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

Chapter 16

Pre-Cenozoic plutonic rocks in mainland Alaska

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INTRODUCTION

Studies during the past decade have revealed that much of Alaska consists of a collection of generally far-traveled tectonostratigraphic terranes, most of which were transported to their present locations and accreted to North America in late Mesozoic to early Tertiary time (Jones and others, 1984; Silberling and others, this volume). This collage results in the exceedingly complex geologic and tectonic framework that constitutes much of present-day Alaska.

Magmatic activity in Alaska was influenced by a host of factors, including many involving plate interactions, such as the rate of subduction, the angle of dip, the motion of individual plates, and the composition, thickness, and age of material that was subducted beneath or collided with Alaska. The identification and interpretation of magmatic patterns as reflected by time of intrusion, areal distribution, and composition can therefore contribute to an understanding of the tectonic history of Alaska.

The following overview focuses on plutonic rocks in mainland (excludes southeastern) Alaska emplaced from the Proterozoic into the earliest Tertiary. Plutonic rocks and belts emplaced during a specific time frame (e.g., the Early Cretaceous) are not necessarily everywhere related in terms of genesis or tectonic setting, and some related rocks may be shown in different temporal episodes. Postplutonic terrane movement and Cenozoic strike-slip faulting with large displacements have further complicated the identification and interpretation of plutonic events and patterns. Rocks assigned to specific plutonic belts are assumed to be cogenetic regardless of the mechanism of formation. The informal name given to a temporal episode of intrusive activity (e.g., Early to Middle Jurassic) may in some cases have been chosen to reflect more accurately the epoch or epochs where the major part of the activity occurred rather than to adhere strictly to absolute ages. Additional data on the latest Cretaceous and Cenozoic plutonism in Alaska are in the chapters by Moll-Stalcup (this volume) and Brew (this volume); and on Plate 13 (Barker and others, this volume).

Overviews of plutonic events in southern Alaska by Hudson (1983) and in southwestern Alaska by Wallace and Engebretson (1984) and Wallace and others (1989) were particularly helpful in preparing this compilation, as was that of Armstrong (1988) for adjacent parts of Canada. This discussion of individual plutonic belts and provinces that crop out over 1,000,000 km^2 is of necessity brief, and an attempt has been made to list pertinent references to guide the reader who wishes to delve further into specific regions.

The age designations used in this chapter are based on the Decade of North American Geology geologic time scale (Palmer, 1983), and plutonic rock classifications are after Streckeisen (1976). The pre-Cenozoic plutonic rocks of Alaska discussed in this chapter are shown in more detail on 1:2,500,000-scale maps in Barker and others (this volume) and Moll and others (this volume). Geographic and physiographic names follow those of Wahrhaftig (this volume).

PROTEROZOIC PLUTONIC ROCKS

Most of the few occurrences of known Precambrian rocks in mainland Alaska (Eberlein and Lanphere, 1988) are in terranes north of the Denali fault (Plate 13), and all those dated are of Proterozoic age (2,500 to 570 Ma). Proterozoic plutonic rocks, generally orthogneiss or otherwise deformed, have been reported at widely separated localities in the Brooks Range, Seward Peninsula, and in a northeast-trending belt in southwestern Alaska (Fig. 1). Compositional data for these plutonic rocks are sparse. Protolith ages are also relatively few but range between 2,050 and 750 Ma; all of these plutons are in accreted terranes that have been subjected to one or more Phanerozoic thermal events.

Brooks Range

The Brooks Range has been included in the Arctic Alaska terrane (Jones and others, 1984), which in turn is subdivided into several subterranes. The structural core of the central and eastern Brooks Range consists of a complex assemblage of slightly to moderately metamorphosed Proterozoic and early Paleozoic rocks that is unconformably overlain by Mississippian strata. Rocks composing the assemblage are largely metasedimentary units of quartzite, quartz arenite, carbonate rocks, phyllite, argillite, chert, and graywacke and intrastratified metavolcanic rocks. These units were deformed during middle Paleozoic, middle Mesozoic, and Tertiary orogenic events and are now exposed in

Miller, T. P., 1994, Pre-Cenozoic plutonic rocks in mainland 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.

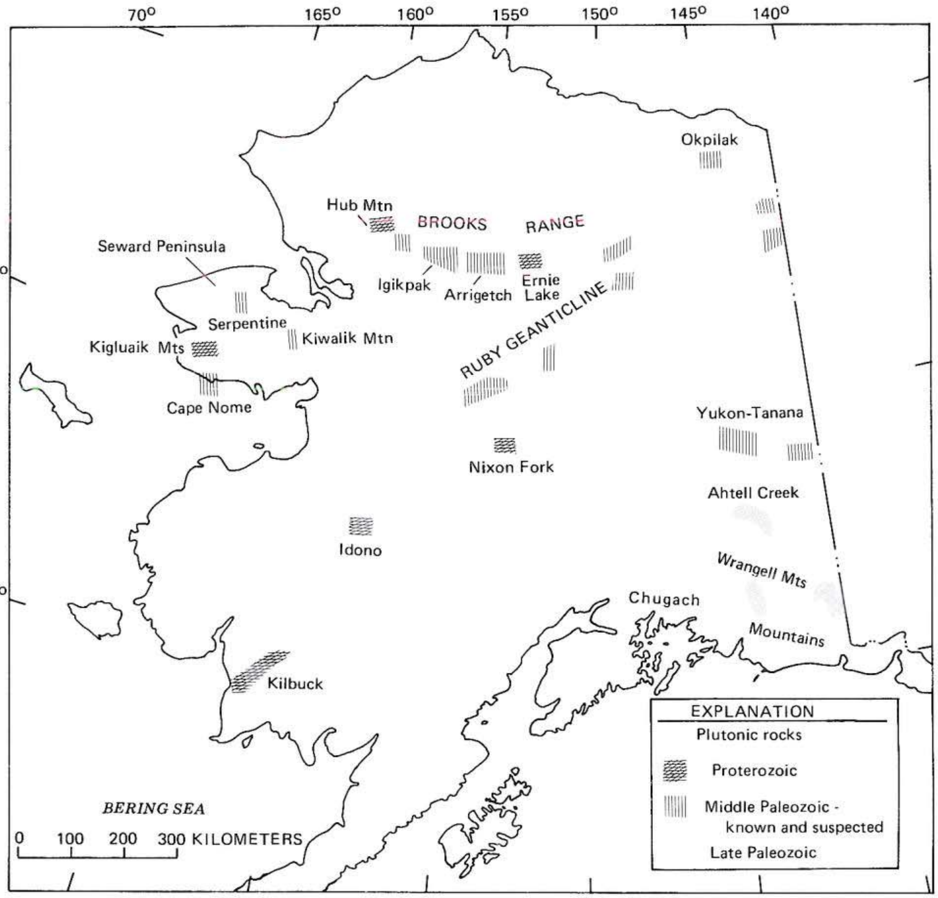

Figure 1. Distribution of Proterozoic and Paleozoic plutons in mainland Alaska.

imbricate thrust sequences and sole complexes. The Late Jurassic to Early Cretaceous thrust faulting is the result of collision between the Arctic Alaska and Angayucham terranes. Metamorphism related to this plate collision affected rocks throughout the southern Arctic Alaska terrane (Dusel-Bacon, this volume). The assemblage is locally intruded by granitic plutons of Proterozoic and middle Paleozoic age (Dillon and others, 1980).

Most felsic meta-igneous rocks in the Brooks Range yield Cretaceous K-Ar isotopic apparent ages (Turner and others, 1979). Dillon and others (1980, 1987), however, obtained preliminary U-Pb zircon ages on metagranitic rocks of the western Brooks Range metamorphic complex at Mount Angayukaqsraq, also known as Hub Mountain (Fig. 1), and of the central Brooks Range. U-Pb ratios from the Ernie Lake orthogneiss pluton (and the adjacent Sixtymile pluton) in the central Brooks Range (Fig. 1) yielded Late Proterozoic U-Pb and Pb-Pb ages (Dillon and others, 1980); however, because the data do not define a well-constrained chord, the time of intrusion and crystallization cannot be determined. The metamorphic country rocks for these bodies are similar in lithology and metamorphic grade to those at Mount Angayukaqsraq (Dillon and others, 1987). These orthogneiss bodies may therefore be similar in age to those at Mount Angayukaqsraq and may represent windows into related Late Proterozoic basement. Further isotopic age studies are needed to resolve this question.

The plutonic rocks at Mount Angayukaqsraq, first described by Mayfield and others (1983), were found by Karl and others (1989) to underlie an area of only about 4 km^2 and to consist chiefly (about 70 percent) of gabbro and leucogabbro intruded by granodiorite and alkali feldspar granite (about 30 percent). The intrusive rocks are typically massive, nonfoliated, medium grained, and possess relict igneous textures. The granite is highly evolved (more than 75 percent SiO_2) and slightly peraluminous. U-Pb zircon dating done on granitic samples from Mount Angayukaqsraq provides a 750 ± 6 Ma intrusive age (Karl and others, 1989) and provides the best measurement yet of the timing of late Proterozoic magmatism in the Brooks Range.

The metamorphic complex, in which the plutonic rocks are included, is part of an antiformal structure at the western end of the structural core of the Brooks Range. The stratigraphically oldest rocks in the metamorphic complex (late Proterozoic to early Paleozoic age) extend discontinuously nearly 800 km to the east (Till and others, 1988) and are part of the "central metamorphic belt" of Moore and others (this volume).

Seward Peninsula

The Seward Peninsula, a structurally and stratigraphically complex region of about 26,000 km ^{2} including the Seward and York terranes, is bounded on the east by the Yukon-Koyukuk basin and on the north by the Brooks Range fold-and-thrust belt. The Seward terrane, forming the east two-thirds of the peninsula, is dominated by blueschist- and greenschist-facies schists of the Nome Group (Till and Dumoulin, this volume). High-grade metamorphic rocks (amphibolite and granulite facies) are exposed in the fault-bounded Kigluaik, Bendeleben, and Darby Mountains (Fig. 1). These metamorphic rocks are composed of continental crustal material of Proterozoic to middle Paleozoic age and were subjected to crustal imbrication and thickening in middle Mesozoic time and widespread plutonism in mid-Cretaceous to Late Cretaceous time. Latest Jurassic to earliest Cretaceous compressional deformation of the Brooks Range–Seward Peninsula continental margin resulted in the formation of a north-directed fold-and-thrust belt with local blueschist metamorphism in its southern part (Forbes and others, 1984; Thurston, 1985; Einaudi and Hitzman, 1986). Late to post-tectonic plutonism occurred in mid-Cretaceous to Late Cretaceous time.

Granitic orthogneiss of possible late Proterozoic(?) to middle Paleozoic age crops out in widely scattered areas on the Seward Peninsula (Fig. 1), only the largest of which are shown on Plate 6. Compositional data are lacking for most of these bodies, and they are generally defined as metamorphosed granite, granodiorite, or tonalite. They range from layers structurally conformable to surrounding rock units and only a few meters thick to masses several kilometers in breadth. These metaplutonic bodies intruded or are intercalated with the late Proterozoic through Devonian miogeoclinal carbonate rocks, pelite, quartzite, and volcanogenic metasedimentary rocks that constitute most of the Seward Peninsula (Sainsbury, 1975; Till and others, 1986). They were subjected to blueschist-facies metamorphism during Middle Jurassic to Early Cretaceous burial, followed by overprinting to greenschist facies during decompression (Armstrong and others, 1986; Evans and Patrick, 1987; Patrick, 1988) and finally to postkinematic intrusion of Cretaceous granitic rocks (Till and others, 1986). The nature of the protoliths is uncertain, but Till and others (1986) suggest that the sediments were deposited on the shallow platform, shelf, and slope of a rifted continental margin.

Although the granitic orthogneiss has not been mapped or studied in detail, these rocks have been assigned ages ranging from Proterozoic (Sainsbury, 1975; Bunker and others, 1979) to Devonian (Till and others, 1986) on the basis of field relations and preliminary radiometric dating. Bunker and others (1979), for example, regarded all orthogneiss bodies on the Seward Peninsula as being Proterozoic in age. Their interpretation was based on Rb-Sr whole-rock ages of orthogneiss and associated schist in the Kigluaik Mountains, which indicated a 735-Ma age for the metamorphism. Till and others (1986), however, reported a U-Pb zircon age of 381 ± 2 Ma from the metagranite at Kiwalik Mountain in the eastern Seward Peninsula and suggested that similar orthogneiss bodies in the northern and southern parts of the peninsula may also be Devonian in age.

The stratigraphic position and structural setting of some orthogneiss bodies (e.g., in the Kigluaik Mountains and at Serpentine Hot Springs), indicate a possible Proterozoic age (Gardner and Hudson, 1984; Armstrong and others, 1986). Armstrong and others (1986), however, in a detailed Rb-Sr and K-Ar study of the Seward Peninsula, found no compelling evidence for Proterozoic metamorphism and therefore no definitive isotopic evidence for a Proterozoic protolith age for the orthogneiss. Their whole-rock Rb-Sr plots of metamorphic rocks and orthogneiss defined a fan bounded by isochrons of about 720 and 360 Ma. The available isotopic data therefore allow but do not confirm a Proterozoic age of intrusion. At present, the existence of Proterozoic plutonic rocks on the Seward Peninsula must be regarded as problematical.

Southwest and central Alaska

Proterozoic plutonic rocks have been identified in three widely separated localities in the Kilbuck, Idono, and Nixon Fork terranes, which are a group of terranes composed chiefly of Proterozoic(?) and Paleozoic metamorphic rocks extending from southwest to central Alaska (Fig. 1). The distribution and compositions of these plutonic rocks are poorly known. The isotopic ages are sufficient to identify these three localities as Precambrian but do not give the relations of one to another.

Kilbuck terrane. The Kilbuck terrane, which was called the "Kanektok metamorphic complex" by Hoare and Coonrad (1979), consists of a narrow, 110-km-long sliver of continental crust, most of which appears to be plutonic in origin. The metamorphic complex consists chiefly of quartz diorite, granodiorite gneiss, granite gneiss, and lesser amounts of greenschist- to amphibolite-facies metasedimentary rocks and marble. Chemical and modal data from these plutonic rocks are lacking, and the compositional nature of the protoliths is therefore uncertain. Box (1985a) has suggested that the continental Kilbuck terrane was partially thrust beneath the accretionary fore arc and intraoceanic volcanic arcs of the Goodnews and Togiak terranes, respectively, in Early Cretaceous time.

Turner and others (1983) interpret U-Th-Pb analyses and Rb-Sr whole-rock plots from granitic orthogneiss as indicating that the plutonic rocks crystallized at about 2,050 Ma and that a later metamorphic event occurred at about 1,770 Ma. The oldest 58 K-Ar mineral ages, most of which have been reset by a Mesozoic thermal event, also suggest a 1,770-Ma metamorphic event.

Idono sequence. Gemuts and others (1983) correlated an area of augen gneiss and amphibolite east of the Yukon River (Fig. 1; Plate 6) (which they called the Idono sequence) on the basis of lithology and geologic setting with similar rocks of Proterozoic(?) and Paleozoic age in the Ruby terrane. M. L. Miller and T. K. Bundtzen (unpublished data, cited in Decker and others, this volume) report preliminary U-Pb isotopic data on whole populations of zircons as indicating a late Proterozoic age of crystallization.

Nixon Fork terrane. The Nixon Fork terrane in central Alaska consists of metasedimentary and felsic metavolcanic and metaplutonic rocks that are overlain by unmetamorphosed Ordovician through Devonian shelf carbonate rocks and Permian to mid-Cretaceous terrigenous sedimentary rocks. Late Cretaceous and early Tertiary volcanism and plutonism were widespread throughout the terrane. Dillon and others (1985) have speculated that the Nixon Fork terrane may be an amalgamation of several Proterozoic terranes.

A sheared porphyritic quartz diorite from one of the metaplutonic units of the Nixon Fork terrane is intrusive into quartz-mica schist thought to be pre-Ordovician in age and has yielded a 921 ± 25 Ma K-Ar age (Silberman and others, 1979a, b). Dillon and others (1985) report a variety of discordant U-Pb zircon ages from associated foliated quartz porphyry metavolcanic rocks. Emplacement ages range from 1,265 ± 50 to 850 ± 30 Ma, with lead-loss events in middle Paleozoic and Late Cretaceous time. The available stratigraphic and radiometric age data indicate that Proterozoic magmatism has occurred, although they are not sufficiently precise to constrain the age of individual events.

PALEOZOIC PLUTONIC ROCKS

Paleozoic plutonic rocks, although relatively dispersed and underlying small areas, are important to the tectonic history of Alaska. Outside of southeastern Alaska, two principal episodes of Paleozoic plutonism are represented. The older and more areally extensive episode is composed of more than 30 middle Paleozoic granitic orthogneiss plutons that extend in a sinuous band from east-central Alaska across much of the Brooks Range and into the Seward Peninsula (Plate 13). A younger, late Paleozoic suite of plutonic rocks that occurs in the eastern Alaska Range and along the south flank of the Wrangell Mountains in southern east-central Alaska has important implications relating to terrane linkages.

Middle Paleozoic

The plutons consist chiefly of peraluminous biotite granite (Fig. 2) ranging in age from Middle Devonian to Early Mississippian. Individual plutons range in area from 5 to 500 km^2, and all have been slightly to moderately recrystallized to give a gneissic fabric. The plutons are intrusive into, and thus link or stitch, the Yukon-Tanana and Ruby terranes in east-central Alaska and Yukon Territory; the Hammond, Endicott, and North Slope terranes of the Brooks Range and Arctic Slope; and the Seward terrane of the Seward Peninsula (Plate 13). They are contiguous with bodies of similar age and composition in the Slide Mountain terrane of southeastern Yukon Territory (Hansen, 1988) and in the British Mountains of northernmost Yukon Territory. The existence of similar rocks in eastern Siberia is uncertain, although early Paleozoic plutons are reported on Wrangell Island in the Arctic Ocean, some 500 km due west of the Brooks Range (Kosygin and Popeko, 1987).

Yukon-Tanana Upland. Metamorphosed granitic rocks were first noted in the Yukon-Tanana Upland (the Yukon-Tanana terrane of Coney and others, 1980; see Foster and others, this volume) by Prindle (1909) and Mertie (1937). The plutons have been mapped by Foster (1970, 1976) and Weber and others (1978). Their petrology, tectonic setting, and distribution have been discussed by Dusel-Bacon and Aleinikoff (1985) and Dusel-Bacon and others (1989).

These studies, particularly that of Dusel-Bacon and Aleinikoff (1985), indicate that a belt of porphyritic peraluminous granitic rocks (Fig. 1), now deformed to augen gneiss, extends 200 km in an east-west direction across the Alaskan part of the Yukon-Tanana terrane and into Yukon Territory. The plutons intrude amphibolite-grade quartz-mica schist, hornblende-bearing schist and gneiss, biotite gneiss, leucocratic gneiss, and quartzite of probable early to middle Paleozoic age.

Early Mississippian intrusive ages are indicated by a 341 ± 3 Ma U-Pb lower intercept age of zircon, a 333 ± 26 Ma Rb-Sr whole-rock isochron for augen gneiss (Aleinikoff, 1984; Dusel-Bacon and Aleinikoff, 1985), and a 342 ± 5 Ma Rb-Sr whole-rock isochron for correlative augen gneiss from Yukon Territory (Mortensen, 1983).

The metagranite characteristically has an augen gneiss character and well-developed fluxion structure. Gneissic banding is generally concordant with layering in the surrounding metamorphic country rocks. Wall-rock contacts are sharp, however, and the plutons are demonstrably intrusive into the country rocks.

The metagranite ranges in SiO_2 content from 71.2 to 77.1 percent (water-free), is peraluminous (normative corundum 1.3 to 3.9 percent), and belongs to the ilmenite series of granitic rocks (Ishihara, 1981). These characteristics plus high initial $^{87}Sr/^{86}Sr$ ratios of 0.728 and 0.719 (Mortensen, 1983; Aleinikoff, 1984), the possibility of primary garnet and muscovite, and several other lines of evidence cited by Dusel-Bacon and Aleinikoff (1985) indicate that the parent magma of the granitoid protoliths was derived from, or more likely, contaminated by, metasedimentary crustal sources. A U-Pb upper intercept age on zircon fractions and a Sm-Nd whole-rock model age suggest an early Proterozoic (2.2 to 2.0 Ga) age for the crustal component (Aleinikoff and others, 1981, 1986).

Ruby geanticline. Middle Paleozoic granitic gneiss is found in the Ray Mountains near the center of the Ruby geanticline (Fig. 1; Plate 13), in the northern part of the Ruby terrane (Patton and others, 1987) in central Alaska. Possibly similar granite gneiss bodies crop out at either end of the Ruby geanticline and, although they have not been dated, are tentatively correlated with the gneiss in the Ray Mountains (Brosgé and Reiser, 1964; Patton and others, 1978).

The Ruby geanticline is a northeast-trending, uplifted area

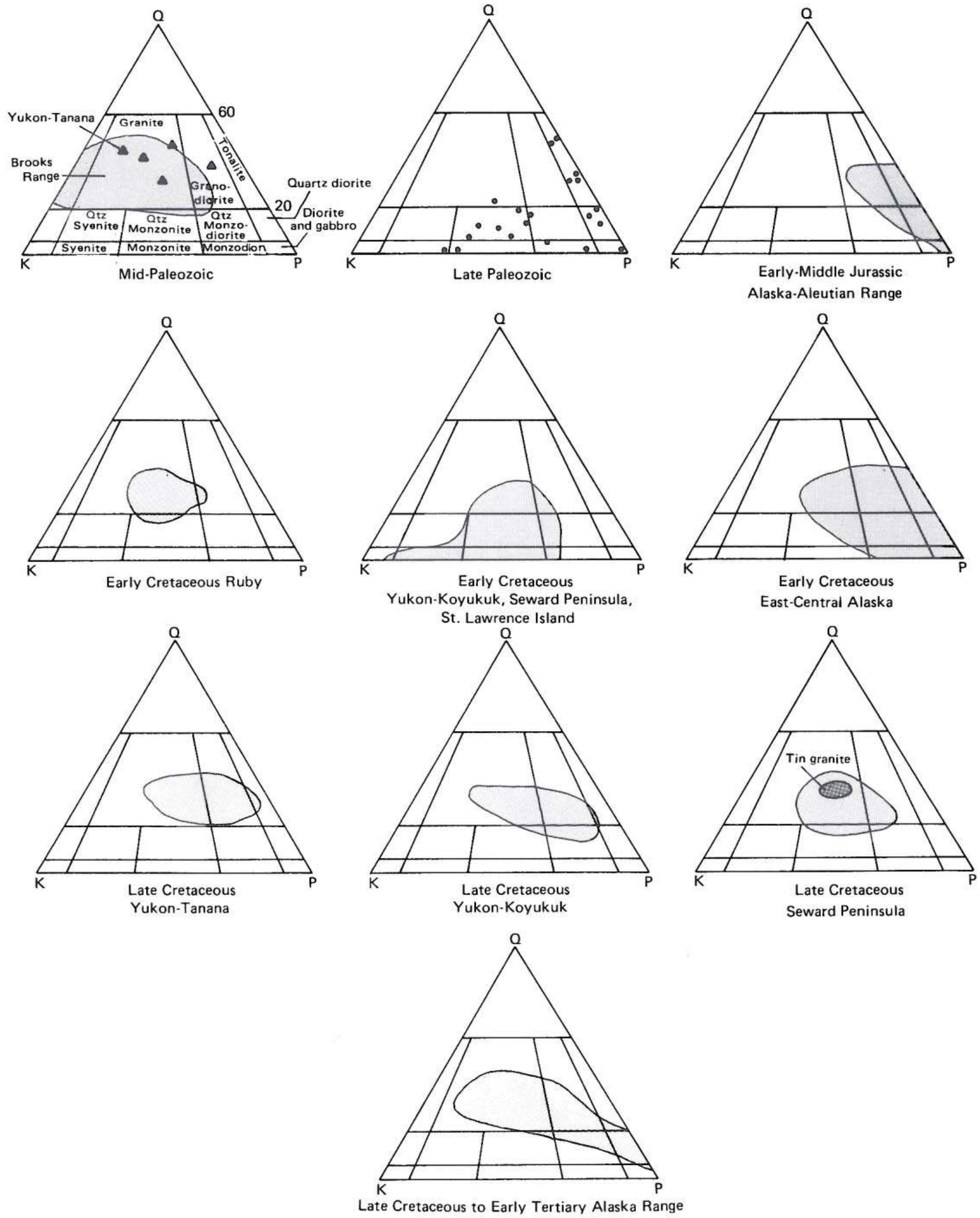

Figure 2. Representative modal compositions of plutonic rock suites in Alaska (classification after Streckeisen, 1976). Q, quartz; K, potassic feldspar; P, plagioclase. See text for references.

composed of a core of Proterozoic(?) and Paleozoic metamorphic rocks flanked by overthrust oceanic rocks of Jurassic age, all of which have been intruded by Early Cretaceous granitic plutons. It is bounded on the northwest by the Cretaceous Yukon-Koyukuk basin and on the southeast by Tertiary and Quaternary rocks of the Yukon Flats. The metamorphic country rocks consist of chlorite-quartz-mica schist, quartzite, greenstone, carbonate rocks, and minor quartzofeldspathic schist and gneiss. These rocks are generally greenschist-facies grade and locally reach almandine-amphibolite facies.

Strongly foliated quartzofeldspathic gneiss crops out on the north and south margin of the Ray Mountains pluton (Plate 13). The gneiss consists of a coarse- to medium-grained, porphyroclastic biotite + quartz + feldspar + muscovite mylonite gneiss with resistant augen of K-feldspar in a finer grained groundmass of biotite + quartz + feldspar + muscovite. The fabric of the gneiss is similar to that of other metamorphic rocks with which it appears to be interlayered. Although detailed compositional data are lacking, field observations suggest that the gneiss has a relatively restricted granitic composition (Patton and others, 1987). Contacts between the gneiss and the crosscutting Cretaceous granite are sharp.

U-Pb zircon ages were obtained from four whole-zircon populations from samples of gneiss that were collected from the Ray Mountains pluton (Patton and others, 1987). The four zircon ages are discordant, but chords (or a chord) indicate that the age of the granite gneiss is 390 ± 25 Ma (Middle Devonian) and that the apparent age of lead loss during metamorphism is about 110 Ma (Early Cretaceous)—the approximate age of the Ray Mountains pluton (Miller, 1989).

Two other masses of poorly mapped granitic gneiss occur at either end of the Ruby geanticline (Fig. 1; Plate 13) in contact with Cretaceous granitic rocks. Brosgé and Reiser (1964) describe the migmatitic rocks at the north end of the Ruby geanticline as consisting of granitic rocks intercalated with biotite schist. A Devonian(?) age is assigned by Brosgé and Reiser (1964) based on field relations with intercalated rocks of supposed Devonian age.

Patton and others (1978) describe the orthogneiss in the southern area as consisting of quartz-feldspar-biotite gneiss. Wall rocks are commonly garnetiferous and locally contain sillimanite. Patton and others (1978) suggest that the orthogneiss and associated wall rocks may be part of a gneiss dome and assign this body a Paleozoic age on the basis of field relations with intercalated Paleozoic rocks. Features such as the foliated character of the gneiss, the intrusive nature of the Early Cretaceous plutons, and the field relations between the gneiss and the other metamorphic rocks suggest that these gneiss bodies may be relatively old. An attempt was made to date the southernmost body of U-Pb analysis of zircon (Dillon and others, 1985). The data from two samples of the orthogneiss were insufficient to determine the protolith age but did indicate that the orthogneiss contained a Proterozoic or Paleozoic component, and that the zircon had lost lead during Cretaceous time. No radiometric age studies have been done on the northernmost gneiss body.

The Middle Devonian age of the orthogneiss near the Ray Mountains pluton is well constrained, but the lack of detailed mapping, petrologic studies, and radiometric age dating makes the tentative correlation of the other two localities subject to considerable uncertainty.

Brooks Range. Middle Paleozoic plutons are exposed along a 900-km-long belt across the length of the Brooks Range (Fig. 1; Plate 13) into the British Mountains of northernmost Yukon Territory (Dawson, 1988). The plutons underlie an aggregate area of about 4,500 km^2, including six bodies whose areal extents range from 200 to 2,000 km^2 and over a dozen smaller bodies of less than 50 km^2 area. Few, if any, plutons have been mapped in detail (1:63,360 scale or larger). The available data base is sparse and consists of approximately 100 major-element chemical analyses and about 120 modal analyses (Fig. 2), chiefly from the five largest plutons; published trace-element data are not available.

The plutonic rocks as described by Sable (1977), Nelson and Grybeck (1980), Dillon and others (1980, 1987), and Newberry and others (1986), consist chiefly (more than 95 percent) of highly evolved, peraluminous biotite and two-mica granite (Fig. 2). Hornblende-bearing metaluminous phases are found only in a few localities, generally as border phases of larger peraluminous plutons. The cataclastic and recrystallized nature of plutonic rocks suggests the possibility of mobilization of alkalis, which may account for the modal scatter reported by Nelson and Grybeck (1980). Most plutons probably belong in the ilmenite series because magnetite is sparse and Fe_2O_3/FeO ratios are usually less than 1. Primary aluminosilicate minerals such as sillimanite are lacking, although most analyzed samples record normative corundum. Many of these highly evolved rocks are "tin" granite, commonly with associated Sn-W skarns and, locally, greisens (Newberry and others, 1986).

The presence of albite-chlorite-muscovite-epidote assemblages in the country rocks indicates greenschist-facies metamorphism. Garnet and biotite isograds surround and extend south of the Arrigetch Peak and Mount Igikpak plutons; elsewhere, mid-greenschist- to epidote-amphibolite-facies assemblages occur in the vicinity of the plutons.

The plutons in the central Brooks Range contain metamorphic fabrics with orientations subparallel to those in the surrounding country rocks, and most of the plutons also contain large blastoporphyritic aggregates of quartz and K-feldspar (Dillon and others, 1980). Many plutons in the central and eastern Brooks Range have been dismembered by thrusting (Till and others, 1988; Hanks and Wallace, 1990). Dynamothermal metamorphism of many of the plutons throughout the area is indicated by strained cataclastic quartz phenocrysts; development of near isotropic, very fine-grained mylonitic zones; granulation and rotation of phenocrysts; the presence of folded dikes; and the development of schistosity and crenulation surfaces.

The plutons intrude Proterozoic(?) to early Paleozoic quartzofeldspathic schist, quartzose and pelitic metasedimentary basement rocks, and Devonian marble. Although contacts are commonly concordant, sheared, or faulted because of subsequent metamorphic transposition, granitic dikes and apophyses are present in the country rocks, and country-rock inclusions are present in the granitic rocks. Early Mississippian, coarse, clastic sedimentary rocks unconformably overlie the Okpilak pluton in the northeastern Brooks Range. Field evidence thus suggests a post-Silurian to pre–Early Mississippian age for at least some of the Brooks Range plutons (Sable, 1977; Dillon and others, 1987).

U-Pb and Rb-Sr age measurements that support a Devonian crystallization age for individual plutons range from 400 to 370 Ma. U-Pb analyses were obtained on 31 zircon fractions from the middle Paleozoic plutons in the central Brooks Range (Dillon and others, 1987) and yielded an interpreted age of 390 ± 20 Ma. Lead-loss ages (lower intercepts on concordia) from multiple fractions of individual plutons range from 150 to 60 Ma. Three samples each from the Mount Igikpak and Arrigetch Peak plutons in the central Brooks Range (Fig. 1) give an $^{87}Sr/^{86}Sr$ $^{87}Rb/^{86}Sr$ age of 373 ± 25 Ma (similar to the U-Pb data) and an intercept (SIR) of 0.714 ± 0.003 (Silberman and others, 1979a). K-Ar studies (Turner and others, 1979) of muscovite and biotite from both metamorphic and plutonic rocks in the western and central Brooks Range indicate a Cretaceous age for cooling following the final metamorphic event but do not rule out earlier metamorphic events. A Tertiary resetting of K-Ar ages appears to have occurred in the northeastern Brooks Range plutons (Dillon, 1987).

These Devonian plutons are probably coeval (based on similar U-Pb zircon ages) and comagmatic (based on similar bulk chemistry) with a 250-km-long belt of felsic metavolcanic and hypabyssal intrusive rocks (Ambler sequence of Schmidt, 1986) that lies 10 to 30 km south of the Devonian plutons of the central Brooks Range. The Ambler (volcanic) sequence is 700 to 3,000 m thick, has a strike length of about 120 km, and is the host for several large volcanogenic massive sulfide deposits.

Seward Peninsula. The aforementioned granitic orthogneiss that crops out in several widely scattered areas on the Seward Peninsula (Fig. 1) occurs as bodies of metamorphosed granite, granodiorite, and tonalite intruded into metasedimentary rocks. The orthogneiss units range from structurally comformable layers only a few meters thick to masses several kilometers across such as at Kiwalik Mountain and Cape Nome (Fig. 1; Plate 13).

Till and others (1986) and Till and Dumoulin (this volume) report a U-Pb age on zircon fractions of 381 ± 2 Ma from the metagranite at Kiwalik Mountain in the eastern Seward Peninsula, an age supported by the crosscutting relations with the surrounding early Paleozoic metamorphic rocks. Armstrong and others (1986) noted that the very radiogenic character of Sr in most orthogneiss samples (SIR range for Kiwalik Mountain is 0.7081 to 0.7088) and the distinctive range of whole-rock Rb-Sr ages occurring between 720 and 360 Ma are characteristics similar to those reported for the middle Paleozoic plutons in the Yukon-Tanana terrane and suggest a common origin.

Discussion. The Middle Devonian to Early Mississippian metaplutonic rocks of northern and east-central Alaska apepar to be cogenetic members of a middle Paleozoic plutonic belt composed chiefly of highly evolved, peraluminous granite. These characteristics, together with high $^{87}Sr/^{86}Sr$ ratios, a geologic setting in miogeoclinal continental rocks, and in the case of the Brooks Range plutons, the associated tin mineralization, suggest that the plutons have an inherited crustal component. Dusel-Bacon and Aleinikoff (1985) propose that these plutons originated as granitic magmas that assimilated early Proterozoic crust or metasedimentary rocks derived from a provenance of that age, and that the Early Mississippian plutonic belt formed by these magmas thus represents a middle Paleozoic continental magmatic arc that developed near the edge of the Proterozoic craton. The actual location of the arc is uncertain because the plutons were probably translated northward to their present location during Cretaceous and Tertiary time. Monger and others (1982), Gabrielse and others (1982), and Aleinikoff and others (1986) have all noted the existence of a belt of Devonian and Mississippian granitic rocks extending from southern British Columbia to the Seward Peninsula. Rubin and others (1989) suggest that magmatic suites of this age in the western North America Cordillera define a middle Paleozoic East Pacific fringing arc system that developed across a host of terranes as far south as the northern Sierra and eastern Klamath terranes.

Late Paleozoic

The existence of late Paleozoic plutonic rocks in east-central Alaska was first confirmed by Richter and others (1975), who obtained Late Pennsylvanian K-Ar ages of 285 and 282 Ma on an assemblage of monzonite, granite, and syenodiorite at the Ahtell Creek pluton in the eastern Alaska Range (Fig. 1). Regional mapping and topical studies in the general area (Nokleberg and others, 1986; Gardner and others, 1988; Plafker and others, 1989; Beard and Barker, 1989) have confirmed several more Late Pennsylvanian plutons of similar composition in the Wrangell and northern Chugach Mountains (Fig. 1; Plate 13). Probable coeval plutonic rocks have been mapped in southernmost Yukon Territory and northern British Columbia (Dodds and Campbell, 1988).

The most extensive areas of Pennsylvanian plutonic rocks are near the Wrangell Mountains in east-central Alaska (Fig. 1; Plate 13). In the eastern Wrangell Mountains, several large plutons, partially fault bounded, underlie a total area of about 1,400 km^2 (MacKevett, 1978; Gardner and others, 1988) and intrude Pennsylvanian rocks of the Station Creek Formation of the Wrangellia terrane and an early to middle Paleozoic unit referred to by Gardner and others as the Kaskawulsh metamorphic rocks of the Alexander terrane. Gardner and others (1988) describe one of these intrusions, the Barnard Glacier pluton, as a composite body, with numerous apophyses extending into the country rocks, and surrounded by a contact aureole. The main body consists chiefly of nonfoliated, medium- to coarse-grained, equigranular to porphyritic quartz monzonite along with subordinate quartz syenite, alkali granite, and monzodiorite. U-Pb zircon analyses indicate that the pluton was emplaced at 309 ± 5 Ma (Late Pennsylvanian), although K-Ar hornblende ages range from 312 to 279 Ma, or into the Early Permian.

Other small bodies of metaplutonic rocks of Late Pennsylvanian age have recently been described (Nokleberg and others, 1986; Aleinikoff and others, 1988; Plafker and others, 1989) along the south and west flanks of the Wrangell Mountains and northern Chugach Mountains (Plate 13). U-Pb zircon ages of 310 ± 29 and 309 ± 11 Ma were obtained from the Dadina pluton at the west end of the Wrangell Mountains and from the Uranatina River pluton 60 km to the south in the northern Chugach Mountains, respectively. Both plutons consist of deformed metagranodiorite with strong enrichment of LREE versus HREE (Plafker and others, 1989). The close similarity in age, composition, and deformational style among all these plutons suggests that they are part of the same suite (Plafker and others, 1989).

Beard and Barker (1989) recently completed a detailed study of the Ahtell Creek and associated plutons along the north flank of the Wrangell Mountains (Fig. 1; Plate 13). They considered these rocks to be part of the late Paleozoic Skolai island arc volcanic system and identified three groups of plutonic rocks that they felt recorded a temporal progression from typical arc magmatism (gabbro-diorite and silicic intrusions, including tonalite, granodiorite, and granite) related to the Skolai island-arc system, to shoshonitic magmatism (monzonite-syenite). U-Pb ages obtained on zircon fractions from the silicic rocks indicate Early to Late Pennsylvanian crystallization ages between 320 and 290 Ma.

Gardner and others (1988) point out that the timing of the Late Pennsylvanian plutonism in east-central Alaska has important tectonic implications. Intrusion of the Barnard Glacier pluton into both the Alexander and Wrangellia terranes means that these terranes were stitched together by Late Pennsylvanian time. Beard and Barker (1989) suggest that the shoshonitic magmatism, commonly thought to occur as a result of tectonic instability, may have resulted from the collision of the Wrangellia and Alexander terranes, and that the age of pluton emplacement is also the age of Wrangellia-Alexander amalgamation.

MESOZOIC PLUTONIC ROCKS

Mesozoic plutonic rocks are widespread and voluminous in Alaska and fall into two principal age groups separated by 40 to 50 m.y. The earlier group spans most of the Jurassic, is confined to the half of Alaska south of the Kaltag and Tintina faults, and is generally concentrated near the south coast of Alaska. The younger and more widespread group ranges in age from Early Cretaceous to early Tertiary. The two principal groups have each been arbitrarily subdivided into three subgroups on the basis of similarities in age, composition, and distribution (Plate 13).

Late Triassic to Middle Jurassic

The earliest reported Mesozoic salic plutonism in Alaska occurs in the eastern Yukon-Tanana Upland of east-central Alaska (Fig. 3; Plate 13). The Taylor Mountain batholith, the largest of several Late Triassic to Early Jurassic plutons in the area, underlies an area of about 650 km^2 and consists of medium-grained granite and subordinate granodiorite to diorite (Foster and others, this volume). Locally, the margins of the pluton are shared and faulted. Other nearby plutons include quartz monzodiorite. Characteristically, the rocks contain abundant hornblende and minor quartz and are not corundum normative (Fig. 2).

Radiometric ages obtained from the Taylor Mountain and associated plutons range from latest Triassic to Middle Jurassic. The Taylor Mountain pluton itself yielded a U-Pb sphene age of 212 Ma (Aleinikoff and others, 1981), $^{40}Ar/^{39}Ar$ age determinations gave an integrated plateau age on hornblende of 209 $\pm$ 3 Ma, and K-Ar ages range from 198 to 180 Ma (Wilson and others, 1985). An associated pluton has provided an $^{40}Ar/^{39}Ar$ age determination of 188 $\pm$ 2 Ma and a K-Ar hornblende age of 177 $\pm$ 5 Ma (Foster and others, this volume).

These plutons are similar in composition and age to a suite of plutonic rocks in neighboring Yukon Territory. Some parts of the Klotassin batholith 75 km east of the Alaska border, for example, are considered Early Jurassic in age bsed on a 192 Ma U-Pb zircon age (Tempelman-Kluit and Wanless, 1975). In addition, Armstrong (1988) and Mortensen (1988) discuss widespread episodes of magmatic activity in western British Columbia that range from latest Late Triassic to Early Jurassic (214 to 200 and 214 to 190 Ma, respectively). Mortensen (1988) suggests that these plutons represent the deeper parts of the continental Stikine volcanic arc, which now borders the Yukon-Tanana terrane on the north and south.

Small (less than 20 km^2) calc-alkaline intermediate-composition plutons of Early to Middle Jurassic age crop out near the south coast of Alaska (Fig. 3; Plate 13). These plutonic rocks are in a complex structural and intrusive relation with the (informal) Border Ranges ultramafic-mafic complex of Burns (1985). The ultramafic to intermediate-composition plutons of this complex form a discontinuous belt that extends 1,000 km across southern Alaska (Fig. 3; Plate 13) from Kodiak Island through the Kenai Peninsula and northern Chugach Mountains to the Copper River. They are thought (Burns, 1985) to represent the lower crust and uppermost mantle of an Early to Middle Jurassic interoceanic island arc that lies on the north side of, and adjacent to, the Border Ranges fault and entirely within the Peninsular terrane.

The plutons are elongate in plan, parallel to regional trends, and locally fault bounded. Intrusive contacts are sharp to migmatitic, and diking and thermal metamorphism of nearby country rocks are locally well developed. Petrologic data are scarce, but the intermediate-composition plutons appear to consist chiefly of quartz diorite, tonalite, and minor granodiorite and make up another 40 percent of the plutonic rocks in the arc. Although the intermediate-composition plutons intrude the mafic plutonic rocks, they are considered by Burns (1985) to be, at least in part, broadly contemporaneous with them.

The emplacement age of the plutons is uncertain, as the available radiometric ages show considerable scatter. Roeske and others (1989) suggest a crystallization age of 217 $\pm$ 10 Ma (Late Triassic) for the intermediate-composition Afognak pluton on Afognak Island based on nearly identical $^{207}Pb^*/^{206}Pb^*$ ages on coarse and fine zircon fractions. K-Ar ages from this pluton tend to be younger, 197 $\pm$ 11 to 188 $\pm$ 11 Ma (Carden and others, 1977; Hudson, 1985), and according to Roeske and others (1989), may record post-crystallization cooling, a major later thermal event, or a lengthy emplacement period. K-Ar ages from

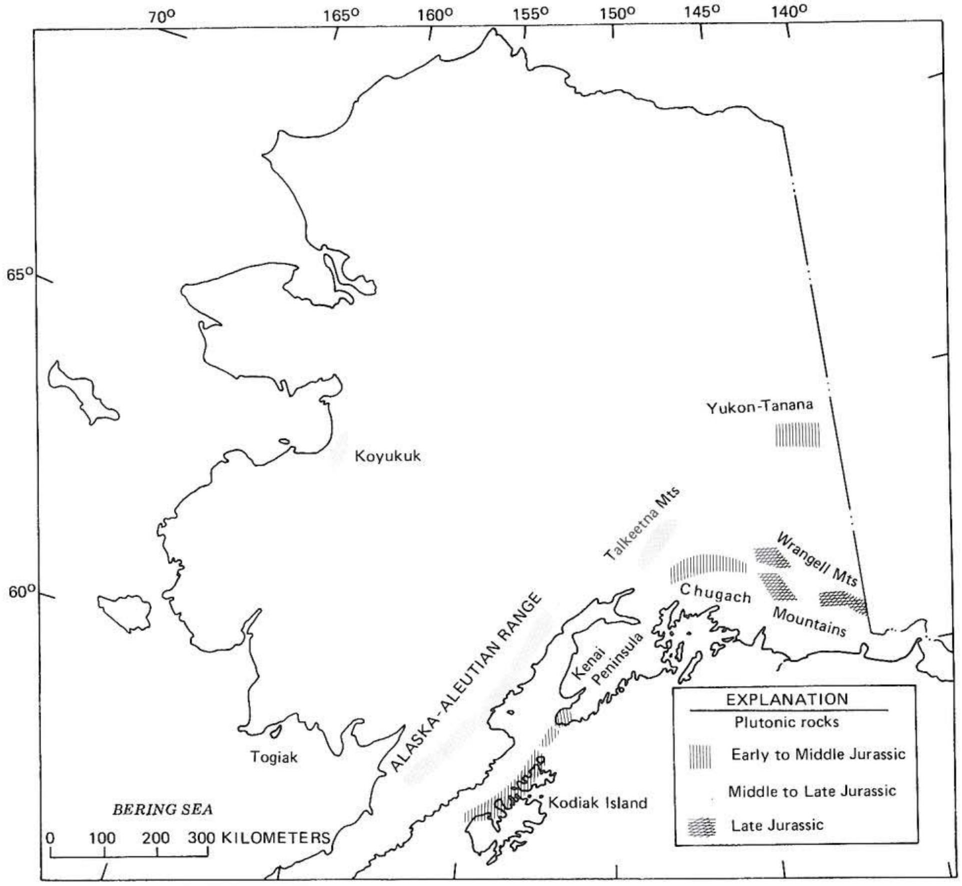

Figure 3. Distribution of Jurassic plutons in mainland Alaska.

the mainland part of the arc range from 194 to 163 Ma (Early to Middle Jurassic).

Middle to Late Jurassic

Plutonic rocks of Middle to Late Jurassic age occur in three widely separated parts of southern and central Alaska (Fig. 3; Plate 13) and represent the roots of the Peninsular, Togiak, and Koyukuk intraoceanic arc terranes. The plutonic rocks typically compositionally expanded calc-alkaline differentiation trends. The relations among these terranes, if any, is unknown, and the amount of detailed petrologic and geochronologic study varies greatly between areas. Box (1985b) has suggested that the Togiak and Koyukuk terranes are dismembered fragments of the same arc, whereas Wallace and others (1989) consider it more likely that these are separate arcs formed in a similar tectonic setting.

Koyukuk terrane. Plutonic rocks are exposed in a narrow, 80-km-long fault-bounded block in west-central Alaska south of the Kaltag fault (Plate 13) and adjacent to the Chirosky fault. These rocks are considered to be the oldest known remnants of an intraoceanic arc that collided with continental North America in latest Jurassic to Early Cretaceous time (Box and Patton, 1989). The plutonic rocks consist of tonalite and trondhjemite that locally intrude an assemblage of late Paleozoic to early Mesozoic volcanic rocks of probable non-arc affinity and appear to underlie the same volcanic arc rocks that make up the major part of the Koyukuk terrane in the north-central part of the Yukon-Koyukuk basin (Box and Patton, 1989). Both intrusive and country rocks are extensively sheared, fractured, and altered by potassic metasomatism. Patton and Moll (1984) report K-Ar ages ranging from 173 to 154 Ma. The plutonic rocks exhibit enrichment of LIL elements and the depletion of Nb-Ta relative to light REE characteristic of subduction-related magmatism (Box and Patton, 1989).

Togiak terrane. Several Middle Jurassic plutons ranging in composition from dunite to hornblende gabbro-diorite to biotite-hornblende granodiorite (only the latter is large enough to be shown on Plate 13) occur in the Goodnews Bay–Hagemeister Island region of southwest Alaska. Although these plutons were originally mapped by Hoare and Coonrad (1979) as Cretaceous to Tertiary in age, K-Ar dating by Box (1985a) on several different rock types yielded ages ranging from 186 to 162 Ma, with the granodiorite from Hagemeister Island giving a hornblende age of 183 ± 7 Ma. Box (1985b) described this granodiorite as medium grained, slightly altered, and intrusive into rocks of the Togiak terrane, a Mesozoic andesitic volcanic and volcaniclastic terrane of Late Triassic through Early Cretaceous age. Clasts of similar granodiorite occur in adjacent early Middle Jurassic (Bajocian) conglomerate.

Few analytical data are available on the granodiorite and associated mafic and ultramafic rocks. Box (1985a, b), however, considers that these ultramafic-mafic-intermediate-composition plutonic rocks represent the roots of a mostly Middle Jurassic magmatic arc that may be correlative with the Koyukuk arc to the north.

Peninsular terrane. One of the more spectacular magmatic belts in Alaska is the Alaska-Aleutian Range composite batholith and its northeastern extension into the Talkeetna Mountains (Fig. 3; Plate 13). This 15- to 35-km-wide, 740-km-long northeast-trending belt of plutonic rocks intrudes rocks of the intraoceanic Talkeetna arc that compose the Peninsular terrane (Jones and others, 1984; Silberling and others, this volume). The plutonic rocks were formed during three distinct magmatic episodes: (1) the Middle to Late Jurassic (174 to 158 Ma) emplacement of chiefly quartz diorite and tonalite; (2) the Late Cretaceous to Paleocene (83 to 58 Ma) emplacement of quartz diorite, tonalite, and granodiorite; and (3) an Oligocene (38 to 26 Ma) event consisting of a varied assemblage of rock types including quartz diorite, peraluminous granite, and alkali granite (Reed and Lanphere, 1969, 1973; Reed and others, 1983). The age, spatial distribution, and broad compositional trends of these plutons are well known following the work of Reed and Lanphere (1969, 1973), Turner and Smith (1974), Csejtey and others (1978), and Reed and others (1983). Published trace-element and isotopic data, however, are sparse.

The Jurassic plutonic rocks in the Alaska-Aleutian Range batholith occur along its southeast side, west of Cook Inlet, and extend into the northern Alaska Peninsula. The plutons intrude the Early Jurassic Talkeetna Formation, an assemblage of basalt, andesitic and dacitic flows, and volcaniclastic rocks with subordinate shale and graywacke (see Barker, this volume). Reed and Lanphere (1969, 1973) showed the plutonic rocks to define a calc-alkaline magmatic suite that ranges from hornblende gabbro through hornblende-biotite diorite, hornblende-biotite quartz diorite (Fig. 2), tonalite and rare granodiorite and quartz monzonite (Reed and others, 1983). Mafic phases appear to have been emplaced first although intrusive relations are complex. SiO_2 content ranges from 45.6 to 67.6 percent (mean = 58.3 percent) and Na_2O content is much greater than K_2O content (Reed and others, 1983).

The calc-alkaline character of the Alaska-Aleutian Range batholith, its emplacement into slightly older andesitic volcanic rocks, and low $^{87}Sr/^{86}Sr$ initial ratios of 0.7033 to 0.7037 (M. A. Lanphere and B. L. Reed, unpublished data, in Reed and others, 1983) led Reed and others (1983) to suggest that the Alaska-Aleutian Range batholith represents the root of the Talkeetna arc.

The relation of the Jurassic plutonic rocks of the Alaska-Aleutian Range batholith and the Talkeetna Mountains to the adjacent Early Jurassic to Middle Jurassic Kodiak-Kenai-Chugach magmatic arc is uncertain. The youngest radiometric ages of the latter belt overlap with some of the oldest ages of the Alsaka-Aleutian Range batholith. Reed and others (1983) thought that the two were unrelated and that the Kodiak-Kenai-Chugach belt might be a slightly older and discrete accreted arc. Alternatively, they suggested that the latter arc might have split parallel to its length and rifted, with the rift opening now occupied by the Cook Inlet basin. The northwest margin of this basin then became the site of renewed calc-alkaline magmatism reflected in the Alaska-Aleutian Range batholith. Hudson (1983) also initially considered the belts as separate but later (Hudson, 1985) raised the possibilitty that Early Jurassic plutonic rocks on Kodiak Island were mafic precursors to the Alaska-Aleutian Range batholith. The actual age range of these adjoining plutonic belts is as yet poorly constrained owing in part to widespread Cretaceous and Tertiary magmatism. If the belts are related, however, and the presently available ages are taken at face value, then, as Roeske (1986) has pointed out, volcanism and associated plutonism covered a long span of about 60 m.y. Since the lack of detailed geochronologic and petrologic studies prevents resolution of this question, the plutonic belts in this compilation are regarded as representing separate magmatic arcs.

Although Reed and Lanphere (1969, 1973) initially suggested that the Alaska-Aleutian Range batholith represented magmatism related to a northwest-dipping subduction zone, more detailed study (Reed and others, 1983) of chemical variation across the batholith led them to suggest that the subduction was directed toward the southeast. Plafker and others (1989) consider this possibility less likely because of the lack of a coeval (with the Talkeetna arc) accretionary prism along the north margin of the Peninsular terrane. A south-dipping subduction zone, however, would be similar in polarity to that postulated for the Togiak and Koyukuk terranes (Box, 1985b; Wallace and others, 1989).

Late Jurassic

Plutonism in Late Jurassic time in Alaska is confined to a narrow belt extending from southern east-central Alaska (Fig. 3; Plate 13) through southwestern Yukon Territory and northwestern British Columbia to Chichagof Island in southeastern Alaska (Dodds and Campbell, 1988; Dusel-Bacon, this volume, Chapter 15 and Plate 4). The plutons are commonly elongate in plan, parallel to regional trends, and typically foliated and mylonitic. They intrude the Strelna Metamorphics, defined and considered by Plafker and others (1989) to be in part as old as Early Pennsylvanian, and are unconformably overlain by Early Cretaceous sedimentary rocks. Preliminary ages are about 164 to 140 Ma, or Late Jurassic to earliest Cretaceous.

Hudson (1983) describes a characteristic compositional range that includes biotite-hornblende quartz diorite, tonalite, and granodiorite. Plafker and others (1989) report the Uranatina River pluton just west of the Copper River as being composed chiefly of diorite with lesser amounts of tonalite and quartz diorite. Sparse major- and trace-element analytical data from metatonalite suggest a calc-alkaline Alk-F-M differentiation trend and strong to moderate enrichment of LREE relative to HREE.

Hudson (1983) referred to these plutons as the Tonsina-Chichagof belt and noted that they were emplaced in the upper plate of the Border Ranges fault. He considered them to be the roots of a Late Jurassic magmatic arc. This arc, referred to as the Chitina arc by Plafker and others (1989), was built along the south margin of the Wrangellia terrane in Alaska. The polarity of the arc is uncertain because an associated accretionary prism or shelf basin has not been found, although northerly subduction is suggested by the presence of coeval volcanic detritus in the adjacent Chugach terrane (Plafker and others, 1989).

Early Cretaceous

Plutonic rocks of Early Cretaceous age occur in widely separated parts of mainland Alaska but are concentrated north of the Kaltag fault and south of the Brooks Range (Fig. 4; Plate 13) in an area that includes the Ruby, Koyukuk, and Seward terranes. Early Cretaceous plutons are voluminous in the part of the Ruby terrane north of the Kaltag fault but sparse and widely scattered in the Ruby and adjacent terranes south of the Kaltag fault. They are abundant in a belt extending more than 1,000 km across the northern Koyukuk basin through the southeastern Seward Peninsula and St. Lawrence Island into the Chukotkan Peninsula of Siberia. Short belts of Early Cretaceous plutonic rocks occur north of the Wrangell Mountains in east-central Alaska and in the western Chugach Mountains. Early Cretaceous plutons also are scattered across the Yukon-Tanana Upland within an extensive mid-Cretaceous (approximately 110 to 90 Ma) granitoid belt; they will be discussed in a later section.

Early Cretaceous plutons in Alaska show a great diversity in composition, including ultrapotassic nepheline syenite, tonalite through granodiorite, and anatectic biotite and two-mica granite. This compositional range is far greater than that seen for any other group of pre-Cenozoic plutons in Alaska.

West-central Alaska. Major plutonism in west-central Alaska took place from 115 to 98 Ma (Early Cretaceous), and a volumetrically lesser episode occurred at 89 to 78 Ma (Late Cretaceous). These plutonic rocks underlie about 5 percent of the region and can be grouped into distinct suites on the basis of their composition, age, and distribution.

Ruby and Angayucham-Tozitna terranes. Cretaceous plutonic rocks underlie a major part of the Ruby geanticline where they constitute a batholith larger than 8,000 km^2. The Ruby

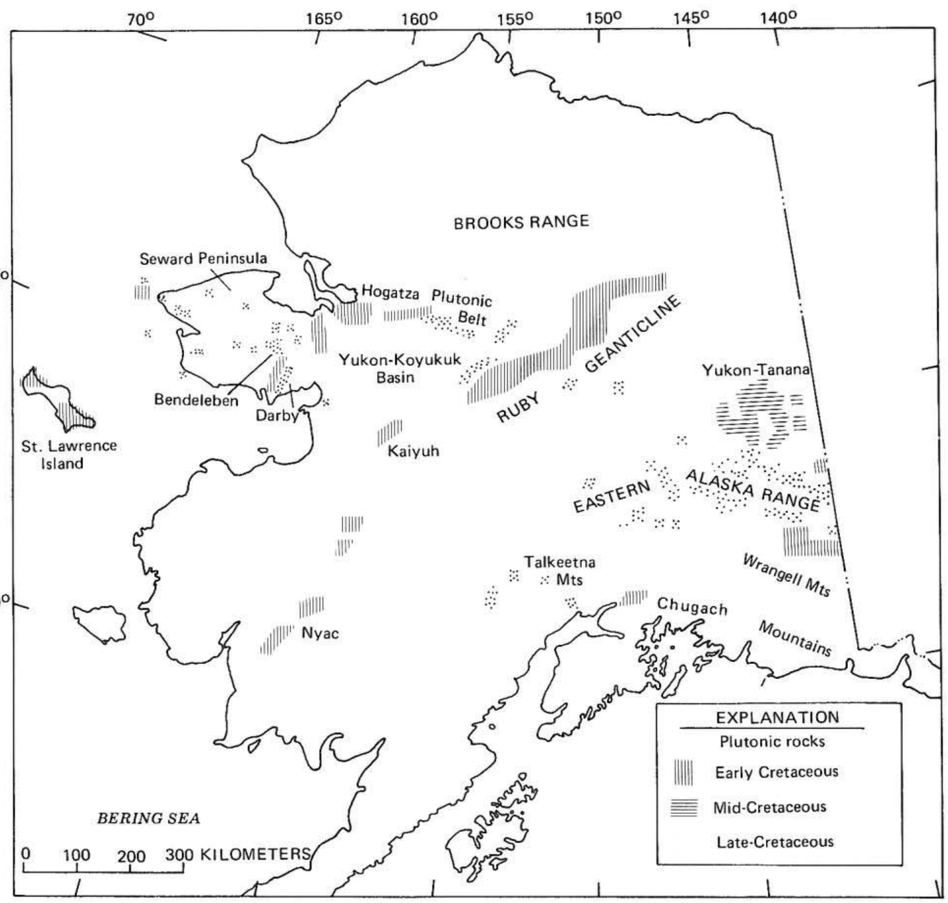

Figure 4. Distribution of Cretaceous plutons in mainland Alaska.

geanticline is a pre–mid-Cretaceous uplift that extends 400 km diagonally southwestward from the Brooks Range to the Yukon River, where it is offset right laterally about 160 km by the Kaltag fault (Patton and others, 1984). The core of the Ruby geanticline composes the northern part of the Ruby terrane (Jones and others, 1984; Silberling and others, this volume) and is truncated at its northeast end by the Brooks Range.

The Ruby terrane is primarily made up of greenschist-facies metasedimentary rocks and metabasite of Proterozoic(?) and Paleozoic age intruded by voluminous mid-Cretaceous plutons. High-pressure glaucophane-bearing greenschist-facies and intermediate- to high-pressure sillimanite-kyanite amphibolite-facies assemblages are present locally. Typical rock types include quartz-mica schist, quartzite, calcareous schist, mafic greenschist, quartzo-feldspathic schist and gneiss, and marble. Regional metamorphism predates the widespread Early Cretaceous plutonism and is thought to be Late Jurassic to Early Cretaceous in age (Turner, 1984; Patton and others, 1984).

Gross similarities between the metamorphic rocks of the Ruby terrane and the so-called schist belt of the Arctic terrane of the southern Brooks Range have led to suggestions that both terranes were once part of a single continuous belt. The Ruby terrane may also be an exotic fragment rafted to its present position prior to overthrusting of the Angayucham and Tozitna terranes (Patton and Box, 1989).

Although the lithologies and mineral assemblages of Brooks Range and Ruby terrane metamorphic rocks suggest similar protoliths, the Cretaceous granitic rocks that are the single most abundant rock type in the Ruby terrane (close to 50 percent of the exposed outcrop) are absent from the Brooks Range. When the voluminous amounts of granite are considered in proportion to the metamorphic country rock, the Ruby terrane more closely resembles the Yukon-Tanana terrane (Jones and others, 1984) to the southeast than the Brooks Range to the north.

The plutonic rocks also intrude the Jurassic mafic volcanic rocks of the Angayucham terrane that overlie the Ruby terrane and in turn are overlain by calc-alkaline volcanic rocks of Paleocene age (59 to 56 Ma; Moll and Patton, 1983). Radiometric dating has more closely constrained the age of the Ruby plutons as Early Cretaceous. K-Ar ages chiefly on biotite from seven different plutons range from 112 to 99 Ma (Miller, 1989). An Early Cretaceous age for these plutonic rocks is strengthened by U-Pb zircon ages of 112 to 109 Ma from the Ray Mountains pluton near the south end of the batholith (Patton and others, 1987) and a Rb-Sr age of 112 Ma (Blum and others, 1987) from the Jim River pluton at the northeast end.

The plutons of the Ruby geanticline are composed chiefly (more than 80 percent) of leucocratic biotite granite (Fig. 2), with lesser amounts of granodiorite and muscovite-biotite granite; syenite and monzonite are rare but occur at the extreme north end of the Ruby geanticline (Blum and others, 1987). The granitic rocks are typically coarse grained, strongly porphyritic, non-foliated and occur in plutons up to 800 km^2 in area. The individual plutons that compose the Ruby batholith are surrounded by narrow thermal aureoles. Contact wall rocks are thermally altered to andalusite-cordierite hornfels, hornblende hornfels, and marble. The plutons are somewhat elongated in an east-west direction and lie oblique to the northeast-striking trend of the Ruby geanticline.

The plutons are highly evolved and generally have SiO_2 contents of 68 to 76 percent. They are K-rich, Na-depleted, and weakly to moderately peraluminous, with normative corundum usually greater than 0.8 percent (Miller, 1989). Primary muscovite occurs in some phases of the large southern plutons, but modal cordierite is lacking. The plutons appear to belong to the ilmenite (magnetite-free) series of granitic rocks (Ishihara, 1981) with low Fe_2O_3/FeO ratios and reduced magnetic susceptibility. Initial Sr^{87}/Sr^{86} ratios are in the range 0.7056 to 0.7294, show large internal variations, and have average values that decrease from southwest to northeast (Arth and others, 1989a). Initial Nd^{143}/Nd^{144} ratios show a reverse relation and increase to the northeast, ranging from 0.51158 to 0.51240 (Arth and others, 1989a).

These modal and major-element characteristics are typical of granitic rocks thought to have been generated by melting, or contamination, of continental crust (Miller, 1989). High SIRs (>0.7056) also indicate the involvement of significant amounts of Paleozoic or older continental crust in the origin of the plutonic magmas (Arth and others, 1989a).

Ruby and Nyack terranes south of Kaltag fault. The difference in the amount of Early Cretaceous plutonic rocks on either side of the Kaltag fault is striking. Plutonic rocks underlie more than 40 percent of the Ruby terrane north of the Kaltag fault, where they are the single most voluminous rock type and constitute one of the major batholithic complexes of interior Alaska, second in area only to the plutons of the Yukon-Tanana Upland.

South of the Kaltag fault, however, Early Cretaceous plutons, though present, are relative sparse and constitute less than 1 percent of the terrane. The plutons occur as several small (less than 200 km^2) bodies scattered along a northeast-trending, 500-km-long belt extending from the Kaltag fault almost to the Bering Sea (Fig. 4; Plate 13). The plutons are intrusive into the Proterozoic(?) to Paleozoic crystalline rocks of the Ruby terrane and into Middle to Late Jurassic accreted volcanogenic rocks of the Nyack terrane. Their ages, however, are poorly constrained, since only the Kaiyuh Mountains pluton at the northeast end of the belt and the Nyack pluton near the southwest end have been dated. Patton and others (1984) report a biotite K-Ar age of 112 ± 3.4 Ma for the Kaiyuh Mountains pluton and speculate that it may be a faulted extension of the Early Cretaceous Melozitna pluton in the Ruby geanticline to the east. The Nyack pluton has yielded K-Ar ages ranging from 117 ± 3.3 Ma (Wilson, 1977) to 101.1 ± 3.0 Ma (Frost and others, 1988). Age designations for the remaining plutons in the belt are based on similarities in composition and geologic setting and are tentative (S. E. Box, oral communication, 1989). Few modal or chemical analyses are available, but the plutons have been mapped as granodiorite, granite, and quartz monzonite.

Koyukuk Basin–Seward Peninsula–St. Lawrence Island. Early Cretaceous plutons form an east-west trending belt that extends from the central part of the northern Koyukuk basin into the southeastern Seward Peninsula and across the Bering Sea shelf (Fig. 4; Plate 13) through St. Lawrence Island (Miller, 1971; Miller and Bunker, 1976; Csejtey and others, 1971; Miller and others, 1966) to the Chukotkan Peninsula (Kosygin and Popeko, 1987). These plutons intrude Neocomian andesitic volcanic rocks of the Yukon-Koyukuk basin and are overlain by, and shed debris into, Albian sedimentary rocks (Patton, 1973). The Early Cretaceous age suggested by their stratigraphic setting is confirmed by numerous K-Ar ages ranging from 113 to 99 Ma (Miller, 1989).

These plutons consist of two distinct but related groups: a potassic series (KS) and an ultra potassic series (UKS; Miller, 1989). The KS series is represented by SiO_2-saturated to slightly oversaturated monzonite, syenite, and quartz syenite characterized by low quartz and abundant K-feldspar (Fig. 2); hornblende and clinopyroxene are the principal varietal mafic minerals. K_2O content is greater than 4.5 percent, and SiO_2 content ranges from 53.8 to 66.1 percent, with a compositional gap from 66.1 to 73.9 percent. The KS rocks have a lower abundance of incompatible elements and radiogenic Sr than the UKS.

The UKS series constitutes about 5 percent of the western Koyukuk terrane plutonic rocks and consists of single-feldspar, hypersolvus nepheline-bearing rocks such as malignite, foyaite, ijolite, biotite pyroxenite, and pseudoleucite porphyry. SiO_2 content ranges from 44.5 to 58.4 percent, K_2O content is as high as 16.6 percent, and the rocks are nepheline and commonly leucite normative. These UKS rocks define an ultrapotassic rock province consisting of 12 known intrusive suites and dike swarms that form a sinuous belt extending some 1,500 km across the northwestern Koyukuk terrane (Plate 13) westward through the southeastern Seward Peninsula and St. Lawrence Island (Csejtey and Patton, 1974) to the east tip of Siberia (Miller, 1972). The trend of this alkaline rock belt is roughly parallel to the contact between the Koyukuk and Seward terranes.

The Early Cretaceous plutons of west-central Alaska are thus divisible into two contrasting compositional trends whose origins are enigmatic: (1) the voluminous, highly evolved, compositionally restricted suite of predominantly biotite and two-mica granite with elevated SIRs confined to the Ruby geanticline; and (2) the more than 1,000-km-long sinuous belt of silica-saturated to undersaturated granite, monzonite, and syenite characterized by strong enrichment in potassium (including an associated ultrapotassic rock province) and intrusive into two very different geologic provinces and terranes.

The compositional characteristics of the Ruby geanticline plutons suggest that they were generated by the melting, or contamination, of continental crust either in response to thickening of that crust following collision of the Koyukuk terrane with the Ruby terrane or perhaps as a result of underthrusting of the Koyukuk terrane beneath the Ruby terrane (Miller, 1989; Arth and others, 1989b). The long sinuous belt of Early Cretaceous plutons in the northern Koyukuk basin and its association over much of its length with the tectonic boundary between the Koyukuk and Seward terranes suggest that these plutons may be subduction related. The coeval Ohkotsk-Chukotsk magmatic belt of the northeastern USSR is considered (Khrenov and Bukharov, 1973; Parfenov and Natal'in, 1986) to result from northward underthrusting of Pacific Ocean crust from the south. The surface trace of such a subduction zone is unknown but could lie concealed beneath younger sedimentary and volcanic rocks to the south.

Ultrapotassic rocks such as those in west-central Alaska are generally considered to have a mantle origin (Bergman, 1987). A gradual increase in K_2O content and $^{87}Sr/^{86}Sr$ initial ratios from east to west across the Yukon-Koyukuk basin reported by Miller (1989) and Arth and others (1989b) suggests that continental crust or a keel of K-rich subcontinental mantle may underlie the west half of the basin.

East-central Alaska. A belt of Early Cretaceous plutons occurs in the eastern Alaska Range along the north flank of the Wrangellia terrane and south of the Denali fault (Fig. 4; Plate 13). The plutonic belt, first described in Alaska by Richter and others (1975) and Richter (1976), extends across southwestern Yukon Territory and northern British Columbia (Dodds and Campbell, 1988) into southeastern Alaska and was called the Nutzotin-Chichagof belt by Hudson (1983). In east-central Alaska, the plutonic belt consists of two relatively large bodies—the Nabesna pluton (250 km^2) and the Klein Creek pluton (more than 305 km^2)—and six smaller (less than 30 km^2) stocks (Richter and others, 1975).

K-Ar ages have been obtained on hornblende and biotite from five of the eastern Alaska Range plutons (Richter and others, 1975) and range from 117 to 105 Ma. The plutons intrude, and are assumed to be cogenetic with, a thick sequence of predominantly andesitic volcanic and volcaniclastic rocks of the Early Cretaceous Chisana Formation.

The plutonic rocks are massive, nonfoliated, and generally equigranular. They are strongly discordant to the country rock and locally contain abundant xenoliths; these features and the association with coeval volcanic rocks indicate that the plutonic rocks are epizonal (Richter and others, 1975).

Individual plutons range from diorite to granite (rare) and include syenodiorite, monzonite, and trondhjemite (Fig. 2). Melanocratic diorite and granodiorite are perhaps the most common lithologies. Chemical data, sparse relative to those available for other Early Cretaceous suites in Alaska, show a narrower range of SiO_2 content (48 to 64 percent) than might be expected from the modal plots. This narrow range is probably a reflection of the high mafic content of the suite.

Western Chugach Mountains. Early Cretaceous plutonic rocks have been reported in an unusual tectonic environment in the western Chugach Mountains (Fig. 4; Plate 13). Pavlis and others (1988) have described a group of tonalite-trondhjemite plutons as recording a period of Early Cretaceous near-trench plutonism along the paleo-Aleutian subduction zone. Radiometric dating of the plutons (summarized in Pavlis and others, 1988) yielded K-Ar ages of 135 to 110 Ma, $^{40}Ar/^{39}Ar$ plateau ages of 129 to 114 Ma, two Rb-Sr mineral isochrons of 133 and 130 Ma, and a U-Pb zircon age of 103 Ma. Pavlis and others (1988) believe that these data are consistent with pluton emplacement in the middle Early Cretaceous at about 135 to 125 Ma.

Most of the plutonic rocks are confined to five elongate stocks ranging from 2 to 12 km^2 in area. They consist chiefly of leucocratic biotite tonalite, with gradations to relatively mafic hornblende-biotite tonalite and biotite trondhjemite. These gradations are thought (Pavlis and others, 1988) to reflect crystal fractionation from a tonalitic magma rather than separate intrusions. Chemically, the plutons define a low-K series with the SiO_2 content of the main plutonic phases ranging from about 60 to 73 percent. MgO, CaO, FeO (total iron), and Al_2O_3 show systematic linear decreases with increased SiO_2, while Na_2O increases slightly and K_2O remains relatively constant; K_2O values are somewhat higher than trondhjemite associated with ophiolite sequences (Pavlis and others, 1988). On ternary K-Na-Ca plots, the rocks display a gabbro-trondhjemite rather than calc-alkaline trend.

The Early Cretaceous plutons were emplaced along the tectonic join between the older Jurassic arc and the younger Cretaceous melange terrane that was accreted by subduction beneath the old arc (Pavlis and others, 1988). The plutonic rocks are interpreted by Pavlis and others (1988) to have been injected during a major thrusting event that placed upper-mantle(?) ultramafic rocks atop the Cretaceous subduction assemblages. The generation of plutonic rocks in the generally cool, near-trench environment is atypical. Pavlis and others (1988) suggest shallow melting of amphibolite or metagraywacke along a young subduction zone as the most reasonable explanation, although a model involving a ridge-trench encounter is also allowable.

Mid-Cretaceous and Late Cretaceous

Mid-Cretaceous and particularly Late Cretaceous plutonic rocks are the most widespread of all plutonic rocks in mainland Alaska (Fig. 4; Plate 13) and record a variety of magmatic events. The age range of these plutonic suites and their tectonic setting, however, suggest that they can be subdivided (for the purposes of this compilation) into those rocks emplaced approximately between 97 and 74 Ma (discussed here) and those whose emplacement spanned the Cretaceous/Tertiary boundary between about 74 and 55 Ma (discussed later). This latter subgroup overlaps, for the sake of completeness, the discussion of Cenozoic magmatic rocks by Moll-Stalcup (this volume).

Mid-Cretaceous plutonic rocks in the age range 115 to 89 Ma are concentrated in the Yukon-Tanana Upland of east-central Alaska; Late Cretaceous plutonic rocks are moderately abundant in south-central Alaska and scattered across west-central Alaska (Fig. 4; Plate 13).

Yukon-Tanana Upland. Plutonic rocks of mid-Cretaceous age are the most widespread of all the voluminous plutonic rocks in the Yukon-Tanana Upland and underlie an area of more than 10,000 km^2; individual bodies range in area from smaller than 1 to larger than 300 km^2. The plutons have a highly irregular map pattern and are post-tectonic. They intrude several large middle Paleozoic and Jurassic plutons and their metamorphosed host rocks and contain numerous roof pendants, screens, and enclaves of the metamorphic country rock. Locally, they are covered by Cenozoic sedimentary and volcanic rocks. Northeast-trending high-angle faults have further disrupted many of the plutons, contributing somewhat to their irregular plan.

This period of plutonism in the Yukon-Tanana Upland began in the late Early Cretaceous and extended into the Late Cretaceous. Wilson and others (1985), in a summary report on 138 K-Ar mineral age determinations from plutonic rocks in the Yukon-Tanana terrane, pointed out that the ages fall into a bimodal cluster—110 and 50 Ma with a sharp maximum at 95 to 90 Ma and a spread of ages from 70 to 50 Ma. The oldest age reported is a 115-Ma U-Pb age on zircon from a post-metamorphic intrusion into a gneiss dome (Aleinikoff and others, 1984). Bacon and others (1985) obtained K-Ar ages of 94 and 90 Ma on welded tuffs in and around three large calderas spatially associated with the Late Cretaceous plutons. A Rb-Sr whole-rock isochron for a pluton in the western Yukon-Tanana terrane near Fairbanks yielded an age of 90.0 ± 0.9 Ma (Blum, 1985), which is similar to K-Ar ages of 95.3 ± 5.0 and 93.0 ± 5.1 Ma from the same group of plutons.

Foster and others (1978, 1987; see also Luthy and others, 1981) report that the plutons consist predominantly of granite and granodiorite and show a compositional range from quartz monzonite to diorite (Fig. 2). Biotite and hornblende are the typical mafic minerals; primary muscovite is rare. The rocks are generally medium grained and equigranular to porphyritic.

Cretaceous plutons of similar age and composition (the Omineca Belt; Armstrong, 1988) in the Yukon Territory and western Canada have distinctive compositional patterns exhibiting some S-type characteristics and enrichment in Al, K, Sr^{87}/Sr^{86} (SIRs commonly are greater than 0.7100), and O^{18}. As pointed out by Armstrong (1988), most of these plutons represent a mixture of mantle-derived magma and continental crust that was later modified by fractionation. The plutons may be subduction-related, but the nature and extent of the magmatic arc are uncertain.

Western Alaska–Seward Peninsula. Late Cretaceous plutonic rocks ranging in age from 94 to 78 Ma occur in a number of short-lived magmatic belts of limited extent in the Yukon-Koyukuk basin and the Seward Peninsula (Fig. 4; Plate 13). Late Cretaceous plutons in the eastern Koyukuk terrane consist of several large bodies in the east half of the Hogatza plutonic belt (Miller and others, 1966) and numerous small stocks (Fig. 4) to the south. They intrude both Neocomian andesitic volcanic rocks of the Koyukuk terrane and overlying Albian graywacke and mudstone, indicating that they can be no older than Albian in age. The plutonic rocks have yielded Late Cretaceous K-Ar ages of 89 to 79 Ma (Miller, 1989), some 10 to 20 m.y. younger than the Early Cretaceous plutons of the western Koyukuk terrane and the adjacent Ruby geanticline.

The plutons range from tonalite to high-silica granite, with granodiorite the most typical lithology; gabbro and quartz diorite are absent (Fig. 2). Individual plutons are commonly compositionally zoned, and they have sharp country-rock contacts. The rocks are generally leucocratic, medium-grained, massive, hypidiomorphic, and generally epigranular; locally they are porphyritic.

SiO_2 content generally ranges from 62 to 73 percent, but a 100-km^2 area of high-silica (76 to 78 percent) granite occurs near the west end of this belt. The rocks are relatively enriched in Na_2O (greater than 3.2 percent; Na_2O/K_2O greater than 1) and CaO; they have high Fe_2O_3/FeO ratios and belong to the magnetite series of Ishihara (1981). SIRs for this eastern suite of plutonic rocks range from 0.7038 to 0.7056 and show little internal variation (Arth and others, 1989b; Arth, this volume).

Mesozoic silicic magmatism on the Seward Peninsula occurred from about 108 to 69 Ma, or from about the middle to the end of the Cretaceous. The plutonic rocks can be grouped into three suites, each of which has a distinctive age range, distribution, and composition. The suites are chiefly of moderately to highly evolved silicic granite (Fig. 2) and consist of (1) the 96- to 91-Ma Darby pluton (Miller and Bunker, 1976; Till and others, 1986) and associated small bodies to the north (Plate 13); (2) scattered granite bodies ranging in area from less than 2 km^2 to over 200 km^2 and in age from 87 to 81 Ma and forming the core of the Bendeleben and Kigluaik Mountains (Miller and Bunker, 1976; Till and others, 1986), and (3) a group of small (0.2 to 70 km^2) tin granite stocks in the northwestern Seward Peninsula that range in age from 80 to 69 Ma (Hudson and Arth, 1983; Swanson and others, 1988). No particular area appears to have been the focus of repeated or episodic plutonism. The oldest plutonic rocks are in the southeastern part of the peninsula; the youngest are in the northwest.

Although the plutons are composed chiefly of granite, compositional differences exist between the suites. The adjacent Darby and Bendeleben plutons are chiefly granite (Fig. 4; Plate 13) and have similar modal compositional ranges, but the Darby pluton has higher SiO_2 contents, a much higher Fe_2O_3/FeO ratio, and higher U and Th contents (Miller and Bunker, 1976). The tin granite of the northwestern Seward Peninsula consists chiefly of highly evolved, compositionally restricted biotite granite (Fig. 2) with SiO_2 content of 72.6 to 77.1 percent (Hudson and Arth, 1983). Arth (1987) reported SIRs of 0.708 to 0.711 for the Darby and Bendeleben plutonic suites and higher SIRs of 0.708 to 0.720 for the northwestern tin granite.

The calc-alkaline trend of the Yukon-Koyukuk basin plutons, together with their relatively high Na_2O and Na_2/K_2O ratio, the oxidized state of Fe (magnetite series), the abundance of hornblende in addition to biotite, and the presence of mafic xenoliths, suggest that the plutons were not derived from sialic crust (Miller, 1989). SIRs and NIRs also show no evidence for the involvement of Paleozoic or older crust in the generation of the plutonic magmas (Arth and others, 1989b) but are compatible with source regions that would include oceanic mantle and Mesozoic supracrustal rocks. These compositional characteristics and the linear configuration of the belt suggest that the Yukon-Koyukuk basin plutons resulted from a short-lived period of subduction. In contrast, the composition and geologic setting of the Late Cretaceous plutons in the Seward Peninsula, particularly the high SIRs, suggest instead that they were derived from melting of the continental Proterozoic and Paleozoic metamorphic rocks.

Late Cretaceous to Early Tertiary

Plutonic rocks of Late Cretaceous to early Tertiary (74 to 55 Ma) age are widespread in the south half of Alaska (Fig. 5; Plate 13), where they form two extensive northeast-trending belts with a probable common origin. Although this suite of plutonic rocks spans the Cretaceous/Tertiary boundary, much of the magmatic activity appears to have been concentrated during the early (Late Cretaceous) part of the magmatic episode (Wallace and Engebretson, 1984). Moll-Stalcup (this volume) discusses this and associated suites of magmatic rocks in additional detail.

The more voluminous of the two belts of Late Cretaceous plutonic rocks occurs in the Alaska Range as a 700-km-long by up to 130-km-wide belt extending from the northern Alaska Peninsula through the Talkeetna Mountains to the central Alaska Range (Fig. 5). The belt is associated with, but on the landward side of, the Middle Jurassic plutonic belt of south-central Alaska and forms a major part of the Alaska-Aleutian Range batholith of Reed and Lanphere (1973). The belt has been termed the "Alaska Range–Talkeetna Mountains belt" by Hudson (1983) and the "Alaska Range belt" by Wallace and Engebretson (1984); farther east in Yukon Territory, British Columbia, and southeastern Alaska, plutonic rocks thought to be correlative have been informally referred to as belonging to the Kluane magmatic arc (Plafker and others, 1989).

The plutons intrude a number of terranes, including the Wrangellia and Peninsular terranes and the Early and Late Cretaceous (Albian and Cenomanian) Kuskokwim Group. Plutonic emplacement within this belt is well constrained by K-Ar dating in the Alaska-Aleutian Range batholith by Reed and Lanphere (1969, 1973) and in the Talkeetna Mountains and Alaska Range by Turner and Smith (1974), Csejtey and others (1978), and Smith (1981). These ages suggest a near continuum of plutonism (Reed and Lanphere, 1973) extending from about 74 to 55 Ma. The older rocks (older than 62 Ma) chiefly lie along the southeast margin of the belt (Hudson, 1983; Wallace and Engebretson, 1984).

The Alaska-Aleutian Range part of the belt consists of an elongate, concordant batholith intrusive into Paleozoic and Mesozoic metamorphic rocks and Mesozoic plutonic rocks. In the Talkeetna Mountains and Alaska Range, the belt consists of scattered plutons bounded by sharp, discordant contacts. The composition appears to vary across the trend of the belt, with biotite-hornblende tonalite, quartz diorite, and granodiorite occurring along the southeast margin and more silicic biotite grano-

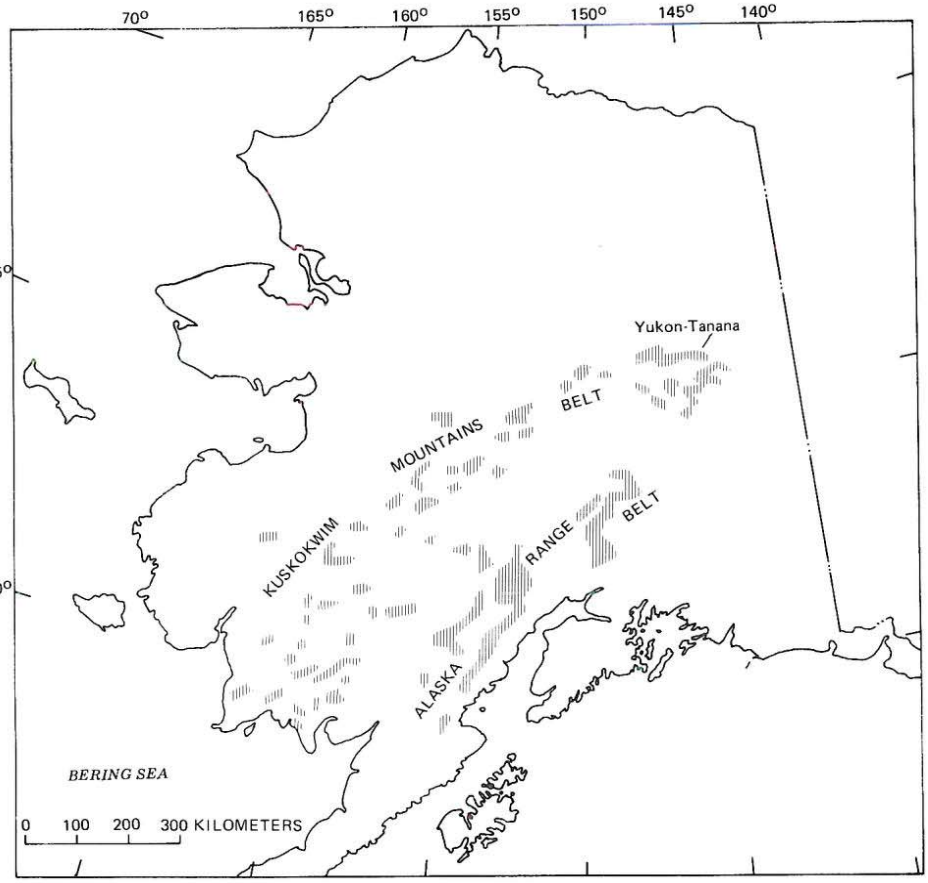

Figure 5. Distributions of Late Cretaceous to early Tertiary plutons in mainland Alaska.

diorite and granite with subordinate quartz monzonite and monzonite along the northwest margin (Hudson, 1983; Wallace and Engebretson, 1984). SiO_2 content ranges from about 60 to 76 percent, and K_2O content from about 2.8 to 5.6 percent (Reed and Lanphere, 1973). The plutonic rocks of this belt define a calc-alkaline trend (Fig. 2) and show a general increase in SiO_2 and K_2O from southeast to northwest.

The second belt of Late Cretaceous to early Tertiary plutonic rocks, though smaller in aggregate area than the Alaska Range belt, is much more widespread. This belt extends in an arcuate northeast direction from the Bering Sea in southwestern Alaska to the western Yukon–Tanana Upland (Fig. 5; Plate 13). More than 100 small (less than 200 km^2) plutons and volcano-plutonic complexes closely associated with a variety of volcanic rocks are more or less equally distributed along this 1,200-km-long by 200-km-wide trend, which Wallace and Engebretson (1984) referred to as the "Kuskokwim Mountains belt." The plutons are circular to irregular in plan, clearly discordant, and surrounded by thermal aureoles. The volcano-plutonic complexes are circular to elliptical piles of volcanic flows with intrusive cores.

A large number of K-Ar ages (Moll and Patton, 1982; Moll-Stalcup, this volume) show that these epizonal plutons and associated volcanic rocks were emplaced between about 72 and 60 Ma. They intruded the Innoko, Yukon-Tanana, Ruby, Nixon Fork, Nyack, Kilbuck, and (composite) Goodnews-Tikchik-Togiak terranes as well as the Early and Late Cretaceous Kuskokwim Group.

The plutons have an intermediate to felsic compositional range (Wallace and Engebretson, 1984; Moll-Stalcup, this volume) from gabbro and monzogabbro to granite. Monzonite, quartz monzonite, and granite predominate to the northeast, whereas tonalite, quartz diorite, and quartz monzonite are more common to the southwest. Major-element data show trends typical of calc-alkaline suites, although a more high-K, subalkalic character occurs to the northeast; some of the volcanic suites have a shoshonitic character (Moll-Stalcup, this volume). SIRs of associated volcanic rocks range from 0.7045 to 0.7053. High Sn, Be, U, W, and F contents, and possibly the SIRs as well, suggest that at least some of the magmas that formed the plutons either were contaminated by continental crust or were partial melts of the crust (Bergman and Doherty, 1986; Moll-Stalcup, this volume).

The Alaska Range and Kuskokwim Mountains plutonic belts are considered part of a more extensive plutonic belt that includes equivalent rocks in southwestern Yukon Territory, British Columbia, and southeastern Alaska (Plafker and others, 1989; Wallace and others, 1989). These rocks all appear to be arc-related and represent northward and eastward subduction during a period of rapid northward movement of the Kula Plate from 74 to 56 Ma (Wallace and Engebretson, 1984; Bergman and Doherty, 1986; Moll-Stalcup and others, this volume). The relation between the Alaska Range and the Kuskokwim Mountains belts is still uncertain, but they may represent a single arc that widened with time in response to a shallow dip of the Kula Plate (Bergman and Doherty, 1986).

SUMMARY

The preceding discussion has illustrated the episodic nature of plutonism in mainland Alaska by delineating a minimum of nine predominantly pre-Cenozoic plutonic episodes scattered about the state. Plutonic rocks defining an individual episode are commonly widely separated. In many cases, they are probably not comagmatic and almost certainly were formed by different processes. Some episodes are quite sharply defined by composition, age, and field relations, whereas others are much less well established. Terrane movements and "post-docking" faulting have further served to complicate the recognition and definition of episodes.

Proterozoic plutonism is so poorly defined in terms of composition and absolute age that it is presently impossible to ascertain the number of intrusive episodes that are represented by the widely separated occurrences of these rocks. All that can be said is that Proterozoic plutonic rocks of diverse composition and ranging in age from 2,050 to 750 Ma have been identified in several terranes of continental affinity in western and northern Alaska.

A belt of middle Paleozoic plutons that extends in sinuous but discontinuous fashion across the north half of Alaska is well defined by existing data. The plutons are continuous with rocks of similar age and composition in western Canada. Additional isotopic studies may narrow the presently rather broad Middle Devonian to Early Mississippian age range or show true spatial age differences along the belt. The plutons are thought to reflect a middle Paleozoic arc system that developed along the west edge of the North American craton. The highly evolved peraluminous composition of these plutons, their high SIRs, and the upper intercept ages of zircon discordia that compose most of the plutons suggest that considerable melting of Proterozoic continental crust was involved in their origin.

The scattered late Paleozoic (Pennsylvanian) plutons of shoshonitic affinities that flank the Wrangell Mountains are considered to be part of the Skolai island arc system (Beard and Barker, 1989) and may well have resulted from, and effectively date, the collision and amalgamation of the Wrangellia and Alexander terranes.

Plutonic rocks of early Mesozoic age are widespread throughout mainland Alaska and form extensive magmatic belts. Most of these pre-Cretaceous plutonic belts reflect the development and migration of a series of magmatic arcs that formed as various terranes impinged against the North American continental backstop (Wallace and others, 1989). The earliest Mesozoic plutonic rocks are associated with the Early to Middle Jurassic development of a north-dipping (present direction) subduction zone beneath an intraoceanic island arc that extended for over 1,000 km across the Peninsular terrane of southern Alaska. Felsic plutonic rocks (chiefly quartz diorite and tonalite) are confined to small bodies along the north side of Kodiak Island, on the tip of the Kenai Peninsula, and in the northern Chugach Mountains. Associated ultramafic and mafic rocks of the (informal) Border Ranges ultramafic-mafic complex of Burns (1985) occur over much of the intervening areas. These intermediate-mafic-ultramafic assemblages are assumed to form the core of the arc.

Several intermediate-composition isolated plutons in the heart of the eastern Yukon-Tanana Upland also were emplaced in latest Triassic to earliest Jurassic time. These plutons are assumed to be correlative with plutons of similar composition and age, including part of the Klotassin batholith, in adjacent Yukon Territory and elsewhere in western Canada and may represent part of a magmatic arc (the Stikine arc) that developed outboard of the North American continent.

Most Jurassic plutonic rocks, however, are Middle to Late Jurassic in age and are represented by three widely separated intraoceanic arc terranes. The most extensive of these arcs resulted in the formation of most of the Alaska-Aleutian Range batholith of south-central Alaska. The relations among these arcs, all of which may have had a south-dipping polarity, is uncertain. Also uncertain is the relation, if any, between the Alaska-Aleutian Range batholith and the seaward Early to Middle Jurassic Kodiak-Kenai-Chugach plutonic belt.

Cretaceous plutonism in mainland Alaska began in late Early Cretaceous time and continued into the early Tertiary. It exceeds that of the Jurassic in terms of area and distribution. Plutonic belts of Cretaceous age occur throughout the state and in some cases clearly represent the root zones of island and continental arc systems that collided with Alaska. In a lesser number of cases, however, subduction-related assemblages are lacking or concealed and the nature and polarity of the postulated arcs are uncertain. In the Ruby geanticline and perhaps in the Yukon-Tanana Upland, large areas of plutonic rocks appear to have formed within thickened continental crust, probably as a response to terrane collision and underthrusting.

Mesozoic plutonism in mainland Alaska ended with the widespread emplacement of Late Cretaceous to early Tertiary plutons throughout much of the south half of the state. This period of magmatic activity is subduction related and apparently resulted from continued underthrusting of the Kula Plate beneath an assemblage of terranes accreted to the North American continent that defined the North American Plate.

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MANUSCRIPT ACCEPTED BY THE SOCIETY FEBRUARY 12, 1991

Printed in U.S.A.