, phyllite, and metavolcanic rocks	Greenschist	Marble layers rare to absent. Light green color characteristic. Some schists have megacrysts of quartz and/or feldspar	Unknown, presumably middle or late Paleozoic
	qs	Quartzite with minor phyllite, carbonaceous quartz schist and graphitic schist	Greenschist	Overall dark gray color characteristic; dark gray quartzite dominant rock type	Unknown, probably Paleozoic
Y_4	gs	Quartzitic and pelitic gneiss and schist, quartzite, marble, and amphibolite	Amphibolite	Thick masses and layers of coarsely crystalline marble. Quartz-biotite-hornblende gneiss a characteristic and common rock type	Probably Paleozoic

composed a thrust sheet over part of subterrane Y_1 early in the development of the subterrane and were metamorphosed and deformed with the rocks of subterrane Y_1.

The metamorphic history of subterrane Y_1 is not known in detail. Nokleberg and Aleinikoff (1985) interpreted the subterrane in the Mount Hayes Quadrangle (Lake George terrane) to be intensely deformed and regionally metamorphosed at least once, and more likely twice, at conditions of the middle amphibolite facies. Then, during a late stage of the second regional metamorphism and deformation, the Lake George terrane was intruded by Cretaceous granitic rocks, which were subsequently metamorphosed, along with the older wall rocks, under conditions of the lower greenschist facies. Interpretation of metamorphic history of subterrane Y_1 in the Big Delta, Eagle, and Tanacross Quadrangles is based largely on the study of the augen gneiss, adjacent wall rocks, and the gneiss dome. Dusel-Bacon and Aleinikoff (1985) suggested that major amphibolite-facies metamorphism and deformation may have closely followed intrusion of the augen gneiss, on the basis of structural characteristics of the augen gneiss and limited isotopic data on wall rocks.

An Early Cretaceous thermal event caused lead loss in zircon from the U-rich zircon fractions from sillimanite gneiss and quartzite and also affected Rb-Sr and K-Ar isotopic systems (Aleinikoff and others, 1986; Wilson and others, 1985). If temperatures reached only greenschist-facies levels in subterrane Y_1, they would have produced minor retrograde effects. However, if amphibolite-facies temperatures were reached, the effects might not be detected because the rocks were already metamorphosed to amphibolite facies. The only recognized petrologic changes that can be attributed to this Early Cretaceous metamorphism outside of the Mount Hayes Quadrangle are minor, and no younger metamorphic events have been identified.

Nokleberg and Aleinikoff (1985) interpreted the Lake George terrane and other terranes to the south as shallow to deep parts of a submarine igneous arc of Devonian age, and believed that it was either an island arc or submerged continental-margin arc. Dusel-Bacon and Aleinikoff (1985) suggested that a Mississippian belt of intrusions developed either below or inland from a continental arc, and that in the latter case, the belt of augen gneiss plutons could be analogous to belts of peraluminous plutons that occur inland from continental margins in some orogenic belts.

Subterrane Y_2 (Circle, northern Big Delta, southwestern Charley River, Livengood, and Fairbanks Quadrangles). The Y_2 subterrane is bounded on the north by the Tintina fault system and on the south and west by thrust faults; the eastern boundary is obscured by Mesozoic granitic plutons. The western fault contact is considered as the terrane boundary of the YT (Laird and Foster, 1984; Foster and others, 1983). Subterrane Y_2 is composed of three fairly distinct groups of rocks: one group (unit qq, Fig. 2) consists mostly of quartzites and quartz schists of greenschist to amphibolite facies and has been referred to informally as the Fairbanks schist unit in the Fairbanks Quadrangle (Bundtzen, 1982); the second group (unit ps, Fig. 2) consists of amphibolite- to epidote-amphibolite–facies schist, quartzite, marble, and amphibolites, some of which have been included in the Chena River sequence (Hall and others, 1984). These two groups of rocks are in thrust contact, as indicated by sharp lithologic changes and their map patterns, but thrusting occurred before major metamorphism because metamorphic isograds do not follow the unit contacts (Foster and others, 1983). A third group of thrust-bounded rocks (unit ec, Fig. 2) occurs in the southwestern Circle and southeastern Livengood Quadrangles and consists of eclogite associated with amphibolite, impure marble, pelitic schist, and rare glaucophane-bearing schist. These rocks, referred to as the Chatanika terrane by Bundtzen (1982), probably had a metamorphic and deformational history different from that of the remainder of subterrane Y_2 before they were thrust together.

Quartzite and quartzitic schists (unit qq). This group of rocks crops out in about half of the Circle Quadrangle and occurs in the Fairbanks and Livengood Quadrangles. Quartzite and quartzitic schist are the most abundant rock types in this unit, but minor amounts of pelitic schist, calc-silicate rocks, mafic schist, and rare marble are interlayered. In the Circle Quadrangle, quartzite and quartzitic schist are fine to coarse grained and equigranular or fine to coarse grained with rare to abundant megacrysts of quartz and less abundant feldspar, ranging from less than a millimeter to more than a centimeter in diameter. Megacrysts are clear, white, gray, blue-gray, or black, and may be strained monocrystalline or polycrystalline grains. The matrix is generally a mosaic of strained quartz, minor feldspar, and white mica. Locally, chlorite, biotite, and small garnets are present. Most of these rocks are mylonites (Wise and others, 1984); many show syntectonic recrystallization in quartz, especially near fault contacts (Foster and others, 1983).

Mylonitization is particularly evident along the northwestern margin of this unit. Foster and others (1983) and Laird and Foster (1984) interpreted this as a major zone of thrusting; however, some workers (Hall and others, 1984) considered the northwestern contact of this unit to be gradational with a grit unit of the Wickersham terrane of Jones and others (1984). A small area of "grit" and quartzite in the south-central part of the Circle Quadrangle was interpreted as a window in the thrust sheet of this unit (Foster and others, 1983).

Quartzitic rocks are interlayered with minor amounts of pelitic schist (quartz + plagioclase + muscovite + chlorite schist commonly with biotite ± garnet or with chloritoid ± garnet). Garnet is absent in the northern part of this unit. Rare, thin marble layers occur. Chlorite schist, locally magnetic, is interlayered and infolded with quartzite and pelitic schist. Interpretation of aeromagnetic data (Cady and Weber, 1983) suggests that magnetic chlorite schists, which are a poorly exposed unit, may be more abundant than is apparent from outcrops in the southwestern part of the Circle Quadrangle.

A mafic schist is the dominant rock type in a 190-km^2 area in the east-central part of the Circle Quadrangle. Green chlorite-quartz-carbonate schist, generally with abundant plagioclase porphyroblasts, is interlayered with amphibole (commonly actinolite) + chlorite + epidote + plagioclase + quartz + sphene + biotite

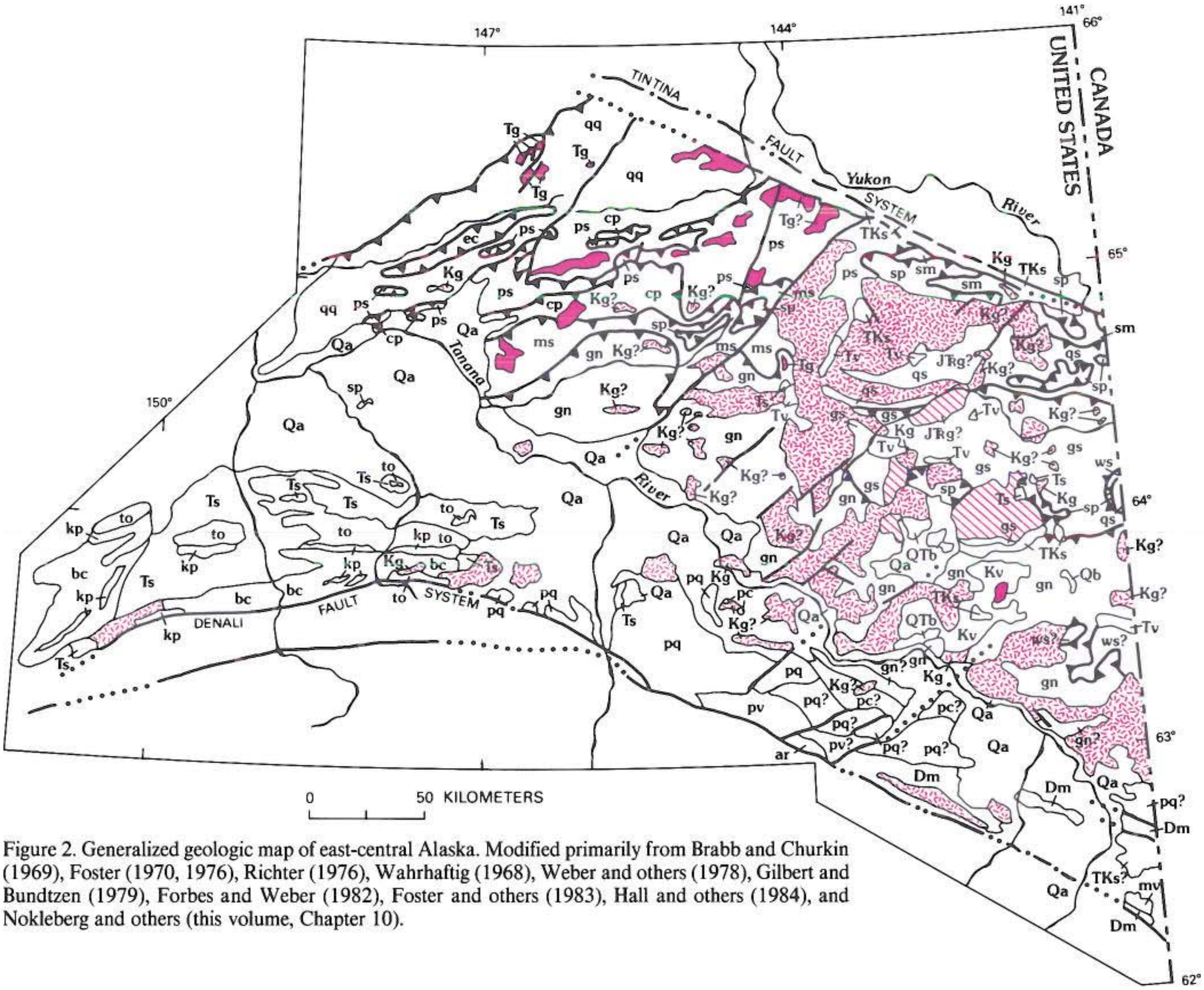

Figure 2. Generalized geologic map of east-central Alaska. Modified primarily from Brabb and Churkin (1969), Foster (1970, 1976), Richter (1976), Wahrhaftig (1968), Weber and others (1978), Gilbert and Bundtzen (1979), Forbes and Weber (1982), Foster and others (1983), Hall and others (1984), and Nokleberg and others (this volume, Chapter 10).

or white mica ± carbonate ± garnet schist. The protolith may have been, in part, mafic pyroclastic rocks. Minor marble, quartzite, and pelitic schist are interlayered with the mafic schist (Foster and others, 1983).

The westernmost metamorphic rocks of the Yukon-Tanana terrane form unit "qq" of the Fairbanks and Livengood Quadrangles (Bundtzen, 1982). Although poorly exposed, they have been examined in detail. In the Fairbanks Quadrangle, this unit is dominantly quartzite and muscovite-quartz schist ± garnet, biotite, and chlorite. It is estimated to be more than 1,000 m thick (Hall and others, 1984). Interstratified near the center of this group of rocks is a 130-m-thick sequence of interlensing felsic schist, micaceous quartzite, chloritic or actinolitic schist, graphitic schist, minor metabasite, metarhyolite, calc-silicate layers, banded gray marble, and quartzite, referred to informally as the Cleary sequence (Bundtzen, 1982). These rocks, interpreted to be largely of distal volcanic origin, host lode mineral occurrences in the Fairbanks mining district (Hall and others, 1984).

Four distinct deformational events are recognized in this unit in the Circle Quadrangle (Cushing and Foster, 1984). The first (D_1) produced a penetrative schistosity (S_1) parallel or subparallel to gently dipping axial planes of rarely observed tight to isoclinal recumbent folds. S_1 commonly parallels compositional layering and is everywhere prevalent in the metamorphic rocks. Folds associated with the second deformational event, D_2, are ubiquitous and range from tight to isoclinal with rounded and chevron fold hinges. Amplitudes and wavelengths range from microscopic to several meters. A second schistosity, S_2, developed locally owing to mechanical rotation of S_1. Folds of the third deformational event, D_3, are recumbent, tight to isoclinal. Because fold styles and orientations are similar, structural features of D_3 are difficult to distinguish from D_2. The fourth deformational event (D_4) is characterized by gentle and open folds that deform all previous structures. Wavelengths and amplitudes are generally less than 50 cm but may be as large as 5 m.

Unit "qq" was subjected to moderate-pressure greenschist-

EXPLANATION

Unconsolidated deposits

- **Qa** — Quaternary alluvial deposits; primarily alluvium but includes colluvial, glacial, and eolian deposits

Sedimentary rocks

- **Ts** — Tertiary sandstone, conglomerate, shale, coal, and tuffaceous rocks. Includes informally designated coal-bearing formation of local usage overlain by the Nenana Gravel
- **TKs** — Cretaceous and/or Tertiary sedimentary rocks (conglomerate, sandstone, coal, shale, and tuffaceous rocks)

Igneous rocks

Volcanic

- **Qb** — Quaternary alkali-olivine basalt
- **QTb** — Tertiary and (or) Quaternary basalt and gabbro
- **Tv** — Tertiary felsic to mafic volcanic rocks
- **Kv** — Cretaceous volcanic and volcaniclastic rocks

Plutonic

- **Tg** — Tertiary granitic rocks
- **Kg** — Cretaceous granitic rocks
- **J̄Rg** — Late Triassic and Early Jurassic granitic rocks

Metamorphic rocks

North of Tanana River

Rocks of higher metamorphic grade

- **ps** — Pelitic schist, quartzite, marble, and amphibolite
- **gs** — Gneiss, schist, marble, amphibolite, and quartzite
- **gn** — Gneiss (including augen gneiss and sillimanite gneiss), schist, amphibolite, and quartzite
- **ec** — Eclogite and associated rocks

Rocks of lower metamorphic grade

- **cp** — Calc-phyllite and quartzite
- **ms** — Mylonitic schist, semischist, quartzite, phyllite, marble, and greenstone
- **ws** — Quartz-chlorite-white mica schist
- **qs** — Quartzite and quartzitic schist
- **sm** — Schist, including greenschist, marble, greenstone, and quartzite
- **qq** — Quartzite, quartzitic schist, mafic schist, and calc-schist
- **sp** — Serpentinized peridotite, greenstone, and associated metasedimentary rocks including chert of Mississippian, Permian, and Triassic age

South of Tanana River

- **gn** — Gneiss (including augen gneiss), schist, amphibolite, and quartzite
- **pc** — Pelitic schist, calc-schist, and quartz-feldspar schist
- **pq** — Pelitic schist, quartzite, and schistose volcanic and plutonic rocks
- **pv** — Phyllite and schistose volcanic rocks
- **ar** — Argillite, limestone, conglomerate, and other metasedimentary rocks
- **mv** — Metavolcanic and volcaniclastic rocks
- **Dm** — Metasedimentary rocks of probable Devonian age intruded by diorite and gabbro
- **to** — Totatlinika schist of possible Late Devonian to Mississippian age; mostly quartzitic schist and metavolcanic rocks
- **kp** — Keevy Peak Formation of possible Ordovician to Devonian age; includes carbonaceous phyllite, quartzite, stretched conglomerate, and white mica-quartz schist
- **bc** — Birch Creek schist of former usage; includes quartzitic, graphitic, chloritic, and calcareous schist, marble, and greenstone

- Contact
- Fault or probable fault—Dashed where approximately located; dotted where concealed
- Thrust fault or postulated thrust fault—Dotted where concealed; sawteeth on upper plate

facies regional metamorphism that was more intense in the southern part of the unit (Foster and others, 1983). Polymetamorphism of regional extent has not been identified. Rolled garnet and plagioclase grains are common but appear to be explained by one syntectonic growth event. Inclusions of chloritoid found within, but not outside of, garnet grains can be explained by progressive metamorphism through and above the conditions of chloritoid stability (Burack, 1983). Contact-metamorphic effects are superimposed upon the regional metamorphism around most Tertiary plutons; biotite and amphibole have developed across the foliation, and garnet is commonly all or partly chloritized.

The ages of the protoliths of this unit are unknown because no fossils have been found. U-Pb determinations on zircon from one quartzite indicate that the protolith included material from an early Proterozoic source of essentially the same age (2.1 to 2.3 Ga) as that of subterrane Y_1 (J. N. Aleinikoff, personal communication, 1983). The very large quartzitic component of these rocks and abundance of quartz megacrysts have led some workers to suggest that the protolith might have been a part of the Canadian Windermere Supergroup (F. R. Weber, personal communication, 1979).

Pelitic schist, quartzite, marble, and amphibolite (unit ps). These rocks are mostly medium- to coarse-grained pelitic schist and gneiss with minor interlayers of quartzite, quartzitic schist, marble, and amphibolite. Other rocks included in this unit are augen gneiss, calc-silicate, and ultramafic rocks. Regional metamorphism ranges from amphibolite to epidote-amphibolite facies (sillimanite + potassium feldspar to garnet grade in pelitic schist and gneiss) with the highest-grade rocks occurring in the southeastern part of the Circle Quadrangle; metamorphic grade decreases northward and westward. A characteristic mineral assemblage of the highest-grade rocks is quartz + plagioclase + white mica + biotite + sillimanite ± potassium feldspar ± garnet. Metamorphic grade seems to be close to the muscovite + quartz = sillimanite + potassium feldspar ± H_2O isograd. Other pelitic assemblages in the higher-grade part of the unit are: biotite + garnet + staurolite ± kyanite; biotite + garnet + kyanite; biotite + garnet + kyanite + sillimanite; all with quartz + white mica + plagioclase. Augen gneiss is mostly a biotite felsic gneiss containing augen-shaped potassium feldspar porphyroblasts. A characteristic mineral assemblage is potassium feldspar, commonly microcline + quartz + plagioclase + brown biotite + white mica. Augen are generally composed of two or more potassium feldspar crystals. Variations in the size of augen, relative proportions of major mineral constituents, and field relations suggest that the augen gneisses do not all have the same origin and that protoliths probably include both igneous and sedimentary rocks. Some augen gneiss occurrences may be folded and metamorphosed sills or dikes (F. R. Weber, personal communication, 1979), but other occurrences, especially those that cap high parts on ridges, could be thrust remnants of subterrane Y_1. A common pelitic assemblage to the north and west of the highest-grade rocks is quartz + white mica + biotite + garnet + chlorite + plagioclase. Mafic schist mineralogy is hornblende + plagioclase + quartz + epidote ± chlorite + biotite.

Small scattered outcrops of metamorphosed ultramafic rocks (too small to show on Fig. 2) consist mainly of actinolite, chlorite, serpentine, magnetite, chlorite, talc, and magnesite. Relict olivine, orthopyroxene, and clinopyroxene are found locally in rocks preserving textures of harzburgite. The ultramafic rocks appear to occur discontinuously at or near the edge of thrust plates composed of this unit.

Unit "ps" appears to have a metamorphic and deformational history similar to that described for unit "qq" in that isograds and folds are not related to contacts between the two units. As in unit "qq," all of the rocks of this unit are polydeformed, but polymetamorphism of regional extent has not been identified. However, contact metamorphism is indicated around some of the Tertiary plutons where pseudomorphs of white mica after staurolite and kyanite porphyroblasts occur.

The age of the protoliths of this unit is unknown. A single U-Pb age of 345 ± 5 Ma (Mississippian) (J. N. Aleinikoff, personal communication, 1985) was obtained on zircon from one augen orthogneiss, an age similar to that obtained on zircon from augen gneiss in subterrane Y_1 (Aleinikoff and others, 1986). Because this dated augen gneiss may be in thrust contact with the associated metasedimentary rocks rather than intrusive into them, its age may not provide an upper constraint on the protolith age of this unit. Although younger protolith ages cannot be ruled out, early and/or middle Paleozoic ages are reasonable possibilities for this unit.

Eclogite and associated rocks (unit ec). The only eclogitic rocks known in east-central Alaska occur in a small area in the southwestern part of subterrane Y_2, where bands and lenses of eclogite are intercalated with amphibolite, impure marble, pelitic schist, and mafic glaucophane-bearing schist (Fig. 2). They were first described by Prindle (1913) in what is now the southeastern part of the Livengood Quadrangle, but because of very limited exposure, were given little attention until rediscovered in the 1960s (Forbes and Brown, 1961). Swainbank and Forbes (1975) described their petrology. Eclogitic rocks also have been found in the southwestern part of the Circle Quadrangle (Foster and others, 1983).

The eclogitic rocks in the Livengood area consist of several combinations of garnet, omphacitic clinopyroxene, amphibole, calcite, phengitic mica, quartz, albite, epidote, sphene, and rutile (Swainbank *in* Hall and others, 1984). Bulk chemistry suggests that they may have been derived from marls and graywackes. Glaucophane and kyanite-staurolite-chloritoid–bearing assemblages also have been found (Brown and Forbes, 1984). Pyroxene-garnet, biotite-garnet, muscovite-paragonite, and aluminosilicate data suggest crystallization temperatures of 600° ± 50°C at pressures of 13 to 15 kb (Brown and Forbes, 1984). These eclogites are similar to eclogites from alpine-type orogenic terranes (Group C of Coleman and others, 1965). They occur in northwest-trending isoclinal recumbent folds that have been deformed by open or overturned folding along northeast-trending axes.

Eclogite in the Circle Quadrangle, which on the basis of garnet composition also falls within Group C of Coleman and others (1965), appears to be in a mafic layer within quartz + white mica + garnet (somewhat retrograded to chlorite) schist and quartzite. Where a contact is visible, foliation has the same orientation in both the mafic and pelitic layers. The mafic layer cuts across foliation and is more massive in the interior, which suggests that its protolith may have been a dike. A typical sample of the mafic layer consists of garnet, omphacite, quartz, clinoamphibole (barroisite to alumino-barroisite), clinozoisite, white mica, rutile, and sulfide (trace). Estimated conditions of metamorphism are 600° ± 50°C and 1.35 ± 0.15 GPa (Laird and others, 1984b).

Swainbank and Forbes (1975) recognized the probable fault relations of the eclogite unit es and suggested that it might be a window of older and more complexly metamorphosed rocks surrounded by an upper plate of younger, less metamorphosed rocks, or two terranes separated by a high-angle fault system. More recent examination of field relations and fabric orientations has led to the interpretation that this unit forms the upper plate of a folded thrust (Hall and others, 1984). In the Circle Quadrangle, Foster and others (1983) also show the eclogite in the upper plate of a thrust.

K-Ar determinations of age were made on several micas and amphiboles from the eclogite-bearing rocks of the Livengood area. A minimum age of 470 ± 35 Ma, determined from an amphibole in eclogite, is interpreted to indicate an early Paleozoic metamorphic event, probably associated with the early recumbent style of folding (Swainbank and Forbes, 1975). Several K-Ar ages of 103 to 115 Ma determined on mica in pelitic schist and garnet amphibolite are associated with a second metamorphic episode and with folding about northeast-trending axes (Swainbank *in* Hall and others, 1984). Because of the fault relations between the eclogite unit and the remainder of subterrane Y_2, the early Paleozoic radiometric age cannot be directly tied to events in other parts of subterrane Y_2 or YT. However, the late event (103 to 115 Ma) is most likely the same event that is widely recognized throughout much of the YT (see discussion of metamorphism in YTTN).

Subterrane Y_3 (Northern Big Delta, Fairbanks, southern Circle, Eagle, Charley River, and eastern Tanacross Quadrangles). Subterrane Y_3 was originally described only in the western part of the YTTN (Churkin and others, 1982), but we extend it to include the greenschist-facies rocks in the northeastern part of the YTTN. In the northern Big Delta, Fairbanks, and southern Circle Quadrangles, subterrane Y_3 separates subterrane Y_1 from Y_2. This part of subterrane Y_3 consists primarily of two distinct units of rocks that are in probable thrust contact with each other as well as with subterranes Y_1 and Y_2. The southernmost unit (unit ms, Fig. 2) consists mostly of greenish gray quartzose mylonitic schist; the more northerly unit (unit cp, Fig. 2) consists of gray calcareous phyllite and gray quartzite. In the eastern part of the Eagle Quadrangle, in the Tanacross Quadrangle, and in the south-central part of the Charley River Quadrangle, subterrane Y_3 includes three other units: one consists of fault blocks and slices of mylonitic schist, greenschist, quartzite, marble, greenstone, and phyllite (unit sm, Fig. 2); a second consists primarily of dark gray quartzite and gray quartz schist (unit qs, Fig. 2); and the third is characterized by light green quartz–chlorite–white mica schist (unit ws, Fig. 2). All three units are separated from one another and from subterrane Y_4 and Y_1 by faults.

Mylonitic schist (unit ms). The principal rock types of this unit (Fig. 2) are mylonitic schist, semischist, and quartz–white mica chlorite schist ± epidote, quartz sericite schist, and quartzite, with minor phyllite, marble, and greenstone.

Mylonitic textures, common throughout the unit, are more intense and more concentrated along the southern margin. Quartzite and quartzitic schist commonly have large gray, blue-gray, and clear glassy quartz grains, and some also have large feldspar grains (mostly microcline). The grains are commonly "eye-shaped" with "tails" of crushed recrystallized quartz. The marbles are fine to coarse grained and interlayered in schist and quartzite. Mafic greenschist and greenstone occur locally, particularly in the eastern exposures of the unit. Rocks of this unit are metamorphosed to the greenschist facies. Foliation, generally well developed, has been folded at least once.

The age of these rocks is unknown. Correlation has been suggested with the Totatlanika Schist in the northern Alaska Range, of probable Late Devonian to Mississippian age (Gilbert and Bundtzen, 1979), the Klondike Schist of the Yukon Territory (Weber and others, 1978), and the Macomb terrane of the Mount Hayes Quadrangle in the northern Alaska Range (W. J. Nokleberg, personal communication, 1985). Although there are some similarities in lithology among these units, the lack of data on age of protoliths and on their structural relations make such correlations speculative.

Calc phyllite–black quartzite (unit cp). A sequence of thin-layered calcareous phyllite, phyllite, and thin, crumbly carbonate layers is overlain by light to dark gray quartzite interlayered with dark gray to black argillite and phyllite. The quartzite is mostly medium grained, and thinly layered to massive. Foliation, incipient cleavage, and small isoclinal folds occur locally.

In the Circle Quadrangle, vitrinite reflectance studies (Laird and others, 1984a) indicate that most of these rocks were subjected to temperatures (180° ± 50°C) no higher than those normally associated with sediment diagenesis. One sample near a fault has been subjected to temperatures as high as 230° ±50°C. In the Big Delta Quadrangle, some of these rocks near Tertiary granitic intrusions have been contact metamorphosed. The grade of these rocks elsewhere in the Big Delta Quadrangle has not been determined but is probably mostly in the same range as those of the Circle Quadrangle.

No fossils have been found in these rocks; stratigraphic relations suggest that they may be of early or middle Paleozoic age. Contacts of this unit appear to be faults except where the contact is with Tertiary granite.

Schist, quartzite, and marble (unit sm). This is a varied unit of greenschist-facies rocks consisting of greenschist, calcareous greenschist, quartz–chlorite–white mica schist, marble, greenstone, quartzite including gray and dark gray quartzite, and schist with large quartz and/or feldspar grains. It crops out in the northeastern part of the Eagle Quadrangle south of the Tintina fault. Although this unit includes some rocks similar to those in units qs and ws (discussed below), it differs in having abundant layers and lenses of marble. The marble is mostly light gray, medium to coarsely recrystallized, and thin layered to massive; some is 100 m or more thick.

These rocks are commonly highly sheared and fractured and locally brecciated. In places they have a well-developed, northwesterly striking foliation. A strong, closely spaced (±10 cm apart) fold-axis lineation is locally conspicuous, especially in the more quartzose rocks. In places the resulting structure resembles mullions. Small faults having prominent gouge and breccia zones are abundant. Locally, the unit has the appearance of melange.

The stratigraphic and/or structural position of this unit is not clear, but the unit is probably overthrust by unit gs, making it the structurally lowest unit in the eastern part of the YTTN. The correlation of these rocks with rocks of the Yukon Territory is unknown. They may be a group of rocks not previously mapped in the western Yukon Territory or possibly a different facies or different part of the section of Green's (1972) unit B and/or unit A. We believe them to be of Paleozoic age on the basis of a few poorly preserved echinodermal fragments found in marble at several localities in the Eagle Quadrangle.

Quartz–chlorite–white mica schist group (unit ws). The most common rock type in this unit is light green or light greenish gray quartz–chlorite–white mica ± carbonate schist. Chlorite generally is minor. In the Tanacross Quadrangle, biotite locally may be present. Other interlayered rock types include quartzite, phyllite, and metavolcanic rocks of both mafic and felsic composition. Some schists have scattered coarse grains of gray, bluish gray, and glassy quartz, commonly with augen shape. Some quartz grains are single crystals; others are polycrystalline. Feldspar grains also occur in some schists. Minor actinolite and epidote locally may be present. Mylonite and partly recrystallized mylonitic texture occur.

Foliation is generally well developed. In the southeastern part of the Eagle Quadrangle, a strong lineation plunging westerly is formed by small, tight-to-isoclinal folds. These folds are refolded by generally northeast-trending folds that we believe may be related to thrusting. This unit probably also has been affected by late open folding that is not easily observed in the Eagle Quadrangle, but is evident in rocks adjacent to this unit in Canada.

In the Eagle Quadrangle, this unit is overthrust by, and in places imbricated with, amphibolite-facies rocks (Foster and others, 1985). In the Tanacross Quadrangle its contacts are poorly exposed. The unit is continuous to the east with similar rocks in the Yukon Territory, which are included in Green's (1972) unit B and were termed the "Klondike Schist" by McConnell (1905).

The age of protoliths of these rocks is unknown, and because all their contacts in Alaska are believed to be thrust faults, their stratigraphic position is also unknown. Middle or late Paleozoic protolith ages have been postulated (Tempelman-Kluit, 1976).

Quartzite and quartzitic schist (unit qs). Light gray to black quartzite, which ranges in grain size from very fine to medium, is the most common rock type in this unit (Fig. 2). Quartz grains are almost always highly strained. Outcrops are massive to schistose depending on the relative amounts of white mica and quartz. Gray phyllite, phyllitic and carbonaceous quartz schist, and graphitic schist layers occur locally.

These rocks generally have a well-developed foliation that regionally strikes approximately east-west, with both northward and southward dips ranging from 5 to 60°. Folds, commonly isoclinal, a few millimeters to several meters in wavelength and amplitude, deform foliation. Axes of these folds generally trend slightly north of west and have a shallow plunge (0 to 20°). Small (1 to 10 cm amplitude and wavelength), asymmetric, rootless folds defined by cream-colored fine-grained polycrystalline quartz may be an early phase of this deformation. An open folding, commonly having a wavelength of about 0.5 m and an amplitude averaging 10 cm, deforms early structures. The axial trend of the open folds is slightly west of north and plunges a few degrees to 25° northwest or southeast.

This unit crops out in a generally westerly trending belt in the east-central part of the Eagle Quadrangle and in a small area in the southeastern corner of that quadrangle. The unit continues eastward into Canada as part of Green's (1972) unit A and the Nasina Series of McConnell (1905). A Paleozoic age has been hypothesized (Foster, 1976), although no fossils have been found and contacts of the unit are probably all faults.

Subterrane Y_4 (Eagle and Tanacross Quadrangles). Subterrane Y_4 consists primarily of quartzitic and pelitic gneiss and schist, quartzite, marble, and amphibolite (unit gs, Fig. 2) metamorphosed to the amphibolite and epidote-amphibolite facies. On the north it is in thrust contact with greenschist-facies rocks of subterrane Y_3, on the west it has been extensively intruded by Cretaceous granitic plutons, and on the south a probable thrust fault separates it from subterrane Y_1. On the east it extends into the Yukon Territory of Canada. The unit typically consists of medium- to coarse-grained amphibolite, quartz–amphibole–biotite gneiss, quartz-biotite gneiss, marble, and quartzite. Because the composition of most of the gneiss and schist is quartzose, aluminum silicate minerals are rare; however, kyanite has been found in a few thin sections. White, light gray, or pinkish white marbles most commonly are coarse grained. Quartzite is mostly light gray and tan. In the northwestern part of subterrane Y_4 the unit consists of mostly schist, quartzite, and marble, all complexly deformed and intruded by dikes and plutonic rocks. The metamorphic grade locally may be as low as upper greenschist facies.

Foliation and compositional layering have been deformed into tight, asymmetric folds that are locally isoclinal. Wavelength and amplitude range from 0.5 m to several hundred meters. Fold axes have an average trend of N50°E and generally plunge less than 20° northwest or southeast. A second generation of folding, probably the same open-folding that has affected the rocks of adjacent subterranes, produced open folds with axes trending nearly north-south. The wavelength of these folds is about 0.5 m, and their average amplitude about 10 cm. Pre-metamorphic folding has not been definitely recognized, but may be indicated by rarely observed small, rootless folds. Thrust slices marked by zones of gouge, breccia, and small fault-related folds are common throughout subterrane Y_4.

The major regional metamorphism and accompanying deformation of these rocks is believed to have taken place during Late Triassic to Middle Jurassic time on the basis of ^{40}Ar-^{39}Ar incremental heating experiments. Granitic intrusion (Taylor Mountain, Mount Veta, and possibly other plutons) was probably synchronous with metamorphism and preceded thrusting of this unit over units ws and qs (Cushing and others, 1984a). The Early Cretaceous metamorphism that affected subterrane Y_1 also affected subterrane Y_4 but was of minor intensity (Cushing and others, 1984a).

The age of these rocks is poorly known, but they are considered Paleozoic on the basis of a few poorly preserved crinoid columnals (Foster, 1976) in marble. We know of no evidence for Precambrian protoliths in this unit.

Nonfoliated igneous rocks

Plutonic rocks. Nonfoliated igneous rocks occur throughout the YTTN and range in composition from ultramafic to felsic, but most are felsic. On the east side of the Shaw Creek fault (Fig. 2), some intrusions are of batholithic size, and small plutons, dikes, and sills are common throughout the YTTN. In the following discussion the terminology of Streckeisen (1976) is used.

Felsic granitic plutons. Three periods of Mesozoic and Cenozoic granitic intrusion are recognized in the YTTN. The oldest, Late Triassic and Early Jurassic (215 to 188 Ma) in age (unit JTrg, Fig. 2), occurs only in the eastern part of the YTTN (subterrane Y_4). The second, of Late Cretaceous age (95 to 90 Ma), occurs throughout the YTTN but is especially prominent in the central part (unit Kg, Fig. 2). The third, of Late Cretaceous and early Tertiary age (70 to 50 Ma), occurs throughout the YTTN but has particular significance in the northwestern part (unit Tg, Fig. 2).

The Late Triassic and Early Jurassic plutons include those of Taylor Mountain and Mount Veta, and possibly some plutons in the central and eastern parts of the Eagle Quadrangle. Locally, the margins of these plutons are sheared, crushed, and faulted. Taylor Mountain, in the south-central part of the Eagle and northern part of the Tanacross Quadrangles, is a batholith about 648 km^2 in area. It is mostly medium-grained, equigranular granite, but locally it is granodiorite to diorite. In places along the southern and eastern margins, its texture is slightly gneissic. Plagioclase (oligoclase to andesine), sericitized potassium feldspar, quartz, hornblende, and biotite are the major constituents; common accessory minerals are sphene, apatite, and opaque minerals. Plagioclase is generally zoned and sericitized. Quartz is strained, and the margins of some quartz grains are granulated. Hornblende is generally more abundant than biotite. Some biotite has altered to chlorite. The southern contact of the pluton is fairly sharp, and there is little evidence of thermal effects on the amphibolite-facies country rock. However, the country rock along the northeastern contact has been altered by the intrusion, and dikes and sills are numerous. Epidote is abundant in the contact zone. Conventional K-Ar dating has indicated an age of about 180 Ma for the Taylor Mountain batholith. ^{40}Ar-^{39}Ar determinations provide an integrated plateau age on hornblende of 209 $\pm$ 3 Ma (Cushing, 1984). A U-Pb determination on sphene gives a concordant age of 212 Ma (Aleinikoff and others, 1981). We thus believe that the batholith was emplaced in Late Triassic time.

Hornblende plagioclase porphyry is a characteristic intrusive rock in the vicinity of Mount Veta. Its mineralogy commonly is that of quartz monzodiorite, but more felsic compositions also occur. Some phases of the intrusion are equigranular. In some very coarse-grained porphyritic phases, a mineral alignment defines a weak foliation. Conventional K-Ar analysis of hornblende from this intrusion yielded an age of 177 $\pm$ 5 Ma (Foster, 1976), and an integrated plateau age of 188 $\pm$ 2 Ma was obtained by the ^{40}Ar-^{39}Ar method (Cushing, 1984). Some other hornblende-bearing plutons nearby have not been dated, but may be of similar age.

Figure 3 is a plot of fields of normative quartz, albite, and anorthite for representative granitic rocks in the YTTN. Two fields are plotted for Triassic and Jurassic plutons (Taylor Mountain and Mount Veta). These rocks are characteristically low in quartz, contain abundant hornblende, and in contrast to most granitic rocks in the YTTN, none is corundum normative. Mineralogical and common lead isotope data (J. N. Aleinikoff, personal communication, 1985) are consistent with a dominantly oceanic source for magmas that formed the Triassic and Jurassic plutons.

The Triassic and Jurassic plutons are similar in lithology and age to plutonic rocks of the Klotassin Suite in the Yukon Territory (Tempelman-Kluit, 1976). The Klotassin Suite has been interpreted as the roots of an island arc that formed on the margin of Stikinia (Tempelman-Kluit, 1979), a continental fragment that was joined to North America in Middle Jurassic time (Tempelman-Kluit, 1979). Tempelman-Kluit (1976) has suggested that the granitic rocks of Taylor Mountain may belong to the Klotassin Suite and thus would be a part of the Stikinia terrane (Silberling and others, this volume). However, the country rocks (subterrane Y_4) intruded by the pluton of Taylor Mountain are not typical of those that compose the Stikinia terrane in the parts of Canada where it is best known. Although subterrane Y_4 may not be a part of Stikinia, this does not preclude correla-

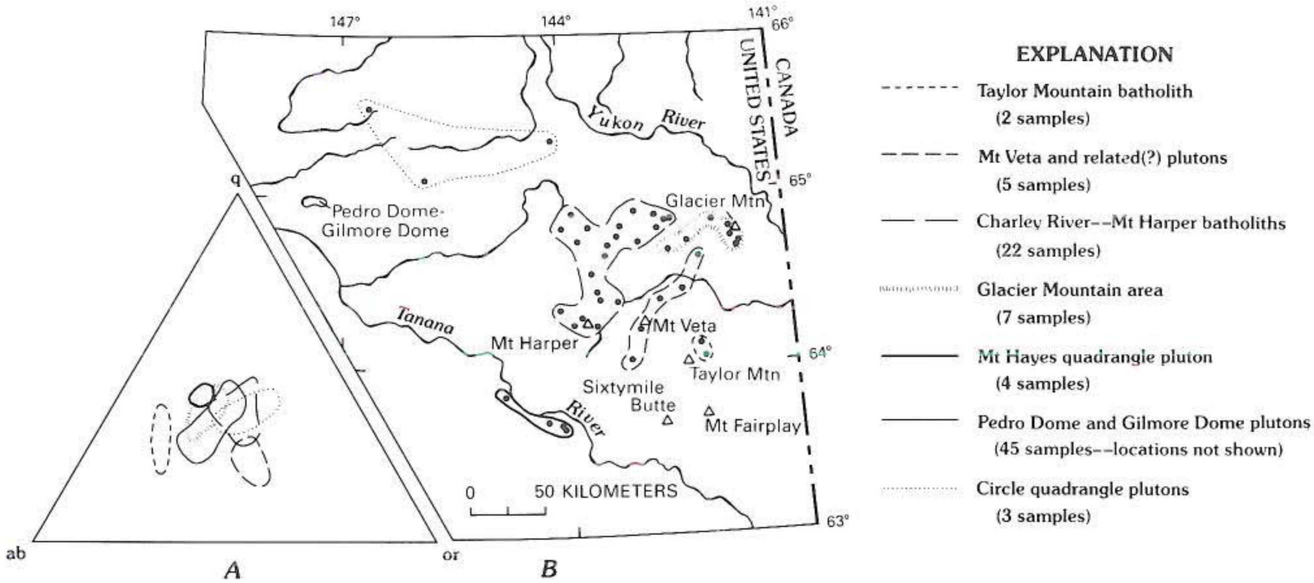

Figure 3. Normative mineralogical data for granitic plutons in the Yukon-Tanana terrane. A. Fields of normative mineralogy for samples of granitic plutons. B. Localities of samples (dots) used to define the mineralogical fields. Data primarily from Holmes and Foster (1968), Foster and others (1978a), Luthy and others (1981), Blum (1983), and Wilson and others (this volume).

tion of the granitic rocks of Taylor Mountain with the Klotassin Suite. Subterrane Y_4 may have been near or joined to the Stikinia terrane in Triassic or Early Jurassic time and involved in the same plutonic event.

Hornblende-bearing granitic rocks in the southeastern part of the Tanacross Quadrangle were included by Jones and others (1984) in the Stikinia terrane because they are adjacent to rocks of similar lithology to the east in the Yukon Territory that are included in the Klotassin Suite. However, these granitic rocks in Alaska are also adjacent, on the west, to lithologically similar Cretaceous granites. Neither the Alaskan nor the Canadian hornblende-bearing granites close to the U.S.–Canada border have been dated. More data are needed to determine the relations of these rocks and the extent of the Stikinia terrane.

Granitic rocks of Cretaceous age occur in bodies that range in size from less than 1 km^2 to plutons of batholithic proportions. Batholiths occur in the southeastern and northwestern parts of the Tanacross Quadrangle, the northeastern part of the Mount Hayes Quadrangle, and in the western part of the Eagle and eastern part of the Big Delta Quadrangle. The plutons range in composition from quartz monzonite to diorite but are dominantly granite and granodiorite. They are equigranular to porphyritic and are generally medium grained. The mafic minerals may be either hornblende or biotite, and most commonly both occur. Primary muscovite is rare and minor when present. Mylonitic textures are locally present, especially along major faults such as the Shaw Creek fault. Alteration of feldspars is slight to moderate, and biotite is commonly partly chloritized.

The age range of this group of intrusions, on the basis of conventional K-Ar analyses, is about 110 to 85 Ma, but most are about 95 to 90 Ma.

Nokleberg and others (1986) described some intrusive rocks of similar age in the northeastern part of the Mount Hayes Quadrangle as locally slightly to moderately schistose and slightly regionally metamorphosed, and suggested that those rocks were intruded during the waning stage of a major regional amphibolite-facies metamorphism in the mid- to Late Cretaceous. This Cretaceous metamorphism is not recognized as the major thermal event in other parts of the YTTN. We suggest that this event affected at least some other parts of the YTTN, but was of minor intensity. For instance, in subterrane Y_4 it has been detected by ^{40}Ar-^{39}Ar incremental heating experiments on minerals from amphibolite-facies metamorphic rocks (Cushing and others, 1984b).

Plots of normative quartz, albite, and orthoclase in samples from individual bodies of Cretaceous granitic rocks fall into distinct compositional fields. Figure 3 shows fields and locations for samples from the batholith(s) in the western part of the Eagle and eastern part of the Big Delta Quadrangle (Mount Harper–Charley River); from plutons in the northeastern part of the Mount Hayes Quadrangle; from small granitic bodies near Fairbanks (Pedro and Gilmore Domes); and from granitic bodies in the northeastern part of the Eagle Quadrangle (Glacier Mountain). The Cretaceous granitic rocks are richer in quartz than the Triassic and Jurassic granites, and most contain normative corundum. Blum (1983), in a detailed study of the small granitic bodies near Fairbanks, concluded, on the basis of petrography, major-oxide chemistry, and initial strontium isotopic ratios, that those granites formed either from a magma generated by partial melting of metamorphic rocks of continental affinities or from an initially mantle- or lower-crustal-derived melt with significant contamination from continental material. Common-lead ratios of Cretaceous granitic rocks from widely scattered localities in the YTTN also suggest a mixture of lead from two sources, one a continentally derived radiogenic source, and the other a more primitive oceanic source (J. N. Aleinikoff, personal communication, 1984).

In addition to granitic plutons, several small (generally less than 2 km^2) pyroxene diorite plutons are known in the Big Delta Quadrangle. These plutons range in age from about 93 to 90 Ma, based on conventional K-Ar analysis (Foster and others, 1979). Granitic rocks of this general age group are common in many parts of Alaska and the Yukon Territory. In the Yukon Territory they are included in the Coffee Creek Suite (Tempelman-Kluit, 1976).

The youngest intrusions, having Tertiary K-Ar ages of 70 to 50 Ma, are most prevalent in the northeastern part of the Big Delta and the Circle Quadrangle, although a few others are widely scattered throughout the YTTN. They are primarily granite in composition, but Mount Fairplay in the Tanacross Quadrangle ranges from hornblende–augite–biotite diorite through hornblende-augite syenite to hornblende-biotite quartz monzonite (Kerin, 1976). The Tertiary plutons are generally small (3 km^2 or less), medium to coarse grained, and equigranular to porphyritic. The mafic mineral is generally biotite. They are quartz-rich and corundum normative, characteristics of granites formed from magmas derived from continental crust. A field of normative quartz, albite, and orthoclase for samples of Tertiary granite from the Circle Quadrangle is shown in Figure 3.

Mafic and ultramafic differentiates. Bodies of coarse-grained (grains commonly 5 to 10 cm long) gabbro, hornblendite, and clinopyroxenite that appear to be mafic and ultramafic igneous differentiates occur in several widely scattered localities in subterranes Y_4, Y_2, and Y_1. Biotite-bearing hornblendite and clinopyroxenite (Type III of Foster and Keith, 1974) are most abundant, and in a few places, very coarse-grained gabbronorite and hornblende gabbro occur in association with coarse-grained ultramafic rocks. Epidote and garnet are locally abundant in the gabbros. The mafic and ultramafic igneous differentiates appear to have intruded regionally metamorphosed greenschist- to amphibolite-facies country rocks. Margins of some of the mafic and ultramafic igneous differentiates are foliated, but there is no foliation within the bodies. Felsic dikes intrude most of the mafic and ultramafic differentiates as well as the surrounding metamorphic country rock, but their genetic relations are not known. In the central part of the Eagle Quadrangle, K-Ar ages of biotite hornblendite are 175 ± 5.1 Ma on hornblende and 185 ± 5 Ma on biotite (recalculated from Foster, 1976). This ultramafic body could have a Late Triassic or Early Jurassic plutonic origin. In subterrane Y_1 in the Tanacross Quadrangle, biotite from olivine gabbro associated with a small ultramafic body has a K-Ar age of 66.6 ± 2 Ma (Wilson and others, 1985).

Ultramafic dikes or small plugs of fresh, nonmetamorphosed, cumulate-textured pyroxenite and olivine pyroxenite intrude greenschist-facies metamorphic rocks in the central Eagle Quadrangle. The dikes or plugs could either be differentiates of nearby granodiorite intrusions, or unrelated ultramafic intrusive rocks.

Volcanic rocks. Post-metamorphic volcanism occurred during the Cretaceous, Tertiary, and Quaternary and was most prevalent in the eastern YTTN. All of the nonmetamorphosed felsic volcanic rocks originally were considered to be of Tertiary age (Mertie, 1937), but K-Ar age dating has shown that welded tuffs and other felsic volcanic rocks (unit Kv, Fig. 2) covering a large area in the Tanacross Quadrangle are as old as Cretaceous (Bacon and others, 1985).

The Cretaceous volcanic rocks occur in and around three poorly exposed calderas in the central part of the Tanacross Quadrangle and consist of welded tuff, air-fall tuff, lava flows, ash-flow sheets, and small hypabyssal intrusions. Most are felsic and range from rhyolite to dacite in composition. Phenocrysts in rhyolite tuff, lava, and hypabyssal intrusions are quartz, sanidine, plagioclase, clinopyroxene, biotite, and iron and titanium oxides ± allanite. All phenocrysts except quartz, clinopyroxene, and allanite are generally altered. Common alteration minerals are sericite, illite, clinoptilolite, kaolinite, chlorite, quartz, and potassium feldspar (Bacon and others, 1985). Tuffaceous sedimentary rocks occur near the margin of one of the calderas.

Mafic and intermediate volcanic rocks are close to the felsic rocks, and we assume that some are also of Cretaceous age. However, in a few places where cross-cutting relations can be seen, the mafic rocks are younger than the felsic ones. Mafic rocks include potassic andesitic lava flows containing plagioclase, biotite, clinopyroxene, and in some places, hornblende phenocrysts, but detailed mineralogy of most of the mafic lavas is not known.

The K-Ar age of sanidine in welded tuff of the northernmost caldera is 93.6 ± 2 Ma, and of hornblende in rocks of the easternmost caldera is 90 ± 2.8 Ma (Bacon and others, 1985). These ages suggest that the volcanic rocks are related to the granitic plutons that were intruded during the 110- to 85-Ma intrusive episode and that they may be roof remnants of some of these plutons. Although the Mount Fairplay intrusive body in the north-central part of the Tanacross Quadrangle is partly surrounded by Cretaceous volcanic rocks, it appears to be unrelated to them and has a Tertiary K-Ar age (Foster and others, 1976).

Tertiary volcanic rocks (unit Tv, Fig. 2), as yet little studied, range from much-altered rhyolite to basalt in composition. They occur in the Tanacross, Eagle, and Big Delta Quadrangles and commonly are associated with hypabyssal dikes and small intrusions. They include lava flows, welded ash-flow tuff, and air-fall tuff. Locally, felsic tuff and possibly flows have been faulted, including thrust faulting, and small-scale deformation has resulted from the faulting. Sedimentary rocks, generally of limited extent, occur locally with volcanic rocks.

Sanidine in porphyritic rhyolite in the eastern part of the Big Delta Quadrangle was dated at 61.6 ± 2 Ma by the K-Ar method, and sanidine in welded tuff in the eastern part of the Tanacross Quadrangle yielded ages of 57.8 ± 2 and 56.4 ± 2 Ma (Foster and others, 1979).

We believe that some undated basaltic rocks (unit Qv, Fig. 2) in the Tanacross Quadrangle are of Quaternary age, largely on the basis of physiographic relations, but Prindle Volcano in the eastern part of the Tanacross Quadrangle leaves no doubt of its young age. Prindle Volcano is an isolated cone with a lava flow extending about 6.4 km downslope to the southeast from a breached crater. The cone and lava flow are composed of vesicular alkaline olivine basalt that contains abundant peridotite and granulite inclusions. The basalt consists of clinopyroxene, olivine, and opaque minerals in a fine-grained groundmass believed to contain occult nepheline and potassium feldspar (Foster and others, 1966). The peridotite inclusions range in size from xenocrysts to polycrystalline masses as much as 15 cm in diameter. Mineral assemblages include olivine, orthopyroxene, clinopyroxene, and spinel in at least five different combinations. The mineral assemblages of the inclusions are characterized by hypersthene and/or clinopyroxene and plagioclase, but also may include quartz and carbonate, along with such accessory minerals as apatite, zircon, magnetite, and rutile. The well-preserved cone suggests that the eruptive activity occurred during Quaternary time. Indirect evidence, which includes its possible correlation with a similar cone in the Yukon Territory, and the fact that its lava flow is overlain by white volcanic ash that is probably the White River Ash Bed, suggests that it is post–early Pleistocene, but older than 1,900 yr B.P. (Foster, 1981).

A number of unconsolidated volcanic ash deposits occur in the YTTN, and some are fairly well dated. Most, such as the White River Ash Bed, probably originated outside of the YTTN (see section on Quaternary geology: Volcanic ash).

Sedimentary rocks (YTTN). The unmetamorphosed sedimentary rocks of the YTTN (unit TKs, Fig. 2) are all of nonmarine origin, of Late Cretaceous and/or Tertiary age, and of limited areal extent. They appear to have been deposited in small, disconnected basins, at least some of which resulted from faulting. Some sedimentary rocks are closely associated with volcanic rocks, and most include considerable amounts of tuff. They have been deformed by folding (Foster and Cushing, 1985) and in some cases, by thrusting and high-angle faulting.

The largest area of sedimentary rocks is in the northern part of the Eagle and southern part of the Charley River Quadrangle both north and south of the Tintina fault. In some places, sedimentary rocks cover the faults of the Tintina system, but in other places they are cut by the faults. These rocks are dominantly conglomerate, but include sandstone, mudstone, shale, breccia, lignite, and coal. Most of the conglomerate consists of well-rounded white and tan quartz and black chert clasts 2 to 13 cm in diameter in a quartzose matrix. Where bedding can be detected, dips as steep as 60° occur, and most of the rocks dip at least 20°. The conglomerate and sandstone were not principally derived from the local metamorphic terrane but probably from more distant sources north of the Tintina fault. Pollen and poorly preserved plant fragments and impressions indicate that the rocks may range in age from Late Cretaceous to Pliocene (Foster, 1976).

Several small patches of Tertiary sedimentary rocks (unit Ts, Fig. 2) occur in the southeastern part of the Eagle Quadrangle. They are mostly conglomerate and sandstone, but near the town of Chicken also include coal seams, white tuff, and glassy tuff containing abundant plant fragments (Foster, 1976).

Folded conglomerate, sandstone, argillite, tuff, tuffaceous argillite, and sandstone with some lignite and carbonaceous layers form a discontinuous belt about 30 km long in the north-central Tanacross Quadrangle. Poorly preserved pollen indicates that deposition was in Late Cretaceous(?) time (Foster, 1967), but pollen in some of the deposits is as young as Neogene (Yaeko Igarashi, personal communication, 1985). In addition to Cretaceous and Tertiary pollen, these rocks also contain monosulcate pollen of Devonian age (Foster, 1967), suggesting that at the time of sediment deposition on the underlying metamorphic terrane, this terrane was located where pollen could be derived from nonmetamorphosed Devonian rocks (Foster, 1967).

Other sedimentary rocks appear to have been deposited in basins associated with a Late Cretaceous volcanic complex near Mount Fairplay and Sixtymile Butte (Foster, 1967).

In the northeastern part of the Tanacross Quadrangle, unconsolidated to poorly consolidated gravel and conglomerate resting unconformably on metamorphic rocks occur in a small area at about 1,266 m altitude. The gravel is composed mostly of yellowish white quartz pebbles and well-rounded, polished chert pebbles 1 to 15 cm in diameter. The chert pebbles are not locally derived. This deposit has been interpreted as most likely late Tertiary in age, but could be of early Pleistocene age (Foster, 1970).

Metamorphism

Regional metamorphism throughout the YTTN ranges from very low grade (about equivalent to burial metamorphism) to amphibolite facies of about the second sillimanite isograd. Changes in metamorphic grade across subterrane boundaries are commonly abrupt and can be attributed to juxtaposition of rocks of different metamorphic grade by faulting, particularly thrust faulting. Gradational changes in metamorphic grade are documented within subterranes Y_1 and Y_2. More than one period of regional metamorphism has not been recognized petrographically, except in the ecologitic rocks, where barroisite is rimmed by hornblende and omphacite is altered to cryptocrystalline material; but further work is needed, especially in consideration of possible evidence from radiometric age determinations of more than one period of regional metamorphism.

Pressures during metamorphism were probably mostly moderate, but the dominance of quartzitic over pelitic compositions makes determining the pressures (and temperatures) of metamorphism difficult. Kyanite is common in the southeastern part of subterrane Y_2 and northern part of subterrane Y_1 and occurs rarely in subterrane Y_4. In the Circle Quadrangle (subterrane

Y_2), mineral assemblages in pelitic rocks indicate progressive metamorphism along a P-T path similar to Barrovian metamorphism in Scotland (path A, Harte and Hudson, 1979). Medium-pressure metamorphism is also indicated by the amphibole composition in mafic schist (using the criteria summarized by Laird, 1982).

Andalusite + kyanite and andalusite + sillimanite occur in the southeastern part of subterrane Y_2, but it is not clear that the andalusite formed at the same time as kyanite and sillimanite, and it may instead be related to nearby Tertiary plutons. In subterrane Y_1, all three Al_2SiO_5 polymorphs have been identified along the Salcha River (Dusel-Bacon and Foster, 1983), suggesting metamorphism at about 0.4 GPa (using the data of Holdaway, 1971). Farther south, sillimanite + andalusite and sillimanite + cordierite (Dusel-Bacon and Foster, 1983, Fig. 2) may indicate low-pressure–facies series regional metamorphism.

Evidence of high-pressure metamorphism has been found in two areas, each fault-bounded. Glaucophane + epidote + chlorite + albite + white mica + sphene + carbonate ± garnet schist occurs in a fault slice in the northern part of the Eagle Quadrangle. Eclogite and rare glaucophane-bearing assemblages have been found in the southwestern part of the Circle Quadrangle and southeastern part of the Livengood Quadrangle. The estimated conditions of metamorphism in both areas of eclogitic rocks are about 600°C and 1.4 GPa (Laird and others, 1984b; Brown and Forbes, 1984).

The highest documented regional metamorphic grade is in the sillimanite gneiss dome of subterrane Y_1, where metamorphic grade reaches and probably surpasses the second sillimanite isograd, and partial melting may have occurred (Dusel-Bacon and Foster, 1983). Temperatures between 655° and 705° ± 30°C are indicated by garnet-biotite geothermometry. To the northeast, metamorphic grade decreases through the staurolite stability field to garnet grade, where the rocks are in contact with the weakly metamorphosed rocks of subterrane Y_3. In subterrane Y_2, metamorphic grade decreases gradually from sillimanite + muscovite and perhaps sillimanite + K feldspar in the southeast to staurolite + kyanite, garnet, and then biotite grade farther north and west.

The lowest metamorphic grade is in rocks in the southern part of the Circle Quadrangle (subterrane Y_3) and in the eastern part of the Eagle Quadrangle (Seventymile terrane). The quartzite and quartzitic schist (unit cp) in the southern Circle Quadrangle have been shown by vitrinite reflectance (Laird and others, 1984a) to be in the range of normal sediment diagenesis. We believe that these rocks are in thrust contact with garnet- and staurolite-grade rocks. In the Eagle Quadrangle, slightly metamorphosed sedimentary rocks occur with greenstone in thrust sheet remnants of the Seventymile terrane.

Contact metamorphism is primarily associated with Tertiary plutons, but in a few places may be peripheral to Cretaceous plutons. Around many Tertiary plutons, biotite has grown across the foliation of the regionally metamorphosed rocks. In the southern part of subterrane Y_2, contact metamorphism associated with Late Cretaceous and/or early Tertiary plutons have retrograded staurolite and kyanite porphyroblasts to white mica. In the central part of the Circle Quadrangle (subterrane Y_2), hornfelsic growth of biotite and amphibole is associated with small felsic intrusions and has overprinted probable garnet-grade regional metamorphism. Contact metamorphism up to sillimanite grade has overprinted staurolite + kyanite-grade regional metamorphism. In the south-central part of the Eagle Quadrangle, contact metamorphism is indicated by andalusite in schist near a small Cretaceous or Tertiary pluton.

Limited radiometric age data suggest that time(s) of major regional metamorphism(s) may have differed in the four subterranes of the YTTN. In subterrane Y_1, U-Pb zircon ages indicate that amphibolite-facies regional metamorphism was synchronous with or followed emplacement of a belt of felsic Mississippian plutons (now augen gneiss), but preceded intrusion of Cretaceous plutons (Dusel-Bacon and Aleinikoff, 1985). Metamorphism predates Tertiary and probable Cretaceous plutonism in subterranes Y_3 and Y_2. ^{40}Ar-^{39}Ar incremental heating experiments indicate that major regional amphibolite-facies metamorphism in subterrane Y_4 peaked about 213 ± 2 Ma, but the extent of the area affected by this event is not known (Cushing, 1984). Conventional K-Ar dating indicates a metamorphic event, which apparently was widespread in the YTTN, in the Early Cretaceous (125 to 110 Ma; Wilson and others, 1985). ^{40}Ar-^{39}Ar data indicate that in the eastern part of the Eagle Quadrangle this Early Cretaceous regional event was of low metamorphic grade and had relatively minor effects, although it could have been a major event elsewhere (Cushing and others, 1984a). Sufficient data are not yet available to delineate and compare the metamorphic events of the four subterranes.

Mineral resources

Gold, primarily in placer deposits, has been the most important mineral resource in the YTTN. It has also been produced from lodes in the Fairbanks district and in minor amounts elsewhere. Small amounts of antimony and tungsten have been produced from lode deposits in the Fairbanks district during periods of high prices. Exploration has identified occurrences of copper-molybdenum porphyry and tungsten skarn. Widespread geochemical anomalies, and scattered occurrences and prospects, suggest that the region may contain granite-related uranium deposits, lode tin deposits (most likely greisen), platinum deposits of mafic igneous association, and sedimentary exhalative zinc-lead deposits.

A little coal has been produced for local use, and unmeasured coal resources in Late Cretaceous and/or Tertiary sedimentary rocks may be significant. Geothermal springs are known at three localities (Fig. 4) in the YTTN, and are exploited for recreation and local use at two locations.

Figure 4 shows the distribution of selected deposits, prospects, and occurrences by probable deposit type. Entries were selected to show: (1) important deposits, (2) spatial patterns of occurrence, and (3) the different types of occurrence. Patterns in the distribution of particular types of deposits suggest that there is some relation of mineral occurrence to subterranes (Nokleberg and others, this volume, Chapter 29 and Plate 11). Although mining has taken place in the region since the 1890s, it is only in recent years that there has been systematic exploration for deposits other than gold lodes and placers. New types of mineral deposits have been found, and as the discovery of a diamond in a placer deposit in the Circle district (Fairbanks Daily News-Miner, Dec. 11, 1984) attests, unexpected types of deposits undoubtedly await discovery.

Gold placers and lode deposits. Gold has been, and continues to be, the most important mineral commodity in east-central Alaska. Most of the gold has been produced from placers; lode production has been significant only in the Fairbanks district, and in most districts the amount of gold in known lode sources is small relative to that in placers. Gold deposits are found in all of the subterranes of the YTTN, but the greatest production

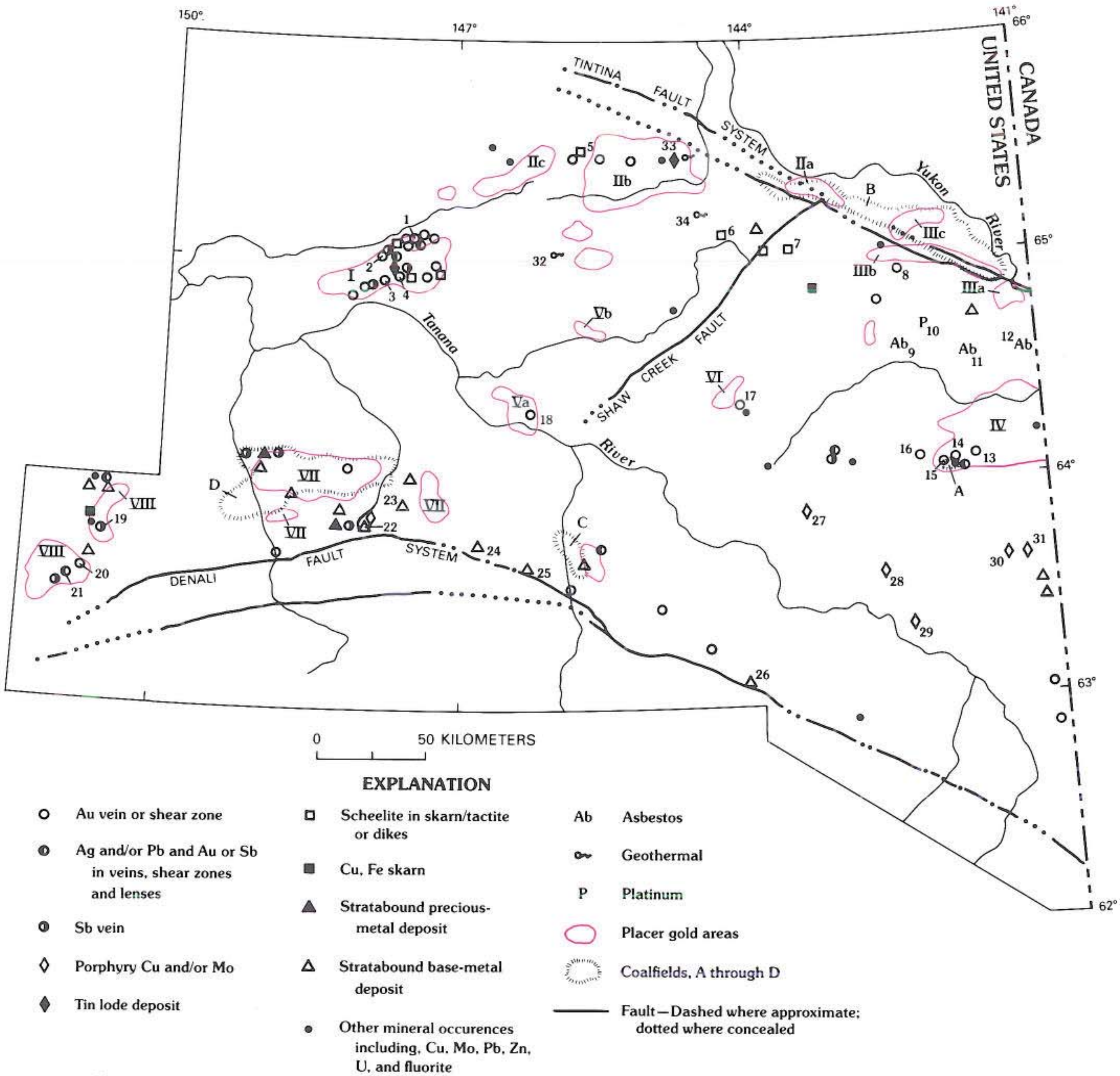

Figure 4. Map showing selected mineral deposits, occurrences, and prospects in east-central Alaska. Numbers and letters refer to localities mentioned in text. Data primarily from Berg and Cobb (1967), Cobb (1973), Singer and others (1976), Eberlein and others (1977), MacKevett and Holloway (1977), Barker (1978), Gilbert and Bundtzen (1979), and Nokleberg and others (this volume, Chapter 29 and Plate 11).

and most extensive placers are in subterrane Y_2. Because geologic characteristics and ore controls vary among the districts, these features are discussed separately for the largest districts.

Fairbanks district. Gold was first discovered in streams of the Fairbanks district (No. I, Fig. 4) in 1902 by Felix Pedro. This district, the largest producer in east-central Alaska, has yielded about 7,750,000 oz of gold from placers and approximately 250,000 oz of gold from lodes (Bundtzen and others, 1984). Production from lodes has been concentrated in four areas: Cleary Hill (No. 1, Fig. 4), Treasure-Vault Creek (No. 2, Fig. 4), Ester Dome (No. 3, Fig. 4), and Gilmore Dome (No. 4, Fig. 4). In each of those areas, placers are closely associated with lodes.

The placers drain, and the lodes occur in, the quartzite and quartzitic schist unit of subterrane Y_2 (particularly the Cleary sequence of the Fairbanks Schist of Smith and Metz, *in* Nokleberg and others, this volume, Chapter 29 and Plate 11). In the Fairbanks area, the quartzite (unit qq) has undergone early isoclinal folding and later east-northeast–trending broad open folding. Cretaceous felsic plutonic rocks (Blum, 1983) have intruded the Cleary sequence along the axes of broad anticlinal structures. Lodes, except on Ester Dome, occur primarily as east-west–trending auriferous veins in shears and crushed zones, but locally lodes lie parallel to foliation. Several types of lodes are recognized, including: (1) simple pyrite-arsenopyrite-gold quartz veins, (2) gold-sulfosalt-sulfide-quartz veins, and (3) late stibnite veins, and (4) gold-scheelite veins. Smith and Metz (*in* Nokleberg and others, this volume, Chapter 29 and Plate 11) present geochemical characteristics of some of the vein types. Early workers (Hill, 1933) stressed the structural control of lodes and their relation to granitic intrusions; recent workers (Smith and Metz *in* Nokleberg and others, this volume, Chapter 29 and Plate 11) have stressed the association of the lodes with the Cleary sequence and have suggested that, because of inherent geochemical enrichment, it is an important ore control.

Circle district. The Circle district, one of the oldest mining districts in interior Alaska, has produced at least 850,000 oz of gold (Bundtzen and others, 1984), all from placers. The deposits occur in three separate areas (Nos. IIa, IIb, and IIc, Fig. 4), and characteristics of the deposits and probable sources of gold vary with the area.

In the eastern area (most of which lies just outside of the YTTN) (No. IIa, Fig. 4) the principal productive streams (Woodchopper and Coal Creeks) have produced at least 20,000 oz of gold, mostly from stream, but including bench, placers. These streams drain a diverse group of rocks including schist and gneiss of subterrane Y_2; phyllite, argillite, and quartzite of subterrane Y_3; Tertiary sedimentary rocks; Cretaceous granite; and unmetamorphosed rocks north of the YTTN. Mertie (1938) believed that the proximal source of the placers was gold in the Tertiary sedimentary rocks.

Most of the district's gold has been produced from stream placers in the eastern half of the central part of the district (No. IIb, Fig. 4). Streams drain the quartzite and quartzitic schist unit of subterrane Y_2 and Tertiary granite. No large lode sources of gold have been discovered, but samples of small limonite-stained quartz veins, arsenopyrite-bearing shear zones, zones of silicified breccia, and felsic dikes contain traces of gold. Mertie (1938) suggested that sources of gold in the streams were auriferous fracture zones, veins, breccias, and felsic dikes that developed and were emplaced above the Circle pluton, and recent work (Menzie and others, 1983) supports this hypothesis.

The western part of the Circle district (No. IIc, Fig. 4) has been the least productive part. Only Nome Creek had substantial production. Considering the mining method, duration of operation, and limited production data, Nome Creek probably produced between 10,000 and 20,000 oz of gold. The streams in the western Circle district drain the quartzite and quartzitic schist unit of subterrane Y_2, a biotite granite pluton, and felsic hypabyssal rocks.

Eagle district. Gold was discovered in streams of the Eagle (Seventymile) district between 1895 and 1898. The district includes American Creek and its tributaries, Discovery Fork and Teddy's Fork (IIIa, Fig. 4); the Seventymile River and its tributaries, Flume, Alder, Barney, Broken Neck, Crooked, and Fox Creeks (IIIb, Fig. 4); and Fourth of July Creek and Washington Creek and their tributaries, which are mostly north of the YTTN (IIIc, Fig. 4). The district has produced at least 30,000 oz of gold and byproduct silver, all from stream and bench placers. Gold alloyed with platinum was found at Fourth of July Creek and the mouth of Broken Neck Creek, and a few platinum nuggets were reportedly recovered from a tributary (Lucky Gulch) to the Seventymile River (Cobb, 1973). Flume, Alder, and American Creeks drain mafic and ultramafic rocks of the Seventymile terrane and quartzite, marble, phyllite, and graphitic schist of subterrane Y_3 (Foster, 1976). Barney, Broken Neck, Fox, Crooked, Fourth of July, and Washington Creeks drain mostly sedimentary rocks of Cretaceous and/or Tertiary age (Foster, 1976; Brabb and Churkin, 1969).

Mertie (1938) believed that the sources of the placer gold in streams that drain the Seventymile terrane and subterrane Y_3 were quartz veins and mineralized zones that were genetically related to granitic rocks, and work by Clark and Foster (1971) supports this view. Clark and Foster reported anomalous values of gold in hydrothermally altered rocks, including silica-carbonate rocks, serpentinite and diorite, and quartz veins adjacent to a northwest-trending fault zone between Alder and Flume Creeks (No. 8, Fig. 4). They also detected arsenic in soil samples taken across a probable fault that strikes northwest across Teddy's Fork. Sources of the gold in streams that drain the Cretaceous and/or Tertiary sedimentary rocks may be paleoplacers (Mertie, 1938), but metamorphic rocks, which underlie the sedimentary rocks, and some dike rocks may also be sources.

Fortymile district. Gold was initially discovered on the Fortymile River in 1886 (Prindle, 1905) and on its tributaries between 1886 and 1895 (Mertie, 1938; IV, Fig. 4). Gold production of at least 417,000 oz (Cobb, 1973) has come mostly from stream and low bench placers; however, a few high bench placers have been worked occasionally. The streams of the Fortymile district drain a diverse group of rocks that include quartz-biotite gneiss and schist, quartzite, marble, and amphibolite of subterrane Y_4; quartzite, marble, phyllite, graphitic schist, and greenschist of subterrane Y_3; greenstone, serpentinite, and associated sedimentary rocks of the Seventymile terrane; granodiorite, quartz monzonite, quartz diorite, and diorite of the Taylor Mountain batholith; and various undivided granitic rocks whose age is thought to be Mesozoic or Tertiary (Foster, 1976).

At least three types of small lode sources of gold are present in the Fortymile district. One type, exemplified by the Purdy (Foster and Clark, 1970), Ingle, and Tweeden lodes (Nos. 14, 15, 16, Fig. 4), comprises gold-bearing quartz + calcite veins in metasedimentary and metavolcanic rocks of the Seventymile terrane and in intermediate-composition plutonic rocks that intrude the terrane. Gold has also been detected in altered diorite in the bedrock of Lost Chicken Creek (Foster and O'Leary, 1982) and in metatuff in an outcrop in the South Fork of the Fortymile River (No. 13, Fig. 4). The second type of lode gold occurrence is gold in quartz veins in subterrane Y_4. Mertie (1938) reported such an occurrence along Wade Creek and thought that the veins were related to a granite intrusion at depth. A third type of gold occurrence is gold in and adjacent to crushed zones and faults. Such zones are thought to be a source of gold in Dome Creek and Canyon Creek (Mertie, 1938). The recognition of major thrust faults within the Fortymile region (Foster and others, 1984) provides other possible sites of lode concentrations of gold.

Richardson district. The Richardson district includes scattered gold placers in the western part of the Big Delta Quadrangle. The two main areas of gold production are: (1) Tenderfoot Creek and adjacent streams, and (2) Caribou Creek and adjacent streams (areas Va and Vb, Fig. 4). Bundtzen and Reger (1977) estimated production at 95,000 oz of gold and 24,000 oz of silver; additional production from residual placers has taken place since 1979 (Eakins and others, 1983).

In the Tenderfoot Creek area, gold has been produced from stream and residual placers; Tenderfoot Creek is the main productive stream. The placers are buried beneath a deep cover of loess. The only known lode source of gold in this area is the Democrat lode (No. 18, Fig. 4), where gold occurs in altered and veined quartz porphyry. A sample of altered quartz porphyry yielded a K-Ar age of 89.1 ± 2.7 Ma (Wilson and others, 1985, after Bundtzen and Reger, 1977). Bundtzen and Reger regarded this age as the probable time of mineralization and noted that the distribution of the quartz porphyry and the gold placers in the Tenderfoot Creek area appears to be controlled by a northwest-trending lineament.

Gold production from the Caribou Creek (No. Vb, Fig. 4) area has come exclusively from stream placers, mostly along Caribou Creek. No lode sources of gold are known. However, the geochemistry of rock samples (Foster and others, 1978c) indicates that iron-stained areas adjacent to dikes, plutons, and local shear zones commonly contain anomalous amounts of arsenic, antimony, and zinc and in places contain silver, lead, or gold.

Tibbs Creek–Black Mountain area. The Tibbs Creek–Black Mountain area is one of the few areas that has produced lode gold, and this production probably exceeded that from the area's placers (VI, Fig. 4). The Blue Lead, Gray Lead, and Grizzly Bear (No. 17, Fig. 4), the principal mines, were operated mainly in the 1930s, although there was an attempt at further production in the late 1970s. About 32 oz of gold and 25 oz of silver were produced from quartz veins that cut metamorphic rocks and Cretaceous(?) granite. The veins are especially abundant and most productive near the contact of the metamorphic and granitic rocks. There are also minor occurrences of antimony and molybdenum nearby. Streams draining the area, such as Tibbs Creek, have had minor placer operations (Menzie and Foster, 1978).

Porphyry copper-molybdenum deposits. Porphyry copper-molybdenum occurrences in the Tanacross Quadrangle and in the adjacent Yukon Territory constitute the "interior porphyry belt" of Hollister and others (1975). A number of occurrences, including Mosquito, Paternie, Asarco, Bluff, and Taurus (Nos. 27, 28, 29, 30, and 31, Fig. 4), are known in the Tanacross Quadrangle (Singer and others, 1976), and ten occurrences are known in the Yukon Territory (Sinclair, 1978). The porphyry occurrences in Alaska are confined to subterrane Y_1 and are thought to be associated with Cretaceous and early Tertiary porphyritic, felsic subvolcanic stocks. These stocks were intruded into coeval volcanic rocks, Cretaceous plutonic rocks, and schist and gneiss. The porphyry deposits formed within and adjacent to subvolcanic stocks and breccia pipes. Although early Tertiary volcanic rocks and associated intrusive rocks occur in the eastern part of the Big Delta and western part of the Eagle Quadrangle, presently known porphyry occurrences are confined to the Tanacross Quadrangle.

The deposits of the interior belt display many characteristics typical of porphyry deposits elsewhere: (1) they are associated with felsic, subvolcanic intrusive rocks; (2) they are surrounded by large areas of hydrothermally altered rocks; (3) common hypogene minerals in the deposits are pyrite, chalcopyrite, molybdenite, and in some cases magnetite; and (4) supergene enrichment is an important control on the grade of mineralization. Deposits of the interior belt differ from other porphyry deposits in their reported lower grades and smaller tonnages (Singer and others, 1976). The inferred resources at Taurus are 50 million tons of 0.3 percent copper and 0.07 percent molybdenum (Chipp *in* Nokleberg and others, this volume). Taurus reportedly contains a considerable amount of supergene-enriched material. Hypogene ore in deposits of the interior belt is reported to be lower in grade than supergene ore by a factor of 1.5 to 2 (Godwin, 1976; Sawyer and Dickinson, 1976).

Tungsten. Tungsten, mainly in scheelite, occurs in the quartzite and quartzitic schist and the pelitic schist units (qq and ps) of subterrane Y_2; small amounts of tungsten have been produced from deposits hosted by the quartzite and quartzitic schist unit adjacent to Cretaceous granite or granodiorite intrusions northeast of Fairbanks. Production has been limited to the Fairbanks district, but exploration has identified a number of significant prospects elsewhere in subterrane Y_2. Near one prospect, Table Mountain (No. 5, Fig. 4), scheelite is present in sediments of streams that drain the quartzite and quartzitic schist unit, and a Tertiary(?) granite intrusion. There, tungsten occurs in thin marble layers in the quartzite and quartzitic schist unit, probably above a cupola of the intrusion. Scheelite is widely distributed in sediments of streams that drain the pelitic schist unit (Menzie and others, 1983). In recent years a number of occurrences have been discovered in this unit adjacent to Cretaceous(?) and Tertiary granitic intrusions in the southeastern part of the Circle Quadrangle (No. 6, Fig. 4), in the southwestern part of the Charley River Quadrangle (No. 7, Fig. 4), and in the northwestern part of the Eagle Quadrangle (Foley and Barker, 1981).

Published studies of the ore controls of the tungsten deposits are limited to the Fairbanks district. Byers (1957), who mapped many of the deposits and favored their contact-metasomatic origin, stated that the distribution of tungsten minerals was probably controlled by the occurrence of limestone within the contact zone of porphyritic granite; by local structural irregularities, such as drag folds, that localized ore deposition; and by tungsten-bearing quartz pegmatite that filled fractures in the rocks above the porphyritic granite. Metz and Robinson (1980), following the ideas of Maucher (1976), suggested, on the basis of amphibolite in the footwall of some of the Fairbanks deposits, that the deposits may be remobilized syngenetic deposits.

Petrologic and geochemical studies of the plutons related to the deposits of the Fairbanks district (Blum, 1983) suggest that they formed by remelting of Precambrian crustal material, but do not identify a specific source for the tungsten.

Tin. Cassiterite is widely distributed as an accessory mineral in stream sediments and placer concentrates of the northwest part of the YTTN; however, only a few lode tin occurrences have been identified, and little has been published on their characteristics. Nevertheless, the occurrence of cassiterite in stream sediments and the presence of both Cretaceous and Tertiary granites, which are petrologically and geochemically similar to granites in tin-bearing regions (Fig. 3), suggest that parts of the YTTN that contain such granites may also contain unidentified lode and/or associated placer tin deposits (Menzie and others, 1983). Lode deposits, if present, are likely to be large, low-grade greisen deposits, although skarn and vein deposits may also occur. A small amount of tin has been recovered from several creeks in the Circle District as a byproduct of gold mining (P. Jeffrey Burton, written communication, 1983).

Uranium. Anomalous levels of uranium have been detected in springs and stream sediments (Barker and Clautice, 1977; Menzie and others, 1983) in the northwestern part of the YTTN. The anomalies are spatially associated with biotite granites of early Tertiary age (Fig. 3).

Platinum. Anomalous amounts of platinum and palladium were detected in samples of a gabbro intrusion at one locality (No. 10, Fig. 4) in the Eagle Quadrangle (Foster, 1975), and smaller amounts of platinum were detected in similar mafic to ultramafic intrusive rocks elsewhere in that quadrangle (Foster and Keith, 1974). Such intrusive bodies could serve as sources for platinum in placer deposits.

Stratabound mineral occurrences. Although no stratabound lode deposits are known in the YTTN, the following general observations suggest that such deposits may be present: Paleozoic metasedimentary and metavolcanic rocks in subterranes Y_2, Y_3, and Y_4 are similar to those hosting such deposits in other parts of the northern Cordillera; geochemical anomalies in stream-sediment samples occur in several areas; and recent exploration has located areas favorable for prospecting for stratabound deposits in several subterranes of the YTTN.

In addition, galena has been reported as float and in stream sediments in subterrane Y_4, and possible stratabound deposits have been identified in the eastern parts of subterranes Y_3 and Y_4. In the western part of the YTTN, anomalous amounts of zinc, silver, and barium in sediment samples from streams draining the calc phyllite-black quartzite unit of subterrane Y_3 led Menzie and Foster (1978) to suggest that this unit may host stratabound deposits.

Coal. Coal deposits occur in Late Cretaceous and/or early Tertiary nonmarine sedimentary rocks in two areas of the YTTN. One area is near the village of Chicken, in the south-central part of the Eagle Quadrangle (A, Fig. 4), and the other is along the northeastern margin of the YTTN and probably extends north of the YTTN (B, Fig. 4). The characteristics of these coal fields are summarized in Table 2; their resources have not been estimated.

Geothermal resources. Three hot spring areas occur in the YTTN, all in the Circle Quadrangle (Waring, 1917). The hot springs are hydrothermal convective systems heated by deep circulation along faults associated with early Tertiary granitic plutons (Miller and others, 1975). The Chena Hot Springs (No. 32, Fig. 4) have a maximum measured surface temperature of 67°C and a discharge of approximately 800 l/min; maximum temperature at Circle Hot Springs (No. 33, Fig. 4) is 57°C, and discharge is approximately 500 l/min. Respective reservoir temperatures are calculated as 100° and 128°C; the springs thus are classified as intermediate-temperature hydrothermal convection systems (Brook and others, 1979). Springs in the third area (No. 34, Fig. 4) have a maximum measured surface temperature of 61°C (Keith and others, 1981b). Chena and Circle Hot Springs are used primarily for recreational purposes, although minor other uses of the hot water have been made. The third hot spring area is not developed because of its remote location.

Application of isotopic-dating techniques

Determining definitive ages of the rocks in the YTTN and the time(s) of their metamorphism, intrusion, and deformation is difficult owing to lack of fossils, poor exposures, and the region's complex metamorphic and deformational history. Isotopic techniques for dating rocks thus have become the principal means of

TABLE 2. COAL FIELDS OF YTTN*

Field	Size	Structure	Seam characteristics	Rank	Sulfur content	Development status
Eagle	130 by 3 to 16 km (80 by 2 to 10 miles)	Open folds	Near Washington Creek, five seams are at least 1.3 m thick	Subbituminous	Low	None
Chicken		Vertical beds	One seam is at least 6.8 m thick	Unknown	Unknown	Minor past production for local use

*Reference: Barnes (1967)

obtaining data on the ages of rocks and the thermal/metamorphic events.

The first isotopic data for rock samples from the YTTN came from lead-alpha (Pb-α) studies in the late 1950s (Matzko and others, 1958; Jaffe and others, 1959; Gottfried and others, 1959). In 1960, Stern (Holmes and Foster, 1968) obtained four Pb-α ages on plutonic rocks in the northern part of the Mount Hayes Quadrangle. K-Ar and Rb-Sr dating methods were applied soon after (Wasserburg and others, 1963). During the next 15 years, many K-Ar ages were determined on both igneous and metamorphic rocks, but mostly on granitic rocks. Ages determined by G. J. Wasserburg, M. A. Lanphere, D. L. Turner, J. G. Smith, F. H. Wilson, and others were compiled by Dadisman (1980). Little Rb-Sr work was done, partly because of the difficulty of obtaining unaltered material, but recently Blum (1983) reported Rb-Sr data for granitic rocks near Fairbanks. The K-Ar ages are most useful on nonmetamorphosed igneous rocks; ages obtained on metamorphic rocks are difficult to interpret. To better interpret the metamorphic rocks, McCulloch and Wasserburg (1978) applied a Nb-Sm method to Alaska Range rocks and Aleinikoff applied U-Pb methods (Aleinikoff and others, 1981) using zircons separated from an augen gneiss and other metamorphic rocks of the YTTN. Rb-Sr work was done to supplement the U-Pb work. Most recently, ^{40}Ar-^{39}Ar incremental heating methods have been used to help decipher the metamorphic history in the eastern part of the YTTN (Cushing and others, 1984a). Integrated studies of the various types of data for the YT have resulted in improved interpretations of the geologic history by making it possible to constrain the ages of many events more closely.

The following conclusions derive largely from K-Ar work based on about 142 age determinations (Wilson and others, 1985; this volume):

1. Three major periods of felsic plutonism occurred after major regional metamorphism, and volcanic rocks are associated with at least one and possibly two of these plutonic events. The oldest period of plutonism, during Late Triassic and Early Jurassic time, resulted in the emplacement of the granitic batholith at Taylor Mountain, and of other plutonic rocks (Mount Veta, Fig. 3B). Plutonic rocks of this age are presently known in eastern Alaska only in the southern part of the Eagle and northern part of the Tanacross Quadrangle.

The second period of plutonism occurred throughout most of the YT from about 105 to 85 Ma. The largest number of ages determined are between 95 and 90 Ma (Wilson and others, 1985; this volume). The largest and most numerous of these plutons are in the eastern part of the YTTN, mainly east of the Shaw Creek fault. The plutons mostly vary from quartz diorite to quartz monzonite. On the basis of K-Ar ages of 90 $\pm$ 2.8 Ma (hornblende) and 93.6 $\pm$ 2.1 Ma (sanidine) (Bacon and others, 1985), we interpret the extensive deposits of welded tuff in the Tanacross Quadrangle mainly as caldera-fill associated with this plutonic event.

The third period of felsic intrusions is indicated by 46 age determinations that range from 70 to 50 Ma (Wilson and others, 1985; this volume). These intrusions are generally small and commonly have contact aureoles. Most are located in the northwestern part of the YTTN northwest of the Shaw Creek fault, but one also occurs in the central part of the Tanacross Quadrangle (Mount Fairplay, Fig. 3). Comagmatic Tertiary volcanic rocks are documented by a K-Ar date of 57.8 $\pm$ 2 Ma in the eastern part of the Tanacross and one of 61.6 $\pm$ 2 Ma in the eastern Big Delta Quadrangles (Foster and others, 1976, 1979).

2. Although protolith ages and timing of metamorphism of metamorphic rocks are difficult to determine from K-Ar data, some important results have been obtained. Wilson and others (1985) studied 59 K-Ar age determinations on metamorphic rocks (43 from the YTTN) and identified two distinct clusters. Eighteen ages (7 from the YTTN) fall between 190 and 160 Ma; 24 ages (all from the YTTN) fall between 125 and 105 Ma. Although there is considerable scatter in the data, the Early Cretaceous cluster includes a number of concordant mineral pairs. Wilson and others concluded that this cluster probably reflects a metamorphic or thermal event that is distinct from the Cretaceous intrusive event and that the metamorphic ages generally are not reset by this later plutonism (F. H. Wilson, personal communication, 1984).

3. Although the number of determinations is limited and only a few are concordant mineral pairs, the K-Ar data strongly suggest a Jurassic metamorphic or thermal event (Wilson and others, 1985; this volume). As discussed below, $^{40}Ar-^{39}Ar$ data show such an event in the Eagle Quadrangle, but its areal extent and local intensities cannot be determined from the available data.

The U-Pb data from zircons indicate the following:

1. Plutonism occurred in subterrane Y_1 in the Mount Hayes Quadrangle (Lake George terrane) at about 360 Ma (Aleinikoff and Nokleberg, 1985a).

2. Extensive granitic intrusions occurred in subterrane Y_1 about 341 ± 3 Ma (lower intercept age) and are now represented by widely distributed augen gneisses (Dusel-Bacon and Aleinikoff, 1985).

3. The augen gneiss contains an inherited component of Early Proterozoic (2.1 to 2.3 Ga) zircons (Dusel-Bacon and Aleinikoff, 1985).

4. U-Pb ages of zircons from metamorphic rocks believed to have volcanic protoliths suggest that they were erupted 360 to 380 m.y. ago (Dusel-Bacon and Aleinikoff, 1985).

5. Time of metamorphism of the augen gneiss is not conclusively known.

6. Protolith age of the metamorphic rocks interpreted as wall rocks to the augen gneiss is not known, but they contain the Early Proterozoic inherited component.

The Rb-Sr whole-rock isochron obtained from widely separated outcrops of augen gneiss has an age of 333 ± 26 Ma, confirming the Mississippian intrusive age of the protolith obtained from the U-Pb determinations on zircon. Sm-Nd data also support the presence of an old crustal component in the augen gneiss (Aleinikoff and others, 1986).

Recent ^{40}Ar-^{39}Ar experiments on rock samples from subterrane Y_4 in the eastern part of the Eagle Quadrangle have established:

1. A cooling history for the granitic rocks of Taylor Mountain by analysis of hornblende, biotite, and K-feldspar. The granite was emplaced about 209 ± 3 Ma, and cooled from 500 to 175°C through a period of about 32 m.y. (Cushing and others, 1984b).

2. A major (amphibolite facies) metamorphic event that reached a peak about 213 ± 2 Ma, followed by igneous intrusions and cooling over a period of about 36 m.y. Amphibolite adjacent to the Taylor Mountain batholith has a Triassic integrated plateau age (213 ± 2 Ma) (Cushing and others, 1984b).

3. That thrusting occurred during cooling from the peak of metamorphism because greenschist-facies greenstone having a metamorphic age of 201 ± 2 Ma is thrust over the amphibolite, which is adjacent to the Taylor Mountain batholith. Other evidence of thrusting at about that time is based on the age of biotite crystallized in a thrust zone. The biotite has an integrated plateau age of 187 ± 2 Ma. The time of thrusting is also constrained by the age of a dike (integrated plateau age of 186 ± 2 Ma on muscovite) that cuts deformed metamorphic rocks in the thrust zone and is not deformed or significantly metamorphosed.

4. That the Cretaceous metamorphic or thermal event identified by the K-Ar work affected subterrane Y_4, as shown by minor plateaus in the ^{40}Ar-^{39}Ar data.

In summary, current radiometric age data indicate plutonism in the YTTN in Mississippian, Triassic, Cretaceous, and Tertiary time, and volcanism in the Mississippian, Cretaceous, and Tertiary. Major parts of the YTTN may have an Early Proterozoic basement or have received sediment from eroding Early Proterozoic sources. Metamorphism took place during Late Triassic and Early Jurassic time in the eastern part of YTTN (Y_4), but its extent is not known. A Cretaceous thermal event, of low grade at least in subterrane Y_4, was widespread in the YTTN. Deformation that included major thrusting occurred in subterrane Y_4 in Early Jurassic time.

YUKON–TANANA TERRANE SOUTH OF THE TANANA RIVER

Although exposure of bedrock in the YT south of the Tanana River is much better than in the YTTN, local cover by Tertiary rocks and by glacial deposits, restricted accessibility in the rugged Alaska Range, and a complex structural history make it difficult to relate this area to the YTTN and to other adjacent areas. Silberling and others (this volume) have grouped the rocks south of the Tanana River into several lithotectonic terranes, and Nokleberg and Aleinikoff (1985) have further divided the rocks in the Mount Hayes Quadrangle into several terranes or, in some cases, subterranes in the terminology used in this chapter. Our discussion of the area south of the Tanana River begins with terranes or subterranes in the Mount Hayes Quadrangle, continues with a description of the rocks of the Tanacross and Nabesna Quadrangles, and ends with the rocks in the Healy and Mount McKinley Quadrangles.

Metamorphic rocks

Mount Hayes Quadrangle. Rocks in the Mount Hayes Quadrangle south of the Tanana River and north of the Denali fault, most of which were included in the Yukon-Tanana terrane by Silberling and others (this volume), were divided by Nokleberg and others (1983) into the Macomb, Jarvis Creek Glacier, Hayes Glacier, and Windy terranes.

Macomb terrane. The Macomb terrane consists primarily of medium-grained mylonitic pelitic schist, calc-schist, and quartz-feldspar-biotite schist, intruded by quartz monzonite, granodiorite, quartz diorite, and diorite (unit pc, Fig. 2). The intrusive rocks have been almost completely recrystallized to mylonitic schist (Nokleberg and others, 1983). U-Pb analyses of zircons from the metamorphosed plutonic rocks indicate a Devonian (about 370 Ma) intrusion (Nokleberg and Aleinikoff, 1985; Aleinikoff and Nokleberg, 1985b). All of the rocks are polydeformed and metamorphosed under conditions of the lower amphibolite facies, but in places they have been retrograded to lower greenschist facies. Because no other age data are available, the age of protoliths of the intruded metasedimentary rocks cannot be determined more precisely than either Devonian or pre-

Devonian (pre-intrusion).

Jarvis Creek Glacier terrane. The Jarvis Creek Glacier terrane consists of fine-grained polydeformed schist (unit pq, Fig. 2) derived from sedimentary and volcanic rocks. Metasedimentary rocks are pelitic schist, quartzite, calc-schist, quartz-feldspar schist, and marble. Metavolcanic rocks are meta-andesite and metaquartz–keratophyre with some metadacite, metabasalt, and rare metarhyolite. All are cataclastically deformed, recrystallized, and metamorphosed under conditions of the greenschist facies. U-Pb analyses of zircons from metavolcanic rocks indicate a Devonian extrusive age of about 370 Ma (Nokleberg and Aleinikoff, 1985). The sedimentary protoliths are also considered to be of Devonian age, because they are interlayered with the metavolcanic schist (Nokleberg and Aleinikoff, 1985). Nokleberg and Lange (1985) suggested that the metavolcanic rock-rich part of Jarvis Creek Glacier terrane may be correlative with the Totatlanika Schist (unit to, Fig. 2) to the west in the Healy Quadrangle because both groups of rocks include abundant intermediate volcanic protoliths.

Hayes Glacier terrane. The Hayes Glacier terrane consists of two groups of phyllites: one is dominantly metasedimentary rocks with few to no metavolcanic rocks, and the other is mainly metavolcanic rocks with moderate to abundant amounts of metasedimentary rocks (unit pv, Fig. 2). Metasedimentary rock types are pelitic, quartzose, and quartz-feldspar phyllites, and minor calc-phyllite and marble. Metavolcanic rocks include meta-andesite, meta-quartz–keratophyre, and sparse metadacite and metabasalt. The rocks are cataclastically deformed and have been metamorphosed under conditions of the lower and middle greenschist facies. An early schistosity is folded into rarely seen, small-scale, isoclinal folds having axial planes parallel to schistosity. The dominant schistosity, which postdates the folding, dips moderately to steeply southward. Metamorphosed and deformed gabbro, diabase, and metagabbro dikes also occur and, on the basis of structural relations, are believed (W. J. Nokleberg, written communication, 1983; this volume, Chapter 10) to be middle or Late Cretaceous in age. Lamprophyre dikes and a small alkali-gabbro pluton were emplaced in early Tertiary(?) time (W. J. Nokleberg, written communication, 1983; this volume, Chapter 10).

Windy terrane. The Windy terrane consists predominantly of argillite, limestone, marl, quartz-pebble siltstone, quartz sandstone, metagraywacke, metaconglomerate, andesite, and dacite (unit ar, Fig. 2). Locally abundant megafossils and sparse conodonts indicate a Silurian(?) and Devonian age for these rocks. The rocks are generally slightly deformed and have poorly developed schistosity. Locally, deformation is intense, and phyllonite and protomylonite have formed in narrow zones. Rocks along the terrane's southern margin adjacent to the Denali fault are characterized by intense shearing, abundant fault gouge, and locally, by low-grade metamorphism (W. J. Nokleberg, written communication, 1985; this volume, Chapter 10).

Origin of terranes. On the basis of field relations and stratigraphic and structural data, Nokleberg and Aleinikoff (1985) interpret the Lake George, Macomb, Jarvis Creek Glacier, and Hayes Glacier terranes from north to south as successively shallower levels of a single, highly metamorphosed and deformed, Devonian submarine igneous arc. They suggest that the arc is either an island arc containing a slice of continental crust that contaminated the Devonian magmas, or a submerged continental-margin arc, with continental detritus being shed into a companion trench and subduction-zone system. Nokleberg (written communication, 1985; this volume, Chapter 10) interprets the Windy terrane as a surface-level slice of a Devonian island arc.

Tanacross and Nabesna Quadrangles. Amphibolite-facies gneiss and schist including augen gneiss (unit ag, Fig. 2) compose the northwestern part of the Alaska Range just south of the Tanana River in the Tanacross Quadrangle. The rocks are generally quartzose and commonly garnetiferous; calcareous rocks are rare. The lithology and metamorphic grade of the rocks, including the augen gneiss, are similar to those north of the Tanana River in subterrane Y_1. Quartz-mica schists in the foothills south of the Tanana River in the south-central part of the Tanacross Quadrangle (unit pc?, Fig. 2) have similarities in lithology and metamorphic grade to rocks in the Macomb terrane of the Mount Hayes Quadrangle.

The rocks in the Alaska Range in the Tanacross Quadrangle decrease in metamorphic grade to the south (Foster, 1970), and 10 to 20 km south of the Tanana River they are mostly greenschist-facies quartz–white mica schist ± chlorite, quartz-graphite schist, and quartzite (unit pq?, Fig. 2). All or part of these greenschist-facies rocks may be coextensive with the Jarvis Creek Glacier terrane of the Mount Hayes Quadrangle.

In the southeastern corner of the Tanacross Quadrangle, low-grade metamorphic rocks are largely light pink, light green, gray, and tan phyllite with discontinuous layers of marble and quartzite (unit pv?, Fig. 2). Greenstone also occurs. Because these rocks are adjacent to those of the Hayes Glacier terrane and have some similar lithologies, we tentatively correlate them. This group of rocks also appears to be coextensive with similar rocks in the Nabesna Quadrangle that have been considered of Devonian age.

In the Tanacross Quadrangle, the greenschist-facies schist and phyllite are intruded by dikes, sills, and lenses of altered diorite (not shown on map), which appear to be slightly metamorphosed (Foster, 1970).

Although there is considerable decrease in grade of metamorphism from amphibolite to greenschist facies from north to south in the Alaska Range within the Tanacross Quadrangle, there is little difference in the deformational characteristics. Foliation most commonly strikes northwest and dips predominantly southwest. Large-amplitude (several hundred meters) folds in layering and/or schistosity are visible in a few places, but small folds (amplitudes of 1 cm to more than 1 m) are common. S.H.B. Clark (written communication, 1972) recognized three generations of folds. The earliest is a set of small tight-to-isoclinal folds that fold the compositional layering and have well-developed axial plane schistosity. These folds are rarely preserved. A second set of folds deforms schistosity, are tight to isoclinal, and have axial-plane schistosity. The third-generation folds are kink folds and deform both previous generations of folds. Although major faults were not mapped between units in the Tanacross Quadrangle, Foster (1970) recognized the possible existence of such faults.

In the northern part of the Nabesna Quadrangle, a group of greenschist-facies rocks (unit pq?, Fig. 2) consists mostly of quartz-muscovite schist, quartz-muscovite-chlorite schist, graphitic schist, and minor calcareous mica schist. These schists may be coextensive with the Jarvis Creek Glacier terrane. South of the schists is a unit of slightly metamorphosed sedimentary and mafic volcanic rocks (unit Dm, Fig. 2). In the northwestern and north-central part of the quadrangle, this unit consists predominantly of dark gray phyllite, quartzite, porcellanite, quartz-mica schist, and marble. These rocks have been extensively intruded by mafic diorite and gabbro, which were emplaced after the main period of folding and metamorphism (Richter, 1976). Much of this area is included in the Pingston terrane of Silberling and others (this volume). Farther south, partly along the north side of the Denali fault, the rocks are chiefly phyllite and metaconglomerate with subordinate quartz-mica schist and quartzite. Scattered along strike are pinnacled outcrops of recrystallized limestone, a few of which contain rugose and tabulate corals of Middle Devonian age. In the east-central part of the Nabesna Quadrangle, probably bounded by faults, are weakly metamorphosed volcanic and volcaniclastic rocks (unit mv, Fig. 2). The western part of this volcanic unit consists mostly of andesite and basalt flows; the eastern part is dominantly volcanic sandstone, cherty argillite, quartzite, and tuff. Some of the east-central Nabesna Quadrangle is included in the Windy and McKinley(?) terranes of Silberling and others (this volume). Protoliths of the metamorphic rocks in the Nabesna Quadrangle are probably of Paleozoic age; the few fossils that have been found indicate that they may be largely Devonian.

Healy and Mount McKinley Quadrangles. Workers in the Healy and Mount McKinley Quadrangles have recognized three major groups of metamorphic rocks; none of these are continuous in outcrop with the metamorphic rocks in the Mount Hayes Quadrangle. The southernmost group, which is bounded on the south by the Hines Creek strand of the Denali fault system, formerly was called the Birch Creek Schist (unit bc, Fig. 2) (Wahrhaftig, 1968; Gilbert and Bundtzen, 1979; Bundtzen, 1981). North of this unit, a group of less crystallized rocks composes the Keevy Peak Formation (unit kp, Fig. 2); and a group of lithologically diverse rocks has been included in the Totalanika Schist (unit to, Fig. 2) (Wahrhaftig, 1968; Gilbert and Bundtzen, 1979). Differences in degree of metamorphism, lithology, and structural history suggest that these units are fault bounded (Wahrhaftig, 1968).

The southernmost group (bc, Fig. 2) consists predominantly of quartz–white mica schist, micaceous quartzite, and lesser amounts of graphitic schist, porphyroclastic quartz-feldspar schist, chlorite schist, greenstone, calcareous schist, and marble (Gilbert and Bundtzen, 1979). It was completely recrystallized during two or more periods of metamorphism: in the central Healy Quadrangle its metamorphic grade is greenschist facies, but to the west and north in the McKinley Quadrangle its grade is higher (Bundtzen, 1981; Wahrhaftig, 1968). In the McKinley Quadrangle, Bundtzen (1981) recognized an upper-greenschist-to-amphibolite–facies prograde event, followed after an unknown interval by lower-greenschist–facies retrograde metamorphism. Bundtzen suggested that differences in metamorphic grade of this unit from southeast to northwest in the McKinley Quadrangle may indicate different structural levels, with deepest levels to the northwest. The unit is complexly folded and faulted. Its age is unknown, but may be at least partly Paleozoic if rocks that contain echinodermal fragments belong to this unit (Gilbert and Bundtzen, 1979). In the Kantishna region of the McKinley Quadrangle, Bundtzen tentatively assigned a Precambrian age to this unit, but recognized that parts of it may be younger.

The Keavy Peak Formation consists of black or dark gray, carbonaceous phyllite; black quartzite; stretched-pebble conglomerate; gray, green, and purple slate; and white mica–quartz schist. Textures are commonly mylonitic, and some schists contain large, scattered bluish gray quartz grains, probably porphyroclasts. These rocks are less intensely deformed and recrystallized than those in the southernmost unit bc, but have been isoclinally folded. Because the Keevy Peak Formation is only slightly metamorphosed, original sedimentary features, such as graded bedding and cross-bedding, are preserved locally. Wahrhaftig (1968) indicated that the Keevy Peak Formation lies unconformably on unit bc. He also stated, "Several features suggest that the schist formations of the central Alaska Range have been cut by numerous unmapped thrusts and that many of the mapped lithologic contacts between schists of different units are, in fact, tectonic contacts whose original nature has been obscured by subsequent metamorphism." We believe that the contact of the Keevy Peak Formation probably is such a thrust; in the Kantishna Hills, Bundtzen (1981) also believed it to be a tectonic contact. Scarce fossils from the upper part of the Keevy Peak Formation are Middle and Late Devonian in age (Gilbert and Redman, 1977). Gilbert and Bundtzen (1979) suggested that the formation may range in age from Ordovician to Devonian.

The most northerly and apparently youngest metamorphosed formation in the Healy and Mount McKinley Quadrangles is the Totatlanika Schist, first defined by Capps (1912) and redefined and divided into five members by Wahrhaftig (1968). The characteristic lithology is quartz-orthoclase-sericite schist (and gneiss) (unit to, Fig. 2) that interfingers complexly with a large variety of lithologies in which felsic and mafic metavolcanic rocks predominate. Gilbert and Bundtzen (1979) described three main lithologies: metafelsite, metabasite, and metasedimentary rocks. The metafelsite consists primarily of porphyritic metarhyolite and felsic metatuff, now primarily quartz–orthoclase–white mica schist and gneiss. Wahrhaftig (1965) described augen of potassium feldspar 2.5 to 25 mm in diameter and smaller augen of quartz. Gilbert and Bundtzen (1979) interpreted the augen as relict phenocrysts and many of the rocks as probable mylonites (terminology of Wise and others, 1984). The metabasite primarily is probably calc-alkaline metabasalt, but there are also minor amounts of metavolcanic rocks of intermediate composition. Metasedimentary rocks predominate in the upper part of the Totatlanika Schist; their protoliths included sandstone, siltstone, and tuff. Locally, the rocks are calcareous, and carbonate layers occur. Relict sedimentary textures are visible in places. Black phyllite, indistinguishable from black phyllite in the Keevy Peak Formation, is interlayered with metavolcanic rocks throughout the Totatlanika Schist.

The Totatlanika Schist has undergone low-grade regional metamorphism, in most places probably no higher than low greenschist facies. A large component of the regional event has been dynamic rather than thermal, as evidenced by extensive development of mylonite (Bundtzen, 1981). Mica crenulations, cleavage, and isoclinal folding are common in the less competent layers of the unit.

A few fossils found in the Totatlanika Schist suggest that it probably ranges from Late Devonian to Mississippian in age. Gilbert and Bundtzen (1979) proposed that it may consist largely of volcanic-arc deposits formed above a subduction zone along the western margin of North America.

Mesozoic igneous rocks

In the Tanacross, Nabesna, and Mount Hayes Quadrangles, granitic rocks, probably mostly of Cretaceous age, intrude the metamorphic rocks. They range in composition from quartz diorite to quartz monzonite and are similar in composition and age to granitic rocks that cover large areas of the YT north of the Tanana River. In the Mount Hayes Quadrangle they occur in the Macomb, Jarvis Creek Glacier, and Hayes Glacier terranes. Nokleberg and others (1986) considered them to be slightly to moderately metamorphosed and suggested that they were intruded during the waning stage of an Early Cretaceous regional metamorphism.

Only a few small granitic bodies are known in the Tanacross Quadrangle south of the Tanana River, but in the Nabesna Quadrangle, three fairly large plutons occur. They are dominantly quartz monzonite, although they vary widely in composition. Most are foliated and have no xenoliths (Richter, 1976). The Gardiner Creek pluton (Richter, 1976) in the northeastern corner of the Nabesna Quadrangle is probably coextensive with the granitic plutons of the YTTN in the southeastern part of the Tanacross Quadrangle.

The Hayes Glacier terrane is intruded also by mafic dikes, commonly much deformed and metamorphosed. They are considered to be of mid- or Late Cretaceous age (W. J. Nokleberg, written communication, 1985; this volume, Chapter 10). In the central part of Jarvis Creek Glacier terrane, an intrusive suite of monzonite, alkali gabbro, lamprophyre, and quartz diorite, of early Tertiary(?) age, is partly surrounded by a ring dike of quartz monzonite. Locally extensive lamprophyre dikes and alkali gabbro are probably temporally associated with this suite. Foley (1982) described two dike swarms of nonmetamorphosed potassic alkali-igneous rocks, one near the West Fork of the Robertson River and the other to the east near the Tok River, and suggested that they are the youngest igneous rocks of the eastern Alaska Range (Late Cretaceous). They include biotite-lamprophyre dikes and sills, associated breccia dikes, and a stock of alkali gabbro and alkali diorite. Some of the mafic rocks of the Mount Hayes Quadrangle may be related to those in the southern part of the Tanacross Quadrangle (Foster, 1970) and/or Nabesna Quadrangle (Richter, 1976).

Mineral resources

In the southern part of the YT, gold has been produced from placer deposits, and gold, silver, antimony, and lead have been produced from several types of vein deposits. Other types of deposits present in the terrane include skarn or tactite deposits, copper vein deposits, and stratabound auriferous-sulfide bodies. Recent exploration for volcanogenic massive sulfide deposits has identified a number of significant prospects and occurrences. Perhaps the most important mineral resource of this region is coal, which occurs in Tertiary sedimentary rocks. Figure 4 shows the distribution of selected lode deposits, prospects, and occurrences in the southern YT.

Gold placers. Placer deposits in the Bonnifield and Kantishna districts (Nos. VII and VIII, Fig. 4) each yielded about 45,000 to 50,000 oz of gold between their discovery in 1903 and 1960 (Cobb, 1973). The deposits are mainly stream placers, but include bench placers. Sources of the gold are likely the various vein and stratabound lode deposits that occur in the districts.

Vein deposits. Most vein deposits in the southern YT belong to three types identified by Bundtzen (*in* Nokleberg and others, this volume, Chapter 29) in the Kantishna district: (1) auriferous quartz-arsenopyrite veins such as the Banjo (No. 20, Fig. 4); (2) galena-sphalerite-tetrahedrite-sulfosalt veins, such as Quigley Ridge (No. 21, Fig. 4), and (3) simple stibnite-quartz veins such as Stampede, Rambler, Glory Creeks, and Rock Creek (No. 19, Fig. 4).

Volcanogenic massive sulfide deposits. Most of the volcanogenic massive sulfide prospects and occurrences are located in the metavolcanic part of the Jarvis Creek Glacier terrane (Lange and Nokleberg, 1984). Important occurrences are known at Anderson Mountain (Freeman *in* Nokleberg and others, this volume, Chapter 29) (No. 22, Fig. 4); near Dry Creek (Gaard *in* Nokleberg and others, this volume, Chapter 29) (No. 23, Fig. 4); Miyaoka, Hayes Glacier, and McGinnis Glacier (Lang and Nokleberg *in* Nokleberg and others, this volume, Chapter 29) Nos. 24 and 25, Fig. 4); and in the Delta district (Nauman and Newkirk *in* Nokleberg and others, this volume, Chapter 29) (No. 26, Fig. 4). The deposits have many characteristics of deposits associated with felsic and intermediate volcanic rocks that form in island-arc settings.

Coal. Two coal fields, the Nenana and Jarvis Creek (D and C, Fig. 4), occur in Tertiary nonmarine sedimentary rocks that are described more fully in the next section. The Nenana field, which consists of several separate basins, has been a significant

TABLE 3. COAL FIELDS OF THE SOUTHERN PART OF THE YT*

Field	Size	Structure	Reserves/ resources†	Seam characteristics	Rank	Sulfur content	Development status
Nenana	Several basins 129 km by 16 to 48 km (80 by 10 to 30 miles)	Open folds and a few faults	780×10^6 $5,400 \times 10^6$ $7,900 \times 10^6$	Separate basins contain 8 to 9 seams that are at least 1.5 and up to 20 m thick	Subbituminous	Low	Produces about 800,000 tons/yr for local use. Export planned.
Jarvis Creek	40 km^2 (16 mi^2)	Open folds	0.3×10^6 12.5×10^6	Basin contains 30 seams that vary in thickness from 0.3 to 2.3 m	Subbituminous	Low	Some past production. Presently being developed for local use.

*References: Barnes (1967); Eakins and others (1983); Wahrhaftig and Hickcox (1955).
†tonnes proven, indicated, or inferred.

source of coal in Alaska, and both fields, whose characteristics are summarized in Table 3, contain substantial resources.

Sedimentary rocks

Tertiary nonmarine sedimentary rocks (unit Ts, Fig. 2) are fairly extensive in the northern part of the Healy Quadrangle and southern part of the Fairbanks Quadrangle and also occur in the southeastern Big Delta Quadrangle, northeastern and north-central Mount Hayes Quadrangle, and northeastern Mount McKinley Quadrangle. Two distinct units, shown as one composite unit on Figure 2, have been recognized: the coal-bearing formation and the overlying Nenana Gravel.

The coal-bearing formation is an informally designated sequence (based on local usage) consisting of interbedded lenses of poorly consolidated sandstone, siltstone, claystone, conglomerate, and lignitic and subbituminous coal (Wahrhaftig and Hickcox, 1955). The generally uncemented and poorly to moderately consolidated rocks erode readily. Both lithology and thickness vary greatly over short distances, and the range in thickness can be at least partly attributed to deposition on an uneven erosion surface of deeply weathered metamorphic rocks (Wahrhaftig and Hickcox, 1955). The total thickness of the coal-bearing formation reaches several hundreds of meters. Bedding is generally horizontal or has gentle dips. In places the formation has been warped and faulted. The number and thickness of coal beds is variable throughout the formation; in the Nenana coal field, however, there are a large number, and they range in thickness from a few centimeters to 20 m (Barnes, 1967). In most places only a few coal beds are thicker than 60 cm. The coal-bearing formation has long been considered of Tertiary age, but its position within the Tertiary is uncertain. A Miocene age is considered probable (Holmes and Foster, 1968).

The Nenana Gravel consists largely of poorly to moderately consolidated, poorly cemented, fairly well sorted conglomerate and sandstone (Wahrhaftig, 1958). Pebbles in the conglomerate are generally slightly weathered. The formation is more resistant to erosion than the underlying coal-bearing formation and commonly supports steep cliffs 15 to 30 m high (Wahrhaftig, 1958). It varies in thickness but is known to exceed 1,300 m in places. It generally has about the same attitude as the coal-bearing formation, and although a minor unconformity locally occurs between these units, the Nenana Gravel has also been warped and faulted since deposition. Patches of poorly consolidated gravel on the north flank of the Alaska Range in the Mount Hayes Quadrangle may be erosional remnants of the Nenana Gravel (Holmes and Foster, 1968). The exact age of the formation is uncertain. Pollen studies (Holmes and Foster, 1968) suggest that it probably is Pliocene, whereas Wolfe and Toshimasa (1980) consider it to be late Miocene and early Pliocene on the basis of Clamgulchian-stage fossils.

Geophysical data

Comparatively few geophysical studies for the YT have been published. Aeromagnetic maps are available for most of the quadrangles at scales of 1:250,000 and 1:63,360, and interpretations of the aeromagnetic maps have been made for the Nabesna (Griscom, 1975), Tanacross (Griscom, 1976), Big Delta (Griscom, 1979), and Circle (Cady and Weber, 1983) Quadrangles. No regional aeromagnetic interpretation that includes the YT has been made since a study based on widely spaced (10 mi) flight lines (Brosgé and others, 1970). Available gravity data for the YT are shown on a Bouguer gravity map of Alaska (Barnes, 1977; Barnes and others, this volume). Gravity maps have been published for the Nabesna and Circle Quadrangles at scales of 1:250,000 (Barnes and Morin, 1975; Cady and Barnes, 1983). The density of gravity stations and quality of data are variable throughout the YT. Geophysical methods have been used by private industry in exploration for asbestos, copper porphyry, and other types of deposits. Some of the geophysical work being done on the Trans-Alaska Crustal Transect (TACT) will include parts of the YT.

SEVENTYMILE TERRANE

The Seventymile terrane is a discontinuous belt of alpine-type (fault-bounded) ultramafic rocks and associated slightly metamorphosed mafic volcanic and sedimentary rocks that have been thrust upon and imbricated with rocks of subterranes Y_3 and Y_4 of the YTTN. Churkin and others (1982) referred to this belt of rocks as the Salcha terrane. The belt trends northwesterly from the Yukon Territory into the northern part of the Eagle Quadrangle; in the northeastern part of the Big Delta Quadrangle, the belt is displaced to the south along the northwest side of the Shaw Creek fault. From there it trends southwestward to the center of the Fairbanks Quadrangle (Fig. 5). Five large peridotite bodies, labeled 1 to 5 on Figure 5 (the peridotites of Boundary, American Creek, Mount Sorenson, Salcha River ["Nail" allochthon of Southworth, 1984], and Wood River Buttes) and three areas of massive greenstone bodies, labeled I to III on Figure 5 (the greenstones of Wolf Mountain, Chicken, and Ketchumstuk), make up the main part of the Seventymile terrane. Some of these rocks in the Eagle Quadrangle have been described as parts of a dismembered ophiolite (Foster and Keith, 1974; Keith and others, 1981a). Numerous sporadically distributed small lenses of serpentinized peridotite and serpentinite crop out south of the main belt of ultramafic rocks (Keith and Foster, 1973), especially in the Eagle Quadrangle. These small bodies may have detached from the sole of the thrust fault at the base of the Seventymile terrane.

Ultramafic rocks

The largest outcrops of the Seventymile terrane are composed mainly of alpine-type ultramafic rocks. The peridotite of Boundary is approximately 8 km^2 in area, the peridotite of American Creek approximately 31 km^2, the peridotite of Mount Sorenson approximately 41 km^2, the peridotite of Salcha River is 40 km long and is approximately 80 km^2 in area, and the peridotite of Wood River Buttes is approximately 6 km^2 in area.

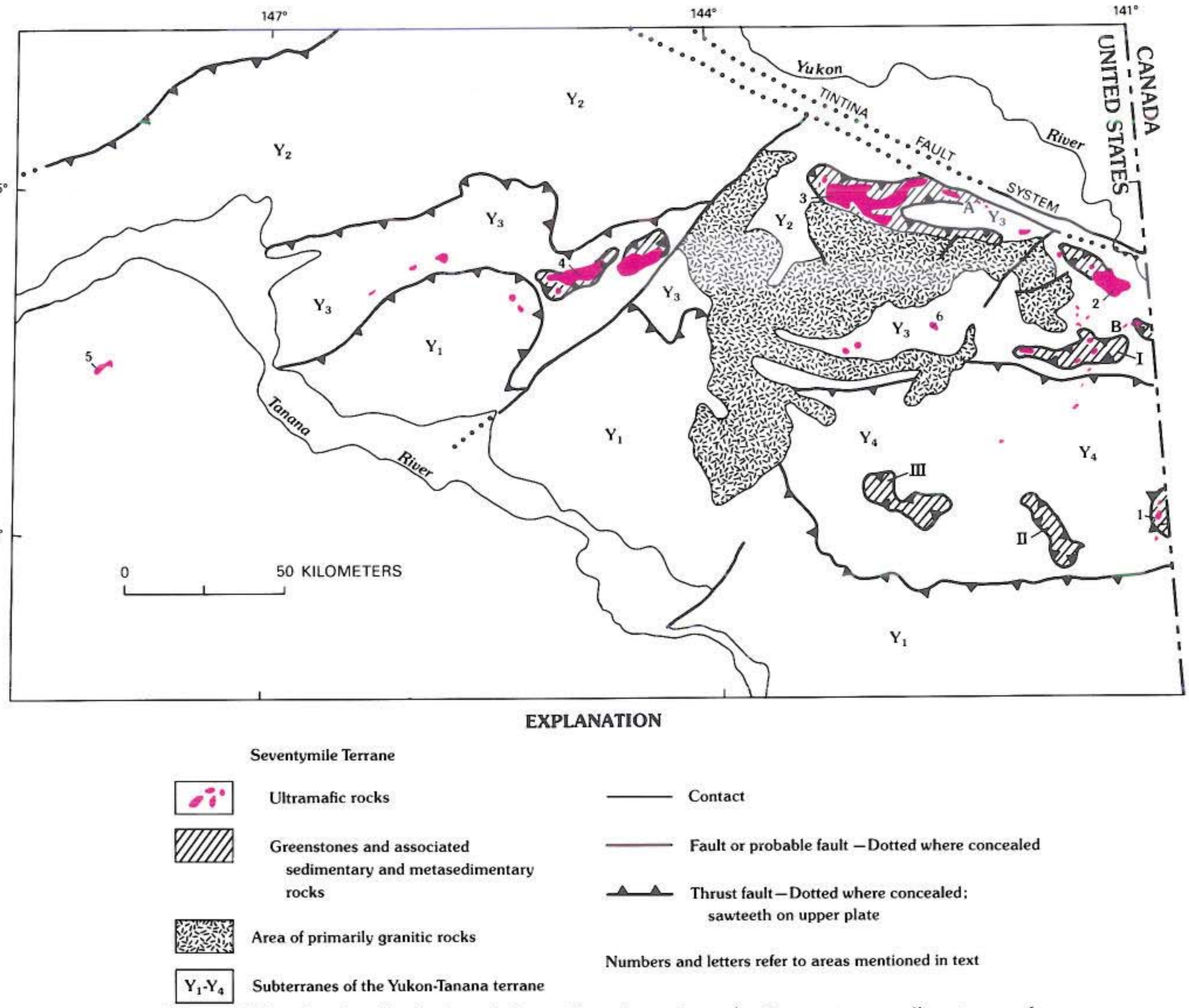

Figure 5. Map showing distribution of ultramafic rocks and associated greenstones, sedimentary, and metasedimentary rocks of the Seventymile terrane. Map after Foster (1976), Weber and others (1978), and Keith and others (1981a).

The rocks mainly are partly serpentinized harzburgite and dunite, and minor amounts of clinopyroxenite. Chromite is locally present, but nowhere abundant. Secondary magnetite that developed during serpentinization is common. Tectonic inclusions of rodingite occur in the large peridotite bodies. Bodies of coarse-grained cumulate gabbro are associated with the peridotite of Mount Sorenson. Silica-carbonate zones are well developed at the base of the peridotite of Salcha River and locally developed in the peridotite of Mount Sorenson.

Small serpentinite bodies, whose relict textures suggest mainly harzburgite protoliths, crop out as lenses or pods. Locally, at the contact with country rock, the small bodies have a rind of actinollite and/or chlorite, or hard slip-fiber serpentine, indicating a tectonic contact with the adjacent rocks. The distribution of the small outcrops is irregular, and they appear to be thrust over, and infolded and imbricated with, metamorphic rocks of subterranes Y_3 and Y_4. One of these small bodies, the serpentinite of Slate Creek (No. 6, Fig. 5), contains asbestos in potentially commercial quantities (Foster, 1969; Mullins and others, 1984).

Volcanic rocks

Greenstone bodies, originally basaltic pillow lavas and mafic lava flows, are in contact with the massive peridotite bodies at all the major outcrops. The greenstones are composed mainly of chlorite, actinolite, epidote, feldspar, magnetite, quartz, and calcite. Large masses of greenstone with minor associated serpentinite and silica-carbonate lenses also crop out as thrust remnants (Nos. I, II, and III, Fig. 5). The greenstones in the south-central part of the Eagle Quadrangle (No. II, Fig. 5), which lie upon subterrane Y_4, show thermal effects from the adjacent Taylor Mountain batholith.

Tuff that is metamorphosed to lower greenschist facies and which generally contains significant amounts of calcite and chlorite is associated with greenstone in many places.

Associated with the peridotite of Mount Sorenson are diabase dikes and plugs; some are metamorphosed and contain small amounts of pumpellyite and prehnite. Nonmetamorphosed basaltic pillow lavas and porphyritic silicic volcanic rocks crop out at the eastern end of the peridotite of Mount Sorenson and are in contact with cumulate gabbro.

At one locality (A, Fig. 5), in the north-central part of the Eagle Quadrangle, glaucophane, epidote, and sphene have formed from basaltic rock under blueschist metamorphic conditions (Foster and Keith, 1974).

Metasedimentary rocks

Low-grade metasedimentary rocks within the Seventymile terrane are chert, argillite, sandstone, conglomerate, graywacke, and fine-grained, dark gray limestone. Many were deposited alternately with submarine basaltic lava flows that now are greenstone; younger sedimentary strata were deposited in local basins. Probably all are submarine in origin and were deposited prior to thrusting of the Seventymile terrane.

Chert is interlayered with some of the greenstones and mafic volcanic rocks. Most is slightly recrystallized and contains abundant silica veins and veinlets. Radiolarians and conodonts from red chert in contact with the peridotite of Salcha River indicate an Early Permian age (Foster and others, 1978b). No fossils have been found in adjacent very low-grade metamorphosed graywacke sandstone and conglomerate adjacent to the peridotite. Slightly recrystallized chert interlayered with pillow basalts on the southeast side of the peridotite of Mount Sorenson has not yet yielded fossils, but Mississippian radiolarians occur in red and gray chert on the north side of the peridotite of Mount Sorenson (D. L. Jones, oral communication, 1984).

Slightly metamorphosed sedimentary rocks north of the Fortymile River (B, Fig. 5) include argillite, volcanic conglomerate, and fine-grained black limestone. An early Late Triassic age (early Early Norian) for a much fractured and deformed carbonaceous limestone is indicated by the conodont *Epigondolella primitia* Mosher (T. R. Carr, written communication, 1985). Some of these rocks are similar to those near the Clinton Creek asbestos deposit in the Yukon Territory that are considered by Abbott (1982) to be Late Triassic in age on the basis of a conodont. Metasedimentary rocks (tuff, argillite, and limestone) of slightly higher metamorphic grade occur near greenstones in the south-central part of the Eagle Quadrangle (C, Fig. 5).

Metamorphism

Much of the pervasive serpentinization of the ultramafic rocks is due to their hydration during emplacement into the crust. Large peridotite masses show no internal textural effects from regional metamorphism. However, many of the smaller ultramafic bodies that have been imbricated with parts of subterranes Y_3 and Y_4 have foliation and low-grade metamorphic mineral assemblages. Metamorphism of the mafic volcanic rocks may have occurred, in part, within an ocean basin prior to thrusting. However, subsequent thrusting and low-grade regional greenschist metamorphism has produced cross-cutting veinlets of serpentine (including cross-fiber asbestos), magnetite, chlorite (penninite), actinolite, anthophyllite, and magnesite. Closely associated tuff and sedimentary rocks show effects of low-grade regional metamorphism by a weak but distinct foliation and by chloritization of ferromagnesian minerals.

Structural and tectonic relations (also see "Geologic history")

The Seventymile terrane has been thrust into its present position with respect to the underlying metamorphic rocks of the Yukon-Tanana terrane. Thrust planes are nearly horizontal in most places. Imbricate thrusting of serpentinized peridotite with subterrane Y_4 and units ws and qs of subterrane Y_3 is prevalent in the central and extreme southeastern part of the Eagle Quadrangle.

The alpine-type ultramafic rocks, originally derived from the mantle, were emplaced into oceanic crust (Coleman, 1977; Patton and others, this volume, Chapter 21) in an ocean basin opening between subterranes Y_1 and Y_4, and also between subterranes Y_1 and Y_2. Later, as the ocean basin gradually closed and the tectonic components of Alaska moved northward into their present positions, some of the rocks of the ocean basin (Seventymile terrane) were obducted southward onto subterrane Y_4, but most were thrust northward as several slices onto subterrane Y_3. The large peridotite bodies were the leading edge of the main thrust sheet, and are structurally the highest part of the Seventymile terrane. Thrusting of the peridotite bodies was followed by thrusting of the greenstone and associated metasedimentary rocks. The trace of the former ocean basin is now indicated primarily by the distribution of the rocks of the Seventymile terrane lying in an arcuate belt upon subterrane Y_3 (Fig. 5).

Mineral resources

The Seventymile terrane contains large deposits of asbestos, minor occurrences of gold, and reported minor occurrences of nickel and chromium. The gold occurrences were discussed under the Seventymile district of the YTTN; because present information suggests that the nickel and chromium occurrences are small, they are not discussed further.

Asbestos. Asbestos occurs in two geologic settings within the Seventymile terrane: (1) in large, partially serpentinized ultramafic bodies, many of which are in contact with greenstone, and (2) in small serpentinite bodies (Keith and Foster, 1973). Significant deposits and prospects are confined to the second geologic setting and include the Slate Creek deposit (No. 9, Fig. 4), the Champion Creek prospect (No. 11, Fig. 4) (Mullins and others, 1984), and the Liberty Creek prospect (No. 12, Fig. 4). Large deposits in the Yukon Territory (Clinton Creek and Caley) occur in the same geologic setting (Abbott, 1982). The Slate Creek deposit has reported reserves of 60 million tons of ore containing 6.4 percent fiber of good quality for asbestos cement products (Mullins and others, 1984) and 67 million tons of indicated and possible ore. The deposits and prospects share a number of common characteristics. The asbestos occurs as cross-fiber chrysotile in 0.03- to 2-cm-thick, closely spaced veins that have been completely serpentinized in small bodies of serpentinized ultramafic rock (Foster, 1969; Hytoon, 1979). The margins of many of these bodies contain fibrous actinolite and slip-fiber serpentine, indicating that the bodies have been sheared.

The deposits and prospects are confined to a narrow zone along and approximately parallel to the contact between amphibolite-facies rocks and greenschist-facies rocks. This contact was interpreted as a thrust fault by Foster and others (1984). The thrust fault probably was formed in early Middle Jurassic time (Foster and others, 1984), and the small, fractured, completely serpentinized ultramafic bodies that host the asbestos deposits and prospects may be part of the thrust that soles the Seventymile terrane.

QUATERNARY GEOLOGY OF EAST—CENTRAL ALASKA

Much of east-central Alaska is covered by Quaternary sedimentary deposits. Almost all of the Fairbanks Quadrangle, for example, is covered by them, and the few natural outcrops occur mostly along rivers and streams and on the highest hilltops. The Quaternary deposits are unconsolidated, but many of them are perennially frozen. In the part of east-central Alaska described in this chapter, the largest area of Quaternary deposits is in the Tanana River valley, and widespread eolian deposits on the surrounding uplands also were derived from the Tanana valley. Quaternary deposits have had a major role in the economy of east-central Alaska in many ways, particularly as a source of rich gold placers, and of sand and gravel.

Ancient gravels

Several small areas of unconsolidated, poorly, or partly consolidated gravel are found at high elevations in parts of the northern Alaska Range and in the YTTN of the Tanacross Quadrangle. These gravels in the northern Alaska Range resemble the Tertiary Nenana Gravel and have generally been correlated with it. However, some of these gravels may be of early Pleistocene age. In the northern Alaska Range, they occur at elevations just under 1,000 to 1,200 m. They are generally only a few meters thick, deeply weathered, apparently flat-lying, and contain well-rounded clasts. They rest unconformably on metamorphic rocks or on coal-bearing sedimentary rocks (Foster, 1970). Small areas of residuum from metamorphic rocks occur on remnants of an old warped erosion surface that extends southeast from Mount Neuberger (in the Alaska Range 23 km southwest of the town of Tok). The surface is about 1,700 m in altitude near Mount Neuberger but is lower to the southeast. The residuum is at least 6 m thick in places. Its age is unknown, but it probably pre-dates the earliest glaciation in this area (Foster, 1970).

Glaciation

Most of east-central Alaska was not covered by glaciers during the Pleistocene. Continental ice sheets were not present, but alpine and piedmont glaciers were abundant in the Alaska Range, and small alpine glaciers occupied the upper reaches of many valleys in the highest parts of the YTTN. Glacial outwash was extensively deposited by the large streams, and morainal deposits are conspicuous in many valleys. Silt and sand derived from the dry exposed material in large outwash aprons that were widely deposited in the Tanana River valley were blown northward to form dunes at the northern edge of the valley and a loess mantle on adjacent hills. Material from the Yukon River valley and the alluvial fans of tributaries was blown southward; some of it mantled hills, terraces, and other landforms in the northernmost part of the area described in this chapter. Lacustrine deposits from ice-dammed lakes occur in the Tanana River valley and a few tributary valleys.

Old glaciations of pre-Wisconsin age have been recognized (Ten Brink, 1983; Weber, 1983) in both the northern Alaska Range and the YTTN. Ten Brink (1983) stated that a broad expanse of piedmont ice spread north from the Alaska Range to cover the ancestral foothills area, probably in late Tertiary time. Two other pre-Wisconsin to early Pleistocene glacial events are also recorded in the Alaska Range. The most extensive and best known Wisconsin-age glaciations are represented in many valleys by two major early Wisconsin advances and four late Wisconsin advances. At least six Holocene ice advances have been recorded, and small glaciers still exist (Table 4).

Weber (1983) recognized three pre-Wisconsin glacial episodes in the YTTN, the oldest being pre-Pleistocene in age, and the other two early(?) and middle(?) Pleistocene. Two probable early Wisconsin advances were followed by three or four advances in late Wisconsin time. Holocene glacial deposits generally only occur in deep north-facing cirques, but there is evidence of two short (less than 3 km) Holocene valley glaciers. No glaciers presently exist in the YTTN (Table 4).

Fluvial, eolian, and lacustrine deposits

The thickest and most extensive fluvial, eolian, and lacustrine deposits in east-central Alaska occur in the Tanana River valley. One of the most useful sections is on the northeast side of the Tanana River, 50 km southeast of the town of Tok, where 40 m of fluvial, eolian, and lacustrine deposits are exposed. Radiocarbon ages indicate that wood from near the base of the section has an age greater than 42,000 yr. An ash bed beneath the modern turf is about 1,400 yr old (Fernald, 1962; Carter and Galloway, 1984). Some interior valleys also have thick eolian and fluvial deposits, but exposures are limited. Commonly, loess is so thick (more than 60 m in places) that fluvial deposits beneath them are rarely exposed. Locally, there are thick carbonaceous silt and peat deposits that mostly are perennially frozen. Sand dunes occur north of the Tanana River in the Tanacross and Big Delta Quadrangles. The maximum thickness of sediments in the Tanana River valley is not known, but parts of the valley floor are below sea level (Péwé, 1974).

Placer gold occurs both in Holocene gravels and in gravels as old as early Pleistocene. Most of the gold-bearing gravels are buried beneath frozen silt and other sediments. Some compose terraces a few to many meters above present stream levels. High terraces are particularly well developed along the Fortymile and Seventymile Rivers and along the Yukon River.

Talus and landslide deposits, particularly abundant in the Alaska Range, also occur in the YTTN. Rock glacier deposits are locally significant in the Alaska Range (Holmes and Foster, 1968).

Frost polygons are well developed in lowland areas where permafrost is generally present and thaw lakes are common. Patterned ground, including stone polygons and stone stripes, is abundant in upland areas. Solifluction is a major mass-movement process on valley slopes. More than 300 open-system pingos are widely distributed mainly north of the Tanana River (Holmes and others, 1968). Most are on south- and southeast-facing slopes near the transition between valley-fill deposits and slope mantle. The pingos are composed primarily of silt, colluvium, and valley-fill material and range from 3 to 35 m in height.

Volcanic ash

Volcanic ash layers ranging in age from early Pleistocene to Holocene occur at several horizons in the Quaternary deposits of east-central Alaska. The most widely distributed is the White River Ash Bed, which originated about 1,400 yr ago at the east end of the Wrangell Mountains near the Alaska-Canada border (Lerbekmo and Campbell, 1969). It commonly occurs just beneath the turf but may be buried to a depth of several meters in active stream valleys or beneath recent eolian deposits. Numerous other ash deposits of unknown origin occur: they include some in the Fairbanks area, lower Delta River area, along the Chatinika River 40 km north of Fairbanks (Péwé, 1975), and in the central and southern Eagle Quadrangle (Weber and others, 1981). The Sheep Creek Tephra of Westgate (1984 *in* Porter, 1985), an ash of unknown source and older than 40,000 yr B.P., has recently been identified at four localities in Alaska and Yukon Territory: Eva Creek, near Fairbanks (Péwé, 1975); Canyon Creek in the Big Delta Quadrangle (Weber and others, 1981); Lost Chicken Creek in the Eagle Quadrangle (Lee Porter, written communication, 1985); and on the Stewart River in Yukon Territory. At Lost Chicken Creek, the ash is associated with in situ fossil mammal remains.

Vertebrate fossils

East-central Alaska is well known for the abundant remains of extinct Pleistocene mammals, found mostly in frozen deposits along rivers and streams. Most of the remains have been uncovered during placer gold mining, and the Fairbanks mining district has been especially productive of fossil vertebrates. At least 45 mammalian genera occupied parts of the area during the late Pleistocene, including the American lion, camels, giant beavers, and ground sloths, of which at least 16 genera have become extinct (Porter, 1985).

Vertebrate fossils were discovered (Weber and others, 1981) in 1974 along the Richardson Highway near the mouth of Canyon Creek, a small tributary to the Tanana River in the Big Delta Quadrangle. There, the Pleistocene fauna includes rodents, woolly mammoth, the Yukon wild ass, western camel, long-horned bison, mountain sheep, wolf, tundra hare, and caribou. Although the fauna is a standard Alaskan Pleistocene assemblage (Guthrie, 1968), it is one of the few central Alaskan mammalian collections that is stratigraphically controlled and radiometrically dated (40,000 yr old; Weber and others, 1981). The fossils from Lost Chicken Creek, a small tributary to the South Fork of the Fortymile River in the southern Eagle Quadrangle, have been intensively collected and studied. This locality has produced more than 1,000 fossils from 37 m of unconsolidated sediments, which range in age from 50,400 to 1,400 yr B.P. (Porter, 1985). The assemblage includes 16 vertebrate genera, among which are the unusual occurrence of gallinaceous birds, wolverine, the extinct American lion, collared lemmings, and saiga antelope. Human involvement may be indicated for some unknown time prior to

TABLE 4. GLACIAL ADVANCES IN EAST-CENTRAL ALASKA

	YTTN Glacial sequences (after Weber, 1983)			Northern Alaska Range Glacial advances (after Ten Brink, 1983)	
	Yukon-Tanana Upland	Mount Prindle area		Local names used and specific valleys by Péwé (1965, 1975) and Wahrhaftig (1958)	Regional informal nomenclature by Ten Brink and others (1983)
HOLOCENE	Ramshorn glaciation		HOLOCENE		Muldrow Foraker II Peters Yanert II Foraker I Yanert I
LATE WISCONSIN	Salcha glaciation	Convert glaciation	LATE WISCONSIN	Donnelly glaciation (Delta River; Péwé, 1965, 1975) Riley Creek glaciation (Nenana Valley; Wahrhaftig, 1958)	McKinley Park glaciation: McKinley Park stade IV McKinley Park stade III McKinley Park stade II McKinley Park stade I
EARLY(?) WISCONSIN	Eagle glaciation	American Creek glaciation	EARLY WISCONSIN	Delta glaciation (Delta River; Péwé, 1965, 1975) Healy glaciation (Nenana River; Wahrhaftig, 1958)	Early Wisconsin III(?) Early Wisconsin II Early Wisconsin I
MIDDLE(?) PLEISTOCENE	Mount Harper glaciation	Little Champion glaciation	PRE-WISCONSIN	Dry Creek glaciation (Nenana River; Wahrhaftig, 1958)	Pre-Wisconsin III
EARLY(?) PLEISTOCENE	Charley River glaciation	Prindle glaciation		Browne glaciation (Nenana River; Wahrhaftig, 1958)	Pre-Wisconsin II
PRE-PLEISTOCENE	Goodpaster glaciation			Nenana Gravel (upper part) (late Tertiary) (Nenana River; Wahrhaftig, 1958)	Pre-Wisconsin I

11,000 yr B.P. by broken and burned bones of mammoth, bison, horse, and caribou (Lee Porter, written communication, 1985). The Lost Chicken fauna represents a hardy, cold- and dry-adapted biologic community that lived during middle and late Wisconsin postglacial time.

The stratigraphy, flora, and fauna of east-central Alaska indicate that early Wisconsin time was cool and dry, that middle Wisconsin time was wetter, and that glacial climates terminated abruptly between 12,000 and 9,000 yr B.P. (Lee Porter, written communication, 1985). The Holocene had an early period (ca. 8,000 yr B.P.) of very warm temperatures, followed by a cool period (ca. 7,000 yr B.P.) (Lee Porter, written communication, 1985).

GEOLOGIC HISTORY

Determining the geologic history of east-central Alaska is hampered by a scarcity of fossils, high grades of metamorphism, and extensive cover by vegetation and surficial deposits. Because of these constraints, it is not surprising that geologists working in different parts of the YT have emphasized different data and arrived at different interpretations. The data of this chapter are presented within the framework of tectonostratigraphic terranes (Silberling and others, this volume). Interpretations are based largely on regional-scale geologic mapping, data from ^{40}Ar-^{39}Ar incremental heating experiments, and structural studies of rocks in the eastern part of the Eagle Quadrangle.

In the following discussion, we consider several tectonostratigraphic assemblages or "packages" of rocks, subterranes Y_1 through Y_4 (described above under "Stratigraphy"), in terms of their relations to each other and to the YTTN, and our conclusions are applied primarily to the YTTN. Nokleberg and others (1983) and Nokleberg and Aleinikoff (1985) have identified tectonostratigraphic assemblages and have proposed interpretations of the geologic relations of the rocks south of the YTTN, particularly in the Mount Hayes Quadrangle, and their conclusions are not discussed further in this chapter. We believe that many subterranes of the YT contain evidence of unique pre-Mesozoic histories, but at present, data are still insufficient to integrate their geologic evolution.

The geologic history recorded in rocks of the YTTN probably begins in latest Proterozoic or early Paleozoic time with deposition of continentally derived sediments in several different environments marginal to North America or to other continents. The deposits include the quartz-rich sediments of unit qq (subterrane Y_2), the pelitic schist, amphibolite, and marble of unit ps (subterrane Y_2), and the quartzose and pelitic sediments of subterrane Y_1. Probably beginning a little later, but perhaps overlapping in time deposition in subterranes Y_1 and Y_2, the protoliths of subterrane Y_4 were deposited. Other continental-margin sediments of Paleozoic age are those of units qs, ws, and cp of subterrane Y_3. Possible fore-arc sediments of Paleozoic age are those of units sm and ms of subterrane Y_3.

The first well-dated event in the YT is felsic intrusion in Devonian time (Aleinikoff and Nokleberg, 1985) in the southern part of subterrane Y_1, followed in Mississippian time by extensive porphyritic granitic intrusion (augen gneiss) throughout much of the northern part of subterrane Y_1. Dusel-Bacon and Aleinikoff (1985) postulated that metamorphism was synchronous with intrusion, although metamorphism may not have occurred until the Cretaceous (Dusel-Bacon, 1986). This continental fragment (subterrane Y_1) was probably a separate entity in mid–late Paleozoic time because the distribution of the augen gneiss is limited to subterrane Y_1, except for possible thrust remnants in the southern part of subterrane Y_2.

From late Paleozoic through Triassic time, basalt and minor amounts of sedimentary chert, graywacke, shale, and limestone accumulated in an ocean basin that separated the continental fragment comprising subterranes Y_2 and Y_3 from the one comprising subterranes Y_1 and Y_4. Mantle peridotite was tectonically emplaced into the oceanic crust and became a part of the ocean basin suite. Remnants of these mantle and oceanic rocks compose the Seventymile terrane. During this period, the continental fragments each had a poorly known but complex history of metamorphism and deformation that is implied by their heterogeneity, but the early histories of these subterranes are as yet undetermined.

The next well-dated events are represented in subterrane Y_4 and may have been limited to that subterrane. Paleozoic sedimentary rocks were metamorphosed to amphibolite facies in the Late Triassic (about 213 ± 2 Ma). Intrusion of granodiorite (Taylor Mountain batholith) occurred at 209 ± 3 Ma, shortly after the peak of metamorphism, and the pluton cooled with the regional geotherm.

During the cooling period, but before approximately 201 Ma, oceanic basalt and associated sediments, probably from the closing ocean basin to the north of subterrane Y_4, were emplaced tectonically. The oceanic strata were metamorphosed to greenschist facies during the waning stages of the regional metamorphism of subterrane Y_4. Deformation, probably related to northwestward movement of subterrane Y_4, produced major northeast-trending folds in unit qs when subterrane Y_4 and remnants of oceanic strata (Seventymile terrane) were thrust northward onto subterrane Y_3. Complex imbrication of subterrane Y_4 with units qs and ws of subterrane Y_3 occurred with the collision of these packages of rocks. The thrusting together of subterranes Y_3 and Y_4 occurred after regional metamorphism of subterrane Y_4, but before 187 ± 2 Ma, as indicated by ^{40}Ar–^{39}Ar dating of undeformed and unmetamorphosed dike rocks that cut subterrane Y_4. With continued northward movement, more imbrication, shearing, mylonitization, and thrusting occurred within the Seventymile terrane, and between it and subterrane Y_3.

In the western part of the YTTN, times of thrusting and metamorphism are not as well known as in the eastern part. However, within subterrane Y_2, thrusting of unit ps over unit qq occurred before regional metamorphism of subterrane Y_2, and the joining of subterranes Y_2 and Y_3 occurred after the regional metamorphism of subterrane Y_2. The Seventymile terrane was probably thrust over the western part of subterrane Y_3 in Jurassic time, at the same time it was thrust over the eastern part. Closing of the ocean basin that separated subterranes Y_4 and Y_1 from subterranes Y_2 and Y_3 is recorded only by the presence of thrust remnants of the Seventymile terrane on top of subterrane Y_3.

Differences in the sedimentary protoliths of subterranes Y_1 and Y_4, the restriction of augen gneiss to subterrane Y_1, and probable differences in ages of metamorphism of these subterranes suggest that they were not joined until after Early Jurassic time. The presence of a late Early Cretaceous metamorphic event in subterranes Y_1 and Y_4 provides an upper constraint to the time that subterrane Y_1 joined the rest of the YTTN. The subterranes were finally welded together by emplacement of the Cretaceous granitic plutons.

In the eastern part of the YTTN, volcanism associated with Cretaceous intrusion produced calderas and extensive deposits of welded tuff. At about the same time, and perhaps related either to volcanism or to further northwestward movement of the YT, the YT developed a northeasterly trending pattern of fractures. The best known of these fractures is the Shaw Creek fault, which appears to have considerable strike-slip displacement (Griscom, 1979). However, the southeast side seems to be upthrown, and on the basis of reconnaissance field data, M. C. Gardner has suggested (written communication, 1983) that the Shaw Creek fault may be a high-angle reverse fault. Some of the northeast-trending faults were reactivated at intervals in Tertiary and Quaternary time. The right-lateral strike-slip Tintina fault system marks the northern boundary of the YT. There is little direct evidence in Alaska of the time, kind, and extent of first and subsequent movements on the Tintina and its subsidiary faults; limited information suggests that, as might be expected, movement occurred at different times on various segments of the fault. In the Eagle Quadrangle, for instance, Upper Cretaceous and/or lower Tertiary conglomerates are broken and pulverized by fault movement at one locality but appear undisturbed at another. In Canada, Gabrielse (1985) has suggested that dextral displacement on faults such as the Tintina date from the mid-Cretaceous or earlier to late Eocene or Oligocene. In order to account for the difference in the amount of displacement on the Tintina from that on the northern Rocky Mountain Trench, he suggested that transcurrent displacement brackets the time of major regional thrusting and folding. If this were the case in Alaska, movement on the Tintina fault could possibly have begun as early as the Jurassic.

The last major plutonic event was the emplacement of felsic plutons primarily in the northwestern part of the YTTN from about 65 to 50 Ma. At about the same time, probably mafic and felsic volcanic rocks, and perhaps shallow felsic intrusions, were emplaced, primarily in the eastern part of the YTTN. A late Mesozoic and/or Tertiary folding event with some thrusting deformed Upper Cretaceous or Paleogene nonmarine sedimentary rocks and Neogene sedimentary and volcanic rocks. Open folding, possibly contemporaneous, affected the metamorphic rocks throughout the YTTN. Regional uplift and northward tilting (Mertie, 1937) followed, probably in Pleistocene time. The effects of this deformation are most evident in the northeastern part of the YTTN, where the Fortymile and Seventymile Rivers are deeply entrenched and are bordered by extensive high-level terraces.

Prindle Volcano, in the eastern part of the Tanacross Quadrangle, is a manifestation of Pleistocene or Holocene alkali-olivine basaltic volcanism. Because its lava contains spinel-bearing peridotite and granulite inclusions (Foster and others, 1966), it also suggests that extension is taking place at deep crustal and upper mantle levels. Prindle Volcano lies at the northern end of a belt of occurrences of alkali-olivine basalts that extends along the western continental margin of North America (Foster and others, 1966).

In general, our interpretation of the geologic history of the YTTN is similar to the one modeled by Tempelman-Kluit (1979) for part of the Yukon Territory. Some events may also correlate with those in other parts of the Canadian Cordillera (Monger and others, 1982). Following Tempelman-Kluit's (1979) model, the amphibolite-facies rocks of subterrane Y_4 might be considered as part of Stikinia (Stikinia terrane), and the Late Triassic Taylor Mountain granitic intrusion could be correlated with the Klotassin Suite of the Yukon Territory. In our view, however, it seems more likely that subterrane Y_4 was not a part of Stikinia, but instead was a discrete terrane that lay north of Stikinia in Late Triassic and Early Jurassic time. Later in Jurassic time, both Stikinia with the intruded Klotassin Suite and subterrane Y_4 with the Taylor Mountain and other Triassic and Jurassic intrusions were amalgamated with other terranes to form terrane I of Monger and others (1982). Subterrane Y_3 could correlate with Tempelman-Kluit's cataclastic unit, and the Seventymile terrane could have originated in the closing of the Anvil Ocean. Although tentative correlations can be made, some details in lithologies and timing of events differ. For instance, closing of the Anvil Ocean is postulated for Middle Jurassic time in Canada but may have been a little earlier in Alaska.

REFERENCES CITED

Abbott, G., 1982, Origin of the Clinton Creek asbestos deposit, *in* Yukon exploration and geology: Exploration and Geological Services Northern Affairs, Indian and Northern Affairs, Canada, p. 18–25.

Aleinikoff, J. N., and Nokleberg, W. J., 1985a, Age of intrusion and metamorphism of a granodiorite in the Lake George terrane, northeastern Mount Hayes Quadrangle, *in* Bartsch-Winkler, S., and Reed, K. M., eds., The United States Geological Survey in Alaska; Accomplishments during 1983: U.S. Geological Survey Circular 945, p. 62–65.

——, 1985b, Age of Devonian igneous-arc terranes in the northern Mount Hayes Quadrangle, eastern Alaska Range, Alaska, *in* Bartsch-Winkler, S., ed., The United States Geological Survey in Alaska; Accomplishments during 1984: U.S. Geological Survey Circular 967, p. 44–49.

Aleinikoff, J. N., Dusel-Bacon, C., and Foster, H. L., 1981, Geochronologic studies in the Yukon-Tanana Upland, east-central Alaska, *in* Albert, N.R.D., and Hudson, T., eds., The United States Geological Survey in Alaska; Accomplishments during 1979: U.S. Geological Survey Circular 823-B, p. B34–B37.

——, 1986, Geochronology of augen gneiss and related rocks, Yukon-Tanana terrane, east-central Alaska: Geological Society of America Bulletin, v. 97, p. 626–637.

Bacon, C. R., Foster, H. L., and Smith, J. G., 1985, Cretaceous calderas and rhyolitic welded tuffs in the Yukon-Tanana terrane, east-central Alaska: Geological Society of America Abstracts with Programs, v. 17, p. 339.

Barker, J. C., 1978, Mineral deposits of the Yukon-Tanana Uplands; A summary report: U.S. Bureau of Mines Open-File Report 88–78, 33 p.

Barker, J. C., and Clautice, K. H., 1977, Anomalous uranium concentrations in artesian springs and stream sediments in the Mount Prindle area, Alaska: U.S. Bureau of Mines Open-File Report 130–77, 18 p.

Barnes, D. F., 1977, Bouguer gravity map of Alaska: U.S. Geological Survey Geophysical Investigations Map GP-913, 1 sheet, scale 1:250,000.

Barnes, D. F., and Morin, R. L., 1975, Gravity map of the Nabesna Quadrangle, Alaska: U.S. Geological Survey Miscellaneous Field Studies Map MF-655-1, 1 sheet, scale 1:250,000.

Barnes, F. F., 1967, Coal resources of Alaska, *in* Contributions to economic geology: U.S. Geological Survey Bulletin 1242-B, p. B1–B85.

Berg, H. C., and Cobb, E. H., 1967, Metalliferous lode deposits of Alaska; U.S. Geological Survey Bulletin 1246, 254 p.

Blum, J. D., 1983, Petrology, geochemistry, and isotope geochronology of the Gilmore Dome and Pedro Dome plutons, Fairbanks district, Alaska: Alaska Division of Geological and Geophysical Surveys Report of Investigations 83-2, 59 p.

Brabb, E. E., and Churkin, M., Jr., 1969, Geologic map of the Charley River Quadrangle, east-central Alaska: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-573, scale 1:250,000.

Brook, C. A., and 5 others, 1979, Assessment of geothermal resources of the United States–1978: U.S. Geological Survey Circular 790, p. 18–85.

Brosgé, W. P., Brabb, E. E., and King, E. R., 1970, Geologic interpretation of reconnaissance aeromagnetic survey of northeastern Alaska: U.S. Geological Survey Bulletin 1271-F, 14 p.

Brown, E. H., and Forbes, R. B., 1984, Paragenesis and regional significance of ecologitic rocks from the Fairbanks district, Alaska: Geological Society of America Abstracts with Programs, v. 16, p. 272.

Bundtzen, T. K., 1981, Geology and mineral deposits of the Kantishna Hills, Mount McKinley Quadrangle, Alaska [M.S. thesis]: Fairbanks, University of Alaska, 237 p.

—— , 1982, Bedrock geology of the Fairbanks mining district, western sector: Alaska Division of Geological and Geophysical Surveys Open-File Report 155, 2 plates.

Bundtzen, T. K., and Reger, R. D., 1977, The Richardson lineament; A structural control for gold deposits in the Richardson mining district, interior Alaska: Alaska Division of Geological and Geophysical Surveys Geologic Report 55, p. 29–34.

Bundtzen, T. K., and 6 others, 1984, Alaska's mineral industry, 1983: Alaska Division of Geological and Geophysical Surveys Special Report 33, 56 p.

Burack, A. C., 1983, Geology along the Pinnell Mountain Trail, Circle Quadrangle, Alaska [M.S. thesis]: Durham, University of New Hampshire, 98 p.

Byers, F. M., Jr., 1957, Tungsten deposits in the Fairbanks district, Alaska: U.S. Geological Survey Bulletin 1024-I, p. 179–215.

Cady, J. W., and Barnes, D. F., 1983, Complete Bouguer gravity map of Circle Quadrangle, Alaska; Folio of the Circle Quadrangle, Alaska: U.S. Geological Survey Open-File Report 83–170D, scale 1:250,000.

Cady, J. W., and Weber, F. R., 1983, Aeromagnetic map and interpretation of magnetic and gravity data, Circle Quadrangle, Alaska: U.S. Geological Survey Open-File Report 83–170–C, 29 p.

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

Carter, L. D., and Galloway, J. P., 1984, Lacustrine and eolian deposits of Wisconsin age at Riverside Bluff in the upper Tanana River valley, 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. 66–68.

Churkin, M., 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. B5, p. 3718–3730.

Clark, S.H.B., and Foster, H. L., 1971, Geochemical and geological reconnaissance in the Seventymile River area, Alaska: U.S. Geological Survey Bulletin 1315, 21 p.

Cobb, E. H., 1973, Placer deposits of Alaska: U.S. Geological Survey Bulletin 1374, 213 p.

Coleman, R. G., 1977, Ophiolites: New York, Springer-Verlag, 229 p.

Coleman, R. G., Lee, D. E., Beatty, L. B., and Brannock, W. W., 1965, Eclogites and eclogites; Their differences and similarities: Geological Society of America Bulletin, v. 76, p. 483–508.

Cushing, G. W., 1984, Early Mesozoic tectonic history of the eastern Yukon-Tanana Upland [M.S. thesis]: Albany, State University of New York, 235 p.

Cushing, G. W., and Foster, H. L., 1984, Structural observations in the Circle Quadrangle, Yukon-Tanana Upland, 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. 64–65.

Cushing, G. W., Foster, H. L., and Harrison, T. M., 1984a, Mesozoic age of metamorphism and thrusting in the eastern part of east-central Alaska: EOS Transactions of the American Geophysical Union, v. 65, no. 16, p. 290–291.

Cushing, G. W., Foster, H. L., Harrison, T. M., and Laird, J., 1984b, Possible Mesozoic accretion in the eastern Yukon-Tanana Upland, Alaska: Geological Society of America Abstracts with Programs, v. 16, p. 481.

Dadisman, S. V., 1980, Radiometric ages of rocks in south-central Alaska and western Yukon Territory: U.S. Geological Survey Open-File Report 80–183, 82 p., scale 1:1,000,000.

Dusel-Bacon, C., and Aleinikoff, J. N., 1985, Petrology and tectonic significance of augen gneiss from a belt of Mississippian granitoids in the Yukon-Tanana terrane, east-central Alaska: Geological Society of America Bulletin, v. 96, p. 411–425.

Dusel-Bacon, C., and Foster, H. L., 1983, A sillimanite gneiss dome in the Yukon crystalline terrane, east-central Alaska; Petrography and garnet-biotite geothermometry: U.S. Geological Survey Professional Paper 1170-E, 25 p.

Eakins, G. R., and 6 others, 1983, Alaska's mineral industry 1982: Alaska Division of Geological and Geophysical Surveys Special Report 31, 63 p.

Eberlein, G. D., Chapman, R. M., Foster, H. L., and Gassaway, J. S., 1977, Table describing known metalliferous and selected nonmetalliferous mineral deposits in central Alaska: U.S. Geological Survey Open-File Report 77–168D.

Fernald, A. T., 1962, Radiocarbon dates relating to a widespread volcanic ash deposit, eastern Alaska: U.S. Geological Survey Professional Paper 450-B, p. B29–B30.

Foley, J. Y., 1982, Alkaline igneous rocks in the eastern Alaska Range; Short notes on Alaskan geology, 1981: Alaska Division of Geological and Geophysical Surveys Geologic Report 73, p. 1–5.

Foley, J., and Barker, J. C., 1981, Tungsten investigations of the VABM Bend vicinity, Charley River and Eagle Quadrangles, eastern Alaska: U.S. Bureau of Mines Open-File Report 29–81, 22 p.

Forbes, R. B., and Brown, J. M., 1961, A preliminary map of the bedrock geology of the Fairbanks mining district, Alaska: Alaska Division of Mines and Minerals Mineral Investigations Report 194–1, scale 1:63,360.

Forbes, R. B., and Weber, F. R., 1982, Bedrock geologic map of the Fairbanks mining district, Alaska: State of Alaska, Division of Geological and Geophysical Surveys Open-File Report AOF–170, scale 1:63,360.

Foster, H. L., 1967, Geology of the Mount Fairplay area, Alaska: U.S. Geological Survey Bulletin 1241-B, p. B1–B18.

—— , 1969, Asbestos occurrence in the Eagle C-4 Quadrangle, Alaska: U.S. Geological Survey Circular 611, 7 p.

—— , 1970, Reconnaissance geologic map of the Tanacross Quadrangle, Alaska: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-593, scale 1:250,000.

—— , 1975, Significant platinum values confirmed in ultramafic rocks of the Eagle C-3 Quadrangle, *in* Yount, M. E., ed., United States Geological Survey Alaska Program 1975: U.S. Geological Survey Circular 722, p. 42.

—— , 1976, Geologic map of the Eagle Quadrangle, Alaska: U.S. Geological Survey Miscellaneous Geologic Investigations Series Map I-922, scale 1:250,000.

—— , 1981, A minimum age for Prindle Volcano, Yukon-Tanana Upland, *in*

Albert, N.R.D., and Hudson, T., eds., The United States Geological Survey in Alaska; Accomplishments during 1979: U.S. Geological Survey Circular 823-B, p. B37–B38.

Foster, H. L., and Clark, S.H.B., 1970, Geochemical and geologic reconnaissance of a part of the Fortymile area, Alaska: U.S. Geological Survey Bulletin 1312-M, 29 p.

Foster, H. L., and Cushing, G. W., 1985, Tertiary(?) folding in the Tanacross Quadrangle, *in* Bartsch-Winkler, S., and Reed, K. M., eds., The United States Geological Survey in Alaska; Accomplishments during 1983: U.S. Geological Survey Circular 945, p. 38–40.

Foster, H. L., and Keith, T.E.C., 1974, Ultramafic rocks of the Eagle Quadrangle, east-central Alaska: U.S. Geological Survey Journal of Research, v. 2, no. 6, p. 657–669.

Foster, H. L., and O'Leary, R. M., 1982, Gold found in bedrock of Lost Chicken Creek, gold placer mine, Fortymile area, Alaska, *in* Coonrad, W. L., ed., The United States Geological Survey in Alaska; Accomplishments during 1980: U.S. Geological Survey Circular 844, p. 62–63.

Foster, H. L., Forbes, R. B., and Ragan, D. M., 1966, Granulite and peridotite inclusions from Prindle Volcano, Yukon-Tanana Upland, Alaska: U.S. Geological Survey Professional Paper 550-B, p. B115–B119.

Foster, H. L., Weber, F. R., Forbes, R. B., and Brabb, E. E., 1973, Regional geology of Yukon-Tanana Upland, Alaska, *in* Pitcher, M. G., ed., Arctic geology: American Association of Petroleum Geologists Memoir 19, p. 388–395.

Foster, H. L., and 6 others, 1976, The Alaskan Mineral Resource Assessment Program; Background information to accompany folio of geologic and mineral resource maps of the Tanacross Quadrangle, Alaska: U.S. Geological Survey Circular 734, 23 p.

Foster, H. L., Donato, M. L., and Yount, M. E., 1978a, Petrographic and chemical data on Mesozoic granitic rocks of the Eagle Quadrangle, Alaska: U.S. Geological Survey Open-File Report 78-253, 29 p., 2 maps, scale 1:250,000.

Foster, H. L., Jones, D. L., Keith, T.E.C., Wardlaw, B., and Weber, F. R., 1978b, Late Paleozoic radiolarians and conodonts found in chert of Big Delta Quadrangle, *in* Johnson, K. M., ed., United States Geological Survey in Alaska; Accomplishments during 1977: U.S. Geological Survey Circular 772-B, p. B34–B36.

Foster, H. L., O'Leary, R. M., McDanal, S. K., and Clark, A. L., 1978c, Analyses of rock samples from the Big Delta Quadrangle, Alaska: U.S. Geological Survey Open-File Report 78-469, 125 p., 1 map, scale 1:250,000.

Foster, H. L., and 6 others, 1979, The Alaskan Mineral Resource Assessment Program; Background information to accompany folio of geologic and mineral resource maps of the Big Delta Quadrangle, Alaska: U.S. Geological Survey Circular 783, 19 p.

Foster, H. L., Laird, J., Keith, T.E.C., Cushing, G. W., and Menzie, W. D., 1983, Preliminary geologic map of the Circle Quadrangle, Alaska: U.S. Geological Survey Open-File Report 83-170A, 29 p., scale 1:250,000.

Foster, H. L., Laird, J., and Cushing, G. W., 1984, Thrust faulting in the Eagle A-1 Quadrangle, Alaska, and its implications for the tectonic history of the Yukon-Tanana Upland [abs.]: EOS Transactions of the American Geophysical Union, v. 65, no. 16, p. 291.

Foster, H. L., Cushing, G. W., Keith, T.E.C., and Laird, J., 1985, Early Mesozoic tectonic history of the Boundary area, east-central Alaska: Geophysical Research Letters, v. 12, no. 9, p. 553–556.

Gabrielse, H., 1985, Major dextral transcurrent displacements along the northern Rocky Mountain Trench and related lineaments in north-central British Columbia: Geological Society of America Bulletin, v. 96, p. 1–14.

Gilbert, W. G., and Bundtzen, T. K., 1979, Mid-Paleozoic tectonics, volcanism and mineralization in north-central Alaska Range, *in* Sisson, A., ed., The relationship of plate tectonics to Alaskan geology and resources: Anchorage, Alaska Geological Society Symposium 6 Proceedings, 1977, p. F1–F22.

Gilbert, W. G., and Redman, E., 1977, Metamorphic rocks of Toklat-Teklanika Rivers area, Alaska: Alaska Division of Geological and Geophysical Surveys Geologic Report 50, 13 p.

Godwin, C. I., 1976, Casino, *in* Brown, S. C., ed., Porphyry deposits of the Canadian Cordillera: Canadian Institute of Mining and Metallurgy Special Volume 15, p. 344–354.

Gottfried, D., Jaffe, H. W., and Senftle, F. E., 1959, Evaluation of the lead-alpha (Larsen) method for determining ages of igneous rocks: U.S. Geological Survey Bulletin 1097-A, p. 1–63.

Green, L. H., 1972, Geology of Nash Creek, Larsen Creek, and Dawson map-areas, Yukon Territory: Geological Survey of Canada Memoir 364, p. 1–157.

Griscom, A., 1975, Aeromagnetic map and interpretation of the Nabesna Quadrangle, Alaska: U.S. Geological Survey Miscellaneous Field Studies Map MF-655H, 2 sheets, scale 1:250,000.

——, 1976, Aeromagnetic map and interpretation of the Tanacross Quadrangle, Alaska: U.S. Geological Survey Miscellaneous Field Studies Map MF-767A, 2 sheets, scale 1:250,000.

——, 1979, Aeromagnetic map and interpretation for the Big Delta Quadrangle, Alaska: U.S. Geological Survey Open-File Report 78-529-B, scale 1:250,000.

Guthrie, R. D., 1968, Paleoecology of the large mammal community in interior Alaska during the late Pleistocene: American Midland Naturalist, v. 79, p. 346–363.

Hall, M. H., Smith, T. E., and Weber, F. R., 1984, Geologic guide to the Fairbanks-Livengood area, east-central Alaska: Fairbanks, Alaska, Alaska Division of Geological and Geophysical Surveys, 30 p.

Harte, B., and Hudson, N.F.C., 1979, Pelite facies series and temperatures and pressures of Dalradian metamorphism in E. Scotland, *in* Harris, A. L., Holland, C. H., and Leake, B. E., eds., The Caledonides of the British Isles–Revisited: Scottish Academic Press, p. 323–337.

Hill, J. M., 1933, Lode deposits of the Fairbanks district, Alaska: U.S. Geological Survey Bulletin 849-B, p. 29–163.

Holdaway, M. J., 1971, Stability of andalusite and the aluminum silicate phase diagram: American Journal of Science, v. 271, p. 97–131.

Hollister, V. F., Anzalone, S. A., and Richter, D. H., 1975, Porphyry copper deposits of southern Alaska and contiguous Yukon Territory: Canadian Institute of Mining and Metallurgy Bulletin, v. 68, p. 104–112.

Holmes, G. W., and Foster, H. L., 1968, Geology of the Johnson River area, Alaska: U.S. Geological Survey Bulletin 1249, 49 p.

Holmes, G. W., Hopkins, D. M., and Foster, H. L., 1968, Pingos in central Alaska: U.S. Geological Survey Bulletin 1241-H, 40 p.

Hytoon, M., 1979, Geology of the Clinton Creek asbestos deposit, Yukon Territory [M.S. thesis]: Vancouver, University of British Columbia, 67 p.

Jaffe, H. W., Gottfried, D., Waring, C. L., and Worthing, H. W., 1959, Lead-alpha age determinations of accessory minerals of igneous rocks (1953–1957): U.S. Geological Survey Bulletin 1097-B, p. 65–148.

Jones, D. L., Silberling, N. J., Coney, P. J., and Plafker, G., 1984, Lithotectonic terrane map of Alaska (west of the 141st Meridian), Part A, *in* Silberling, N. J., and Jones, D. L., eds., Folio of the lithotectonic terrane maps of the North American Cordillera: U.S. Geological Survey Miscellaneous Field Studies Map MF-1874-A, 1 sheet, scale 1:2,500,000.

Keith, T.E.C., and Foster, H. L., 1973, Basic data on the ultramafic rocks of the Eagle Quadrangle, east-central Alaska: U.S. Geological Survey Open-File Report 73-140, 4 sheets.

Keith, T.E.C., Foster, H. L., Foster, R. L., Post, E. V., and Lehmbeck, W. L., 1981a, Geology of an alpine-type peridotite in the Mount Sorenson area, east-central Alaska, *in* Shorter contributions to general geology: U.S. Geological Survey Professional Paper 1170-A, p. A1–A9.

Keith, T.E.C., Presser, T. S., and Foster, H. L., 1981b, New chemical and isotope data for the hot springs along Big Windy Creek, Circle A-1 Quadrangle, Alaska, *in* Albert, N.R.D., and Hudson, T., eds., The United States Geological Survey in Alaska; Accomplishments during 1979: U.S. Geological Survey Circular 823-B, p. B25–B28.

Kerin, L. J., 1976, The reconnaissance petrology of the Mount Fairplay igneous complex [M.S. thesis]: Fairbanks, University of Alaska, 95 p.

Laird, J., 1982, Amphiboles in metamorphosed basaltic rocks; Greenschist to amphibolite facies, *in* Veblen, D. R., and Ribbe, P. H., eds., Amphiboles; Petrology and experimental phase relations: Mineralogical Society of America Reviews in Mineralogy, v. 9B, p. 113–138.

Laird, J., and Foster, H. L., 1984, Description and interpretation of a mylonitic foliated quartzite unit and feldspathic quartz wacke (grit) unit in the Circle Quadrangle, Alaska, *in* Reed, K. M., and Bartsch-Winkler, S., eds., The United States Geological Survey in Alaska; Accomplishments during 1982: U.S. Geological Survey Circular 939, p. 29–33.

Laird, J., Biggs, D. L., and Foster, H. L., 1984a, A terrane boundary of the southeastern Circle Quadrangle, Alaska?; Evidence from petrologic data: EOS Transactions of the American Geophysical Union, v. 65, no. 16, p. 291.

Laird, J., Foster, H. L., and Weber, F. R., 1984b, Amphibole eclogite in Circle Quadrangle, Yukon-Tanana Upland, 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. 57–60.

Lange, I. M., and Nokleberg, W. J., 1984, Massive sulfide deposits of the Jarvis Creek Terrane, Mount Hayes Quadrangle, eastern Alaska Range: Geological Society of America Abstracts with Programs, v. 16, p. 294.

Lerbekmo, J. F., and Campbell, F. A., 1969, Distribution, composition, and source of the White River Ash, Yukon Territory: Canadian Journal of Earth Sciences, v. 6, p. 109–116.

Luthy, S. T., Foster, H. L., and Cushing, G. W., 1981, Petrographic and chemical data on Cretaceous granitic rocks of the Big Delta Quadrangle, Alaska: U.S. Geological Survey Open-File Report 81–398, 12 p.

MacKevett, E. M., Jr., and Holloway, C. D., 1977, Table describing metalliferous and selected nonmetalliferous mineral deposits in eastern southern Alaska: U.S. Geological Survey Open-File Report 77–169, 99 p.

Matzko, J. J., Jaffe, H. W., and Waring, C. L., 1958, Lead-alpha age determinations of granitic rocks from Alaska: American Journal of Science, v. 256, no. 8, p. 529–539.

Maucher, A., 1976, The strata-bound cinnabar-stibnite-scheelite deposits, *in* Wolf, K. H., ed., Handbook of strata-bound and stratiform ore deposits, Volume 7: Amsterdam, Elsevier Publishing Company, p. 477–503.

McConnell, R. G., 1905, Report on the Klondike gold fields: Geological Survey of Canada Annual Report, n.s., v. 14, pt. B, 71 p.

McCulloch, M. T., and Wasserburg, G. J., 1978, Sm-Nd and Rb-Sr chronology of continental crust formation: Science, v. 200, no. 4345, p. 1003–1011.

Menzie, W. D., and Foster, H. L., 1978, Metalliferous and selected nonmetalliferous mineral resource potential in the Big Delta Quadrangle, Alaska: U.S. Geological Survey Open-File Report 78–529D, 60 p.

Menzie, W. D., Foster, H. L., Tripp, R. B., and Yeend, W. E., 1983, Mineral resource assessment of the Circle Quadrangle, Alaska: U.S. Geological Survey Open-File Report 83–170B, 57 p.

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

—— , 1938, Gold placers of the Fortymile, Eagle, and Circle districts, Alaska: U.S. Geological Survey Bulletin 897-C, 261 p.

Metz, P. A., and Robinson, M. S., 1980, Investigation of mercury-antimony-tungsten metal provinces of Alaska, II: Fairbanks, University of Alaska, Mineral Research Industry Laboratory Open-File Report 80-8, 39 p.

Miller, T. P., Barnes, I., and Patton, W. W., Jr., 1975, Geologic setting and chemical characteristics of hot springs in west-central Alaska: U.S. Geological Survey Journal of Research, v. 3, no. 2, p. 149–162.

Monger, J.W.H., Price, R. A., and Tempelman-Kluit, D. J., 1982, Tectonic accretion and the origin of the two major metamorphic and plutonic welts in the Canadian Cordillera: Geology, v. 10, p. 70–75.

Mortensen, J. K., 1983, Age and evolution of the Yukon-Tanana terrane, southeastern Yukon Territory [Ph.D. thesis]: Santa Barbara, University of California, 155 p.

Mullins, W. J., McQuat, J. F., and Rogers, R. K., 1984, The Alaska asbestos project; Part 1, Project review: Industrial Minerals, no. 199, p. 41.

Nokleberg, W. J., and Aleinikoff, J. N., 1985, Summary of stratigraphy, structure, and metamorphism of Devonian igneous-arc terranes, northeastern Mount Hayes Quadrangle, eastern Alaska Range, Alaska, *in* Bartsch-Winkler, S., ed., The United States Geological Survey in Alaska; Accomplishments during 1984: U.S. Geological Survey Circular 967, p. 66–71.

Nokleberg, W. J., and Lange, I. M., 1985, Volcanogenic massive sulfide occurrences, Jarvis Creek Glacier terrane, western Mount Hayes Quadrangle, eastern Alaska Range, *in* Bartsch-Winkler, S., and Reed, K. M., eds., The United States Geological Survey in Alaska; Accomplishments during 1983: U.S. Geological Survey Circular 945, p. 77–80.

Nokleberg, W. J., Aleinikoff, J. N., and Lange, I. M., 1983, Origin and accretion of Andean-type and island arc terranes of Paleozoic age juxtaposed along the Hines Creek fault, Mount Hayes Quadrangle, eastern Alaska Range, Alaska: Geological Society of America Abstracts with Programs, v. 15, p. 427.

—— , 1986, Cretaceous deformation and metamorphism in the northeastern Mount Hayes Quadrangle, eastern Alaska Range, *in* Bartsch-Winkler, S., and Reed, K. M., eds., Geologic studies in Alaska by the U.S. Geological Survey during 1985: U.S. Geological Survey Circular 978, p. 64–69.

Péwé, T. L., 1965, Delta River area, Alaska Range, *in* Péwé, T. L., Ferrians, O. J., Jr., Nichols, D. R., and Karlstrom, T.N.V., eds., Guidebook for Field Conference F, Central and south-central Alaska; International Association for Quaternary Research, 17th Congress, U.S.A. 1965: Lincoln, Nebraska Academy of Science, p. 55–93.

—— , 1975, Quaternary geology of Alaska: U.S. Geological Survey Professional Paper 835, 145 p.

Porter, L., 1985, Late Pleistocene fauna of Lost Chicken Creek, Alaska [Ph.D. thesis]: Pullman, Washington State University, 173 p.

Prindle, L. M., 1905, Fortymile, Birch Creek, and Fairbanks regions, Alaska: U.S. Geological Survey Bulletin 251, 89 p.

—— , 1913, A geologic reconnaissance of the Fairbanks Quadrangle, Alaska: U.S. Geological Survey Bulletin 525, 220 p.

Richter, D. H., 1976, Geologic map of the Nabesna Quadrangle, Alaska: U.S. Geological Survey Miscellaneous Investigations Series Map I-932, scale 1:250,000.

Sawyer, J.P.B., and Dickinson, R. A., 1976, Mount Nansen, *in* Brown, S. A., ed., Porphyry deposits of the Canadian Cordillera: Canadian Institute of Mining and Metallurgy Special Volume 5, p. 336–343.

Sinclair, W. D., 1978, Porphyry occurrences of southern Yukon, *in* Current Research, Part A: Geological Survey of Canada Paper 78–1A, p. 283–286.

Singer, D. A., Curtin, G. C., and Foster, H. L., 1976, Mineral resources map of the Tanacross Quadrangle, Alaska: U.S. Geological Survey Miscellaneous Field Studies Map MF-767-E, scale 1:250,000.

Southworth, D. D., 1984, Geologic and geochemical investigations of the "Nail" allochthon, east-central Alaska: U.S. Bureau of Mines Open-File Report 176–84, 19 p.

Streckeisen, A. L., 1976, To each plutonic rock its proper name: Earth Science Reviews, v. 12, p. 1–33.

Swainbank, R. C., and Forbes, R. B., 1975, Petrology of eclogitic rocks from the Fairbanks district, Alaska, *in* Forbes, R. B., ed., Contributions to geology of the Bering Sea Basin and adjacent regions: Geological Society of America Special Paper 151, p. 77–123.

Tempelman-Kluit, D. J., 1976, The Yukon crystalline terrane; Enigma in the Canadian Cordillera: Geological Society of America Bulletin, v. 87, p. 1343–1357.

—— , 1979, Transported cataclasite, ophiolite, and granodiorite in Yukon; Evidence of arc-continent collision: Geological Survey of Canada Paper 79–14, 27 p.

Ten Brink, N. W., 1983, Glaciation of the northern Alaska Range, *in* Thorson, R. M., and Hamilton, T. D., eds., Glaciation in Alaska: Fairbanks, University of Alaska Museum Occasional Paper 2, p. 82–91.

Wahrhaftig, C., 1958, Quaternary geology of the Nenana River valley and adjacent parts of the Alaska Range, Part A *of* Quaternary and engineering geology in the central part of the Alaska Range: U.S. Geological Survey Professional Paper 293, p. 1–68.

—— , 1968, Schists of the central Alaska Range, *in* Contributions to stratigraphy: U.S. Geological Survey Bulletin 1254-E, p. E1–E22.

Wahrhaftig, C., and Hickcox, C. A., 1955, Geology and coal deposits, Jarvis

Creek coal field, Alaska: U.S. Geological Survey Bulletin 989-G, p. 353–367.
Waring, G. A., 1917, Mineral springs of Alaska: U.S. Geological Survey Water-Supply Paper 418, 118 p.
Wasserburg, G. J., Eberlein, G. D., and Lanphere, M. A., 1963, Age of Birch Creek Schist and some batholithic intrusions in Alaska: Geological Society of America Special Paper 73, p. 258–259.
Weber, F. R., 1983, Glacial geology of the Yukon–Tanana Upland; A progress report, *in* Thorson, R. M., and Hamilton, T. D., eds., Glaciation in Alaska: Fairbanks, University of Alaska Occasional Paper 2, p. 96–100.
Weber, F. R., Foster, H. L., Keith, T.E.C., and Dusel-Bacon, C., 1978, Preliminary geologic map of the Big Delta Quadrangle: U.S. Geological Survey Open-File Report 78-529-A, scale 1:250,000.
Weber, F. R., Hamilton, T. D., Hopkins, D. M., Repenning, C. A., and Haas, H., 1981, Canyon Creek; A late Pleistocene vertebrate locality in interior Alaska: Quaternary Research, v. 16, p. 167–180.
Wilson, F. H., Smith, J. G., and Shew, N., 1985, Review of radiometric data from the Yukon Crystalline Terrane, Alaska and Yukon Territory: Canadian Journal of Earth Sciences, v. 22, no. 4, p. 525–537.
Wise, D. U., and 7 others, 1984, Fault-related rocks; Suggestions for terminology: Geology, v. 12, p. 391–394.
Wolfe, J. A., and Toshimasa, T., 1980, The Miocene Seldovia Point flora from the Kenai Group, Alaska: U.S. Geological Survey Professional Paper 1105, 52 p.

MANUSCRIPT ACCEPTED BY THE SOCIETY MAY 8, 1990

ACKNOWLEDGMENTS

The authors were assisted throughout the preparation of this chapter by many fellow workers. The following colleagues and their contributions of unpublished data, written sections, and expertise are particularly acknowledged: Jo Laird, metamorphic stratigraphy and metamorphism north of the Tanana River, University of New Hampshire, Durham, New Hampshire 03824; G. W. Cushing, ^{40}Ar-^{39}Ar incremental heating experiments and structural geology, ARCO Oil and Gas Company, Plano, Texas 75075; F. H. Wilson and Nora Shew, K-Ar determinations, history of application of radiometric age dating methods, and results of K-Ar work in the Yukon-Tanana terrane, U.S. Geological Survey, Anchorage, Alaska 99508; J. N. Aleinikoff, U-Pb determinations on zircons and common lead studies, U.S. Geological Survey, Denver, Colorado 80225; W. J. Nokleberg, geology of the Mount Hayes Quadrangle and mineral resources of the Yukon-Tanana terrane, U.S. Geological Survey, Menlo Park, California 94025; Cynthia Dusel-Bacon, distribution and petrology of metamorphic rocks, U.S. Geological Survey, Menlo Park, California 94025; Lee Porter, vertebrate paleontology, Gig Harbor, Washington 98335; M. C. Gardner, the Shaw Creek fault, ARCO Oil and Gas Company, Plano, Texas 75075; T. R. Carr, identification of conodonts, ARCO Oil and Gas Company, Plano, Texas 75075; and P. J. Burton, general information on mineral resources, State of Alaska, Department of Natural Resources, Fairbanks, Alaska 99708. Assistance was also given by R. M. Chapman and Béla Csejtey, Jr., U.S. Geological Survey, Menlo Park, California 94025; J. T. Dutro, Jr., U.S. Geological Survey, Washington, D.C. 20560; F. R. Weber, U.S. Geological Survey, Fairbanks, Alaska 99708; John W. Cady, U.S. Geological Survey, Denver, Colorado 80225; T. K. Bundtzen and T. E. Smith, State of Alaska, Division of Mines and Geology, Fairbanks, Alaska, 99708; S. C. Bergman and Michael Churkin, Jr., ARCO Oil and Gas Company, Plano, Texas 75075; and other colleagues.

The able assistance of Christa Marting in drafting and other aspects of manuscript preparation and of W. M. Trollman in typing and word processing are also gratefully acknowledged.

NOTES ADDED IN PROOF

Major additions to the geologic and geophysical data for the western Yukon–Tanana region, made since this chapter was completed in 1986, have resulted largely from the Trans-Alaska Crustal Transect program (TACT) of the U.S. Geological Survey. The TACT data include new radiometric ages obtained both on metamorphic and igneous rocks (Aleinikoff and others, 1987, and Nokleberg and others, 1989). Data were also collected that were interpreted to indicate Cretaceous crustal extension in the western Yukon–Tanana region (Pavlis and others, 1993); these data provide additional information for interpreting the Mesozoic structural history of the region. Geophysical studies, particularly the use of deep-sensing, low-frequency magnetotelluric (MT) and shallow-sensing, high-frequency audiomagnetotelluric (AMT) soundings, along with a seismic reflection profile, provide information on the deep structure of the Yukon-Tanana terrane north of the Denali fault. One model for the Yukon-Tanana terrane suggested by these geophysical data is that of thin-skinned thrusting of the rigid units of the Yukon-Tanana terrane over Mesozoic flysch (Labson and Stanley, 1989; Beaudoin and others, 1992). Further testing of this model is taking place and alternative interpretations need more investigation.

In the eastern Yukon-Tanana region, recent data have been derived from largely U.S. Geological Survey-supported geothermobarometric studies of selected amphibolite-facies metamorphic rocks (Dusel-Bacon and Hansen, 1992; Dusel-Bacon and others, 1993). Other new information includes structural observations (Hansen, 1990), and new age dates both on igneous and metamorphic rocks (Hansen and others, 1991). Geothermobarometric calculations suggest that high-pressure amphibolite-facies metamorphic rocks are present both in the Y_4 subterrane (Taylor Mountain terrane of Dusel-Bacon and Hansen, 1992) and the Y_1 (Lake George subterrane of Dusel-Bacon and Hansen, 1992).

ADDITIONAL REFERENCES

Aleinikoff, J. N., Dusel-Bacon, C., Foster, H. L., and Nokleberg, W. J., 1987, Lead isotope fingerprinting of tectono-stratigraphic terranes, east-central Alaska: Canadian Journal of Earth Sciences, v. 24, p. 2089–2098.
Beaudoin, B. C., Fuis, G. S., Mooney, W. D., Nokleberg, W. J., and Christensen, N. I., 1992, Thin, low-velocity crust beneath the southern Yukon-Tanana terrane east-central Alaska: Results from Trans-Alaska Crustal Transect refraction/wide-angle reflection data: Journal of Geophysical Research, v. 97, no. B2, p. 1921–1942.
Dusel-Bacon, C., and Hansen, V. L., 1992, High-pressure amphibolite-facies metamorphism and deformation within the Yukon-Tanana and Taylor Mountain terranes eastern Alaska, *in* Bradley, D. W., and Dusel-Bacon, C., eds., Geologic studies in Alaska by the U.S. Geological Survey, 1991: Geological Survey Bulletin 2041, p. 140–158.
Dusel-Bacon, C., Csejtey, B., Jr., Foster, H. L., Doyle, E. O., Nokleberg, W. J., and Plafker, G., 1993, Distribution, facies, ages, and proposed tectonic associations of regionally metamorphosed rocks in east- and south-central Alaska: U.S. Geological Survey Professional Paper 1497-C, p. C1–C73.
Hansen, V. L., 1990, Yukon-Tanana terrane; A partial acquittal: Geology, v. 18, p. 365–369.
Hansen, V. L., Heizler, M. T., and Harrison, T. M., 1991, Mesozoic thermal evolution of the Yukon-Tanana composite terrane: New evidence from $^{40}Ar/^{39}Ar$ data: Tectonics, v. 110, p. 51–76.
Labson, V. F., and Stanley, W. D., 1989, Electrical resistivity structure beneath southern Alaska, *in* Nokleberg, W. J., and Fisher, M. A., eds., Alaskan Geological and Geophysical Transect, Field Trip Guidebook T104: Washington, D.C., American Geophysical Union, p. 75–78.
Nokleberg, W. J., Foster, H. L., and Aleinikoff, J. N., 1989, Geology of the northern Copper River Basin eastern Alaska Range and southern Yukon-Tanana Basin, southern and east-central Alaska, *in* Nokleberg, W. J., and Fisher, M. A., eds., Alaskan Geological and Geophysical Transect, Field Trip Guidebook T104: Washington, D.C., American Geophysical Union, p. 34–63.
Pavlis, T. L., Sisson, V. B., Foster, H. L., Nokleberg, W. J., and Plafker, G., 1993, Mid-Cretaceous extensional tectonics of the Yukon-Tanana terrane, Trans-Alaska Crustal Transect (TACT), east-central Alaska: Tectonics, v. 12, no. 1, p. 103–122.

Printed in U.S.A.