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OPHIOLITES AND OTHER MAFIC-ULTRAMAFIC COMPLEXES
IN ALASKA

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ABSTRACT

The mafic-ultramafic complexes of Alaska are divided into four distinct groups, each with a different geologic setting and tectonic history: 1) In northern and western Alaska the complexes form large allochthonous sheets which, together with tectonic slices of oceanic crustal rocks, structurally overlie metamorphosed Paleozoic and Precambrian continental rocks. The complexes typically consist of a cumulate suite and a tectonic mantle suite and appear to represent the lower part of a dismembered ophiolite. 2) In the Alaska Range and Livengood area of central Alaska the mafic-ultramafic complexes form narrow elongate bodies aligned along or near suture zones that bound diverse allochthonous terranes. The age and mode of emplacement of these highly serpentinized bodies are uncertain; possibly they represent fragments of former ocean basins collapsed during accretion of the allochthonous terranes. 3) In southern Alaska large allochthonous complexes of layered gabbro and ultramafic rocks are distributed along the Border Ranges fault, bounded on the north and west by a Jurassic volcanic arc in the Peninsula terrane and on the south and east by a Cretaceous accretionary wedge in the Chugach terrane. The mafic-ultramafic complexes represent the roots of the Jurassic arc which was underthrust from the south by the accretionary wedge in Late Cretaceous time. 4) In southeastern Alaska the mafic-ultramafic complexes consist of a linear belt of distinctively zoned intrusive bodies that typically have dunite cores surrounded by concentric shells of pyroxenite. The origin of these unusual mafic-ultramafic bodies is unclear, but their parallelism with terrane boundaries suggests a possible relationship with subduction or accretion.

INTRODUCTION

Mafic and ultramafic complexes are widespread throughout Alaska, ranging in size from huge allochthonous masses several hundred square kilometers in area to tiny isolated blocks (Fig. 1). Some of these, such as the complexes in northern and western Alaska, clearly can be labeled ophiolites; others, such as the concentrically

Figure 1 near here

zoned bodies of southeastern Alaska, are not ophiolites; and still others, such as those in the Livengood belt of central Alaska, have uncertain affinities. All of the complexes discussed here, however, belong to well-defined belts that for the most part are confined to specific lithotectonic terranes or lie along terrane boundaries. Few of these complexes have been studied in detail, and the mode and time of emplacement of most are uncertain or controversial. In this report, we review available information on the structural setting and petrography of the complexes,

and we describe the tectonic models that have been suggested to explain the mode of emplacement.

NORTHERN AND WEST-CENTRAL ALASKA

In the northern and west-central parts of Alaska, mafic-ultramafic complexes are exposed in three separate belts (Fig. 1): western Brooks Range, Angayucham, and Tozitna-Innoko. The complexes in the western Brooks Range and Angayucham belts are included in the Angayucham lithotectonic terrane as defined by Jones and others (1987); and the complexes in the Tozitna-Innoko belt are included in the Tozitna and Innoko lithotectonic terranes as defined by Jones and others (1987) (Fig. 1). All three belts are composed of late Paleozoic and Mesozoic oceanic rocks which have been thrust onto Precambrian and Paleozoic miogeoclinal assemblages. Within each of these belts we recognize two separate thrust panels: a lower panel consisting of multiple thrust slices of pillow basalt, chert, nonlayered gabbro, and volcanoclastic rocks; and an upper panel composed of mafic-ultramafic complexes (Patton and others, 1977). Most workers agree that the mafic-ultramafic complexes of the upper panel represent the lower part of a classic ophiolite sequence (Roeder and Mull, 1978; Patton and others, 1977; Mayfield and others, 1983b; Loney and Himmelberg, 1984, 1985a, 1985b). The composition of the upper panel and its close spatial relationship to the higher level oceanic rocks in the lower panel led to an earlier suggestion that the two panels together form a nearly complete dismembered ophiolite sequence (Patton and others, 1977; Roeder and Mull, 1978). However, recent dating by K-Ar and fossils has shown that the mafic-ultramafic complexes of the upper panel are of probable Jurassic age, whereas the pillow basalt, gabbro, chert, and volcanoclastic rocks of the lower panel range in age from Devonian to Jurassic.

Western Brooks Range

Scattered mafic-ultramafic complexes, including some of the largest in Alaska, extend in a broad arcuate belt across the western Brooks Range from Siniktanneyak Mountain to the Chukchi Sea, a distance of about 350 km. Five separate complexes have been mapped from east to west: Siniktanneyak Mountain, Misheguk Mountain, Asik Mountain, Avan Hills, and Iyikrok Mountain. The Avan Hills, Misheguk Mountain, and Asik Mountain complexes may coalesce beneath the alluviated lowlands of the lower Noatak River to form a single large body.

Recent workers in the western Brooks Range agree that these mafic-ultramafic complexes represent synformal remnants of a south-dipping allochthonous sheet that had its roots along the northern edge of the Yukon-Koyukuk basin (Mayfield and others, 1983b; Roeder and Mull, 1978; Patton and others, 1977). Both the synformal remnants in the western Brooks Range and the root zone along the northern edge of the Yukon-Koyukuk basin are included in the Angayucham terrane of Jones and others (1987). In the western Brooks Range, Mayfield and others (1983b) assign these rocks to the Misheguk Mountain allochthon, the highest of seven imbricated sequences that have overridden the western Brooks Range. They summarize the major features of the Misheguk Mountain sequence as follows:

"This sequence is the lower part of a classical ophiolite sequence. The layers of the basalt and oceanic sediments above the gabbroic and ultramafic rocks have not been reported and presumably were stripped away by erosion. The bottom of the sequence is a zone of olivine-rich peridotite and dunite with both tectonite and cumulate characteristics. Above this is a transitional zone that contains alternating layers of peridotite, pyroxenite, and gabbroic rocks. The top of the sequence mainly consists of gabbroic rock that tends to display cumulate layering of pyroxene-rich and plagioclase-rich layers in the lower part; in the upper part, it is not layered and is more leucocratic. Local occurrences of granitoid rocks are more prevalent in the upper part and seem to occur both as layers and as cross-cutting dikes in the gabbro (Roeder and Mull, 1978; Nelson and others, 1979; and Zimmerman and others, 1981)."

Mayfield and others (1983b) estimate that the Misheguk Mountain allochthon is no more than 1 to 2 km thick.

Description of complexes

Siniktanneyak Mountain (locality 1 on Fig. 1) -- The easternmost complex of the western Brooks Range belt has a roughly oval-shaped exposed area of 150 km². Another small body of ultramafic rocks occurs 15 km to the southwest of the main mass and, if the covered area between is also underlain by ultramafic and mafic rocks, the total size of the complex may be as much as 300 km² (Inyo Ellersieck, oral commun., 1984). A geologic map by Nelson and Nelson (1982) indicates that the exposed body at Siniktanneyak Mountain is composed of about 20 percent ultramafic rocks--chiefly serpentinitized dunite with cumulus layers of wehrlite, harzburgite, and olivine pyroxenite--and about 80 percent layered gabbro. The northern and western part of the complex is intruded by two small stocks ranging in composition from hornblende diorite to biotite-hornblende alaskite and the southeastern part by muscovite-biotite granite and alaskite dikes. A K-Ar age of 151±15 Ma (Late Jurassic) was measured on hornblende from a hornblende pegmatite boulder in a stream draining Siniktanneyak Mountain (Patton and others, 1977). According to I. L. Tailleux (oral commun., 1984), similar hornblende pegmatites are common within the complex. Potassium-argon ages of 162±8 and 171±9 Ma (Middle or Late Jurassic) were measured on a coexisting biotite-hornblende mineral pair from a quartz diorite intrusive body (C. F. Mayfield and Inyo Ellersieck, oral commun., 1984).

Misheguk Mountain (locality 2 on Fig. 1) -- The largest of the western Brooks Range mafic-ultramafic complexes is 50 km long by 10 to 15 km wide and has a total exposed area of 460 km². Few petrographic details of the complex are known. Mapping by Ellersieck and others (1982) and Curtis and others (1982) indicates that only about 10 percent of the complex is made up of ultramafic rocks--chiefly peridotite, serpentinitized dunite, and minor pyroxenite dikes. The main mass of the complex consists of medium- to coarse-grained layered gabbro intruded by dikes of peridotite, pyroxenite, and hornblende-plagioclase pegmatite. A small pluton of diorite, quartz diorite, and granite occurs in the northeastern part of the complex. Cross sections by Ellersieck and others (1982) show that the ultramafic rocks form a

slablike body dipping to the southeast beneath medium- to coarse-grained layered gabbro, which in turn is succeeded along the southern margin of the complex by fine-grained gabbro. Locally, along the northwestern border of the complex, the ultramafic rocks are underlain by a wedge of pelitic schist and marble of uncertain age. K-Ar ages of 147.2 ± 4.4 Ma and 155.8 ± 4.7 Ma have been obtained recently from hornblende gabbro and hornblende-bearing diorite from the upper part of the complex (Boak and others, 1985). The ages are thought to postdate crystallization of the mafic-ultramafic rocks and are attributed to thermal metamorphism during emplacement.

Avan Hills (locality 4 on Fig. 1) -- This roughly oval-shaped complex has a total area of about 200 km² and probably extends another 100 km² beneath the heavily alluviated areas bordering the Avan River. The complex is divided into three separate zones: an ultramafic tectonite zone of unknown thickness, a transitional zone about 1 km thick in which ultramafic and mafic rocks are interlayered, and a mafic zone about 2.5 km thick (Frank and Zimmerman, 1982; Zimmerman and others, 1981; Zimmerman and Soustek, 1979). The ultramafic tectonite zone is composed of interlayered dunite, harzburgite, and minor amounts of pyroxenite. The ultramafic rock is foliated nearly parallel to compositional layering and shows evidence of plastic strain and recrystallization. The mafic zone is composed of about 90 percent layered gabbro, chiefly leucogabbro, and subordinate amounts of troctolite and anorthosite. Small bodies of biotite granite, biotite tonalite, and tonalite are reported by Frank and Zimmerman (1982) in the western part of the complex, and a small body of "metabasite" is reported by Zimmerman and Frank (1982) at the base of the ultramafic zone. No age data for the Avan Hills complex have been published.

Iyikrok Mountain (locality 5 on Fig. 1) -- This a mafic-ultramafic complex is made up of two poorly exposed bodies, the larger of which is located at Iyikrok Mountain and the smaller about 20 km west of Iyikrok Mountain. The Iyikrok Mountain body has a total outcrop area of about 30 km², but Mayfield and others (1983a) suggest that it extends an additional 20 km² beneath an area of few exposures northwest of Iyikrok Mountain. The smaller body is about 15 km² in area, judging from the distribution of scattered exposures. Few details about the composition of either of these two bodies are known.

Asik Mountain (locality 3 on Fig. 1) -- A roughly rectangular-shaped complex crops out in a 100-km² area at Asik Mountain on the east side of the lower Noatak River basin. Gravity and magnetic data suggest that it extends westward beneath the Noatak River for an additional 300 km² (Barnes and TAILLEUR, 1970; Mayfield and others, 1983b). No detailed study of the Asik complex has been carried out; based on reconnaissance mapping, Inyo ELLERSIECK (oral commun., 1984) estimates that the complex is made up of about 5 percent ultramafic rocks, exposed chiefly along the southern and western margins, and about 95 percent gabbro.

Geologic setting.

The western Brooks Range mafic-ultramafic complexes belong to the highest of seven allochthonous sheets that constitute the stack of south-dipping imbricated thrust plates making up the western Brooks Range (Mayfield and others, 1983b). The mafic-ultramafic complexes of allochthon 7 and the pillow basalt and chert-forming allochthon 6 appear to have a close spatial, if not genetic, relationship. They are

preserved in small synformal remnants, which overlie Devonian to Early Cretaceous continental and continental margin deposits composing allochthons 1 to 5. Allochthons 6 and 7 appear to be rooted along the northern margin of the Yukon-Koyukuk basin where they rest in thrust contact upon metamorphosed Proterozoic and early Paleozoic strata of the southern Brooks Range schist belt (Hammond subterrane) (Fig. 1).

Thin slices of metamorphic rocks are reported locally along the sole of the mafic-ultramafic allochthon. On the northwest side of the Misheguk Mountain complex, a wedge of metamorphic rocks including quartz-muscovite-chlorite-garnet schist, actinolite-albite-chlorite schist, and marble separate the complex from the underlying allochthon of pillow basalt and chert (Elliessieck and others, 1982). The protoliths of these rocks are believed to be pelitic sedimentary rocks, mafic igneous rocks, and limestone, but their age and stratigraphic relations are uncertain. In the Avan Hills complex "metabasites" are reported by Zimmerman and Frank (1982) at the base of the mafic-ultramafic allochthon. At both localities, metamorphism has been attributed to emplacement of the mafic-ultramafic allochthons. From the zone of amphibolite and hornblende gneiss at the base of the Iyikrok Mountain complex, Boak and others (1985) obtained K-Ar ages of 154.2 ± 4.6 and 153.2 ± 4.6 Ma.

Time of emplacement.

Several lines of evidence suggest that Brooks Range orogenic activity leading to emplacement of the mafic-ultramafic allochthon began in the Late Jurassic and continued into the Early Cretaceous. Orogenic flyschoid deposits rich in mafic debris derived from the mafic-ultramafic rocks and containing Late Jurassic and Early Cretaceous fossils are incorporated in thrust sheets that underlie the mafic-ultramafic allochthon (Mayfield and others, 1983b). Metamorphism and, in particular, the occurrence of "blueschist" (glaucophane) mineral assemblages in the southern Brooks Range are thought to be associated with overthrusting of the mafic-ultramafic allochthonous rocks. Greenschist-facies metamorphic mineral assemblages in this glaucophane-bearing schist belt yield predominantly Early Cretaceous potassium-argon cooling ages (Turner, 1984), which probably record the time of uplift following metamorphism. Added evidence on the timing of emplacement comes from the southeast side of the Yukon-Koyukuk basin, where garnet-amphibolite tectonites at the base of the mafic-ultramafic allochthon yield Late Jurassic metamorphic-mineral K-Ar ages (Patton and others, 1977). Emplacement of the mafic-ultramafic complexes must have occurred before late Early Cretaceous because: 1) Albian conglomerates, eroded from the Brooks Range and deposited along the northern margin of the Yukon-Koyukuk basin, contain debris from mafic-ultramafic complexes and from the underlying metamorphic rocks; and 2) granitic plutons of Albian and Cenomanian age on the southeast side of the basin intrude both the mafic-ultramafic complexes and the underlying metamorphic rocks (Patton, 1984).

Angayucham

The Cretaceous Yukon-Koyukuk basin of west-central Alaska (Patton and others, 1989) is bordered on the northern and southeastern sides by the Angayucham terrane (Fig. 1)--a narrow but nearly continuous belt of oceanic rocks that dips inward beneath the basin and is thrust outward onto the Proterozoic and Paleozoic

metamorphic rocks of the bordering Arctic Alaska and Ruby terranes. In this area we recognize three separate thrust panels in the Angayucham terrane (Patton and others, 1989): the lower or Slate Creek thrust panel composed of phyllite and metagraywacke, the middle or Narvak thrust panel composed of pillow basalt, chert, and gabbro, and the upper or Kanuti thrust panel composed of mafic-ultramafic complexes. The middle and upper panels appear to correlate with allochthons 6 and 7 of the Angayucham terrane in the western Brooks Range. The Angayucham terrane in the Yukon-Koyukuk basin can be traced for about 500 km along the northern edge of the basin from the lower Kobuk River to the northeastern apex of the basin and for 400 km along the southeastern side from the northeastern apex of the basin to the Kaltag fault. The Kaltag fault offsets the margin of the basin and the adjoining Angayucham terrane about 140 km to the west (Patton and Hoare, 1968; Patton and others, 1984). South of the fault the offset extension of the Angayucham terrane can be followed for an additional 50 km from near the village of Kaltag to the Innoko River lowlands (Fig. 1).

Description of complexes.

Large mafic-ultramafic complexes composing the upper thrust panel of the Angayucham terrane are preserved in three separate localities bordering the Yukon-Koyukuk basin. Each of these localities is described below.

Kanuti (locality 6 on Fig. 1) -- The largest volume of mafic-ultramafic complexes bordering the Yukon-Koyukuk basin is exposed along a 100-km segment of the Angayucham terrane on the southeast limb of the basin in the Kanuti River drainage. The complexes vary in width from 1 to 10 km and have a total exposed area of about 300 km². According to Loney and Himmelberg (1985b), the complexes can be subdivided into a cumulus plutonic suite and a tectonite mantle suite. The cumulus suite, which makes up the upper part of the mafic-ultramafic thrust panel and lies generally northwest of the mantle suite, is composed of interlayered cumulus wehrlite, olivine clinopyroxenite, and gabbro. The mantle suite, which makes up the lower part of the thrust panel and lies southeast of the plutonic suite, is composed of harzburgite, dunite, and minor clinopyroxenite. Overall, the complexes are composed of about 65 percent cumulate plutonic suite and 35 percent mantle tectonite suite. The base of the mafic-ultramafic thrust panel commonly has a layer of amphibolite that is 10 to 25 m thick and consists of a highly tectonized aggregate of amphibole, plagioclase, and garnet. The basal thrust, where well exposed, dips from 15° to 26° to the northwest (Loney and Himmelberg, 1985b).

Two K-Ar ages of latest Jurassic (149±9.6 Ma) and earliest Cretaceous (138±8 Ma) were obtained from amphibole-bearing dikes in the cumulate plutonic suite, and a K-Ar age of Late Jurassic (161±4.9 Ma) was obtained from metamorphic amphibole from the thin layer of garnet amphibolite at the base of the mafic-ultramafic thrust panel (Patton and others, 1977). These ages are interpreted as cooling ages related to tectonic emplacement of the thrust panel.

Jade Mountains and Cosmos Hills (locality 7 on Fig. 1) -- The mafic-ultramafic complexes of the upper thrust panel of the Angayucham terrane are preserved on the northern limb of the Yukon-Koyukuk basin in the Jade Mountains and Cosmos Hills. The main mass of the Jade Mountains is composed of pillow basalt belonging to the middle thrust panel. The pillow basalt is overlain on the south flank of the mountains by the upper thrust panel consisting of a 500-m-thick slab of serpentinite

that dips gently to the south. The total exposed area of the ultramafic rocks is about 9 km², but several small rubble patches of serpentinite in the adjoining Kobuk lowlands to the south suggest that the total area underlain by the serpentinite slab may be as much as 40 to 50 km². Although the ultramafic rock has been thoroughly serpentinized, the original fabric of the rock can be recognized. Remnant olivine and orthopyroxene are visible in thin section indicating that the protolith rock was predominantly a harzburgite tectonite (Loney and Himmelberg, 1985a).

In the Cosmos Hills, the upper thrust panel of the Angayucham terrane is represented by tabular bodies of serpentinite, as much as 130 m thick and 8 km long, distributed around the metamorphic core of the Cosmos Hills antiform. Structurally, these highly tectonized bodies underlie sheared Cretaceous conglomerate of the Yukon-Koyukuk basin and overlie schist of the southern Brooks Range metamorphic belt (Hammond subterrane). Highly altered and sheared bodies of mafic volcanic rocks are also found along this contact and may represent fragments of the middle thrust panel of the Angayucham terrane. Asbestos Mountain, a tabular body of serpentinite resting on the schist along the axis of the Cosmos Hills antiform, appears to be a klippe or remnant of the upper thrust panel that once covered the metamorphic core of the antiform.

No age data are available for the ultramafic complexes in the Jade Mountains or Cosmos Hills.

Magitchlie Range (locality 8 on Fig. 1) -- Mafic-ultramafic complexes belonging to the upper thrust panel of the Angayucham terrane are also preserved on the southeast limb of the Yukon-Koyukuk basin south of the Kaltag fault. This belt of complexes, which lies along the east side of the Magitchlie Range, can be traced by scattered patches of rubble and a strong positive aeromagnetic anomaly (Department of Energy, 1982) for about 50 km from the Kaltag fault to the Innoko River lowlands. Because of limited exposure, it is difficult to judge the size and continuity of the ultramafic bodies along this belt. The largest exposed complex, estimated to be about 10 km² in area, forms an unnamed isolated knob at benchmark "Peak No. 7" (Ophir A-5 quad.). According to R. A. Loney and G. R. Himmelberg (oral commun., 1984) this complex consists chiefly of partly serpentinized cumulus wehrlite, dunite, and olivine gabbro cut by dikes of hornblende gabbro and hornblende pegmatite. Another smaller complex composed of highly altered, sheared, and locally talcose serpentinite occurs in the Innoko River lowlands 27 km southeast of "Peak No. 7."

The geologic setting of these ultramafic complexes is obscured by heavily vegetated lowlands that separate them from the surrounding geologic terranes. However, their location between the metamorphic rocks of the Ruby terrane in the Kaiyuh Mountains to the east and conglomerates of the Yukon-Koyukuk basin in the Magitchlie Range to the west, strongly supports the interpretation that they represent an extension of the Angayucham terrane.

A Late Jurassic K-Ar amphibole age of 151 ± 4.5 Ma was obtained from a gabbro pegmatite dike that cuts the peridotite at benchmark "Peak No. 7" (Patton and others, 1984).

Tectonic Setting.

The Angayucham terrane, composed of an upper thrust panel of mafic-ultramafic complexes, a middle thrust panel of pillow basalt, chert, and gabbro, and a lower thrust panel of phyllite and metagraywacke, represents the root zone of huge nappes that overthrust the metamorphic cores of the southern Brooks Range (Arctic Alaska terrane) and the Ruby geanticline (Ruby terrane) in Early Cretaceous time (Patton and others, 1977; Roeder and Mull, 1978; Mayfield and others, 1983b). Emplacement of these three thrust panels occurred when a volcanic arc (Koyukuk terrane) rooted in oceanic crust collided with the Proterozoic and early Paleozoic continental rocks that border the basin (Roeder and Mull, 1978; Gealey, 1980; Box, 1985b; Patton and others, 1989). Cretaceous K-Ar ages of metamorphic minerals from the metamorphosed continental borderlands probably are related to the Early Cretaceous overthrusting (Turner, 1984; Patton and others, 1984). Collision of the arc and thrusting of the oceanic rocks onto the continental rocks must have occurred before the late Early Cretaceous because: (1) Albian conglomerate, eroded from the borderlands and deposited along the margins of the basin, contains clasts of both oceanic and continental rocks; and (2) granitic plutons of Albian and Cenomanian (111 to 91 Ma) age intrude both the Ruby terrane and the Angayucham terrane along the margin of the Ruby geanticline (Patton, 1984). The Late Jurassic K-Ar ages obtained from metamorphic amphibole, from garnet amphibolite tectonite on the sole of the upper thrust panel, and from amphibole-bearing dikes within the upper thrust panel are believed to reflect thermal events related to thrusting of the upper thrust panel over the middle thrust panel. These ages suggest that this overthrusting preceded thrusting of the Angayucham terrane over the metamorphic borderlands (Mayfield and others, 1983b; Patton and others, 1989).

Although most workers agree that the oceanic rocks of the Angayucham terranes are allochthonous with respect to the metamorphic assemblages of the southern Brooks Range and Ruby geanticline, not all agree on the mode of emplacement. Coney (1984), for example, suggested that the oceanic rocks were rooted in an ocean basin that lay to the south and were thrust northward across the Ruby geanticline and Yukon-Koyukuk basin. In another interpretation, Gemuts and others (1983) envisaged generation of the oceanic rocks in rifts along the margins of the Yukon-Koyukuk basin and subsequent thrusting of the oceanic rocks onto the metamorphic borderlands during a later compressional event. Similarly, Dover (in preparation) suggests that the mafic-ultramafic rocks were generated within the continental rocks of the Ruby geanticline and southern Brooks Range and were tectonically emplaced by nonaccretionary processes.

Tozitna-Innoko

The mafic-ultramafic complexes on the Ruby geanticline (Patton and others, 1989) are shown on Fig. 1 as the Tozitna-Innoko belt. They consist of allochthonous synformal masses of late Paleozoic and Mesozoic oceanic crustal and mantle rocks thrust onto the metamorphosed autochthonous and para-autochthonous Proterozoic(?) and early Paleozoic Ruby terrane in the core of the Ruby geanticline. They are roughly correlative in age and lithology with the Angayucham terrane and may represent remnants of the same overthrust sheets. Like the Angayucham terrane, they are composed of separate thrust panels: an upper thrust panel composed of mafic-ultramafic complexes and a lower thrust panel composed of

multiple thrust sheets of pillow basalt, radiolarian chert, gabbro, volcanoclastic rocks, and argillite. A third thrust panel composed of phyllite and metagraywacke, similar to that found in the lower part of the Angayucham terrane in the Yukon-Koyukuk basin, is also present locally at the base of the Tozitna-Innoko complexes in the area north of the Kaltag fault.

Description of complexes

Four major mafic-ultramafic complexes located along the Tozitna-Innoko belt are described below:

Christian (locality 9 on Fig. 1) -- Mafic-ultramafic complexes occur along the axis of a large synformal mass of Tozitna terrane located at the northeastern end of the Ruby geanticline where the geanticline merges with the Brooks Range. The bulk of the Tozitna terrane consists of nonlayered gabbro, basalt, diabase, chert, shale, and carbonate rock (Brosge' and Reiser, 1962). The structurally higher mafic-ultramafic complexes form two oblong bodies that have a total exposed area of about 170 km². They are composed largely of interlayered hornblende leucogabbro, anorthosite, hornblende gabbro, pyroxenite, and peridotite cumulates (Reiser and others, 1965; D. L. Jones, oral commun., 1984). The contact at the base of the complexes is poorly exposed, but we believe it is a thrust fault. A hornblende mineral separate from leucogabbro yielded a Middle Jurassic K-Ar age of 172 ± 8 Ma (Reiser and others, 1965; Patton and others, 1977).

Pitka (locality 10 on Fig. 1) -- A mafic-ultramafic complex in the Tozitna terrane is located 140 km to the southwest of the Christian bodies in the upper drainages of the Hodzana River (Brosge' and others, 1973). This complex is exposed over an area of about 25 km² and is interpreted by Brosge' and others (1974) as a klippe resting on a structurally lower sheet of basalt, gabbro, and chert. Brosge' and others (1974) describe the complex as a synform of strongly foliated dunite and harzburgite, banded garnet amphibolite, and gneissic leucogabbro. At the base of the klippe a layer of garnet amphibolite, similar to the one that occurs on the sole of the mafic-ultramafic allochthon in the Kanuti segment of the Angayucham belt, yielded a Late Jurassic K-Ar metamorphic mineral age of 155 ± 4.6 Ma (Patton and others, 1977).

Yuki (locality 11A on Fig. 1) -- Mafic-ultramafic complexes occur at the southwestern end of the Tozitna terrane in the Yuki River drainage of the Kaiyuh Mountains. Several large complexes that have a total exposed area of about 140 km² are distributed along a northeast-trending belt within a broad synformal mass of pillow basalt, radiolarian chert, and nonlayered gabbro (Patton and others, 1977). The complexes are composed of partly serpentinized harzburgite tectonite and of ultramafic cumulates that include dunite, wehlite, and olivine clinopyroxenite (Loney and Himmelberg, 1984). Structural relations at the base of the complexes are obscured by a dense cover of vegetation, but scattered exposures of banded garnet amphibolite tectonite suggest that the contact is a thrust fault. A Middle Jurassic K-Ar age of 172 ± 5.2 Ma was measured on metamorphic amphibole from the amphibolite (Patton and others, 1984).

Mt. Hurst-Dishna (locality 11B on Fig. 1) -- Mafic-ultramafic complexes within the Innoko terrane occur at Mt. Hurst and 35 km on strike to the southwest on the upper Dishna River (Chapman and others, 1985; Miller and Angeloni, 1985). The

contacts of the complexes are poorly exposed, and their precise relations to the subjacent upper Paleozoic and lower Mesozoic chert, argillite, basalt, and tuff of the Innoko terrane are uncertain. On the northwest side, the Mt. Hurst complex appears faulted against a narrow band of metamorphic rocks that presumably belongs to the Ruby terrane. The Mt. Hurst complex is well exposed over an area of about 30 km²; the Dishna complex is less well exposed but appears to be of similar size. The Mt. Hurst complex is composed of about one-third harzburgite and two-thirds cumulate ultramafic rocks that include dunite, wehrlite, and olivine clinopyroxenite (Loney and Himmelberg, 1984). The Dishna complex consists of harzburgite, lherzolite, pyroxenite, dunite, and locally gabbro (Miller and Angeloni, 1985). All of the ultramafic rocks are partly to wholly serpentinized. Age data for the complexes are not available.

SOUTHWESTERN ALASKA

Mafic-ultramafic complexes are distributed along a belt extending 220 km north-northeast from Cape Newenham. Along this belt we recognize the following groups of complexes, each with a distinctive history and mode of occurrence.

Description of complexes

Cape Newenham (locality 12 on Fig. 1) -- Mafic-ultramafic complexes in the vicinity of Cape Newenham are exposed over an area of about 90 km². They appear to represent thrust sheets of the disrupted base of the Togiak terrane resting in fault contact on the Goodnews terrane (Box, 1985b). The complexes consist of about 90 percent nonlayered gabbro and 10 percent serpentinized harzburgite and dunite. Pillow basalt and gabbro are closely associated with the mafic-ultramafic complexes in the Togiak terrane and, although contacts are everywhere faulted, we believe the pillow basalt and gabbro represent higher levels of the same ophiolite succession. The pillow basalt, which is Late Triassic in age, grades upward through a thick volcanic breccia section into Lower Jurassic shallow-marine andesitic volcanic and volcanoclastic strata. The structurally underlying Goodnews terrane is composed of schistose nappes, the highest of which consists of foliated basalt and gabbro. Lower nappes in the Goodnews terrane are composed of metasedimentary rocks. The schistose rocks are characterized by transitional greenschist-blueschist-facies metamorphic assemblages.

The mafic-ultramafic complexes at Cape Newenham have not been dated by isotopic methods. However, the associated pillow basalt, which we infer to be a stratigraphically higher part of this ophiolite succession, is intercalated with red radiolarian chert of Late Triassic age (J. M. Hoare, written commun., 1976). The Cape Newenham complexes were structurally emplaced along north-directed thrust faults onto the schistose rocks between Late Triassic and Middle Jurassic time. The older constraint on time of emplacement is the age of the radiolarian chert in the pillow basalt; the younger constraint is the K-Ar isotopic age of crosscutting intrusive rocks of the Platinum complexes (see below).

Platinum (locality 13 on Fig. 1) -- The Platinum complexes underlie an area of about 25 km² near Goodnews Bay. They consist of two zoned bodies that have cores of weakly serpentinized dunite, intermediate shells of clinopyroxenite and hornblende gabbro-diorite, and outer rims of coarse pegmatitic hornblendite (Mertie, 1940; Bird

and Clark, 1976; Southworth, 1984). Closely associated with these zoned bodies are scattered bodies of hornblende gabbro which yield K-Ar ages similar to those of the pegmatitic hornblendite. The zoned bodies intrude the schistose nappes of the Goodnews terrane; the hornblende gabbro bodies intrude both the schistose rocks of the Goodnews terrane and the overlying ophiolite and andesitic volcanic arc rocks of the allochthonous Togiak terrane. Hornblende pegmatites that rim the zoned bodies yield K-Ar ages of Middle Jurassic (187 and 176 Ma); the associated hornblende gabbro bodies give K-Ar ages of Middle and Late Jurassic (187-162 Ma).

Arolik (locality 14 on Fig. 1) -- The Arolik mafic-ultramafic complexes have a total exposed area of about 70 km² in the drainage of the Arolik River north of Goodnews Bay. They also include scattered small serpentinite bodies extending for 120 km northeast from the Arolik River. The Arolik complexes consist of about 75 percent pyroxene gabbro and 25 percent harzburgite and minor amounts of dunite. Little is known about the petrography of these rocks, but generally they appear similar in composition to the Cape Newenham complexes. We interpret the Arolik complexes as klippen overlying transitional greenschist-blueschist facies metamorphic rocks that are faulted on the northwest against the metamorphic rocks of the Kilbuck terrane. They appear to have been emplaced in Early Cretaceous time by northwestward thrusting associated with collision between the continental rocks of the Kilbuck terrane and the arc rocks of the amalgamated Togiak and Goodnews terranes. Cretaceous K-Ar and Rb-Sr metamorphic ages of 120-150 Ma (Turner and others, 1983) from the Kilbuck terrane may be related to this collision. The "root zone" of the Arolik bodies is uncertain, as are their igneous ages.

EAST-CENTRAL ALASKA

Salcha-Seventymile

A discontinuous belt of ultramafic complexes more than 200 km long is exposed in the Salcha and Seventymile Rivers area of the Yukon-Tanana Upland. This belt, which was named the Seventymile terrane by Jones and others (1987) (Fig. 1), extends from the Alaska-Yukon boundary near Eagle west-southwest to the Wood River south of Fairbanks. The total exposed area of these complexes is approximately 200 km². From east to west they include: 1) the American River body south of Eagle (locality 15 on Fig. 1); 2) the Mt. Sorenson body in the upper Seventymile River drainage (locality 16); 3) a linear belt of smaller bodies north of the Salcha River (locality 17); and 4) an isolated body in the Tanana-Kuskokwim Lowlands at Wood River Buttes (locality 18). Aeromagnetic data (Decker and Karl, 1977) suggest that the body at Wood River Buttes occurs along a southwestward extension of the Salcha River belt. The ultramafic rocks consist of variably serpentized bodies of harzburgite and subordinate amounts of dunite and clinopyroxenite. Most of these ultramafic bodies are closely associated with altered basalt ("greenstone") and minor amounts of gabbro and chert. The contact relations between those rocks and the ultramafic rocks are unclear, but their close spatial association suggests a possible genetic relationship. Both the ultramafic rocks and the basalt, gabbro, and chert assemblages are surrounded by, and appear to rest structurally upon, greenschist-facies pelitic and psammitic schists of the Yukon-Tanana terrane. Glaucophane has been reported from one locality in the schists about 20 km east of the Mt. Sorenson body (Keith and others, 1981).

Direct information on the age of the ultramafic complexes is not available. Early Permian radiolarians and conodonts have been recovered from chert associated with an ultramafic body on the Salcha River (Weber and others, 1978). If the chert is part of a dismembered ophiolite succession that included the ultramafic rocks at the base, then the ultramafic rocks presumably are Permian or older.

All of the ultramafic complexes and the closely associated basalt, gabbro, and chert assemblages of the Seventymile terrane are allochthonous with respect to the underlying schist of the Yukon-Tanana terrane (Helen Foster, oral commun., 1985). However, the direction of transport and location of the root zone of these thrust sheets are uncertain and the time of emplacement cannot be fixed more closely than Permian or later.

To the southeast, in the adjoining Yukon Territory, the steep Teslin fault is considered the "root zone" for both the metamorphic and mafic-ultramafic nappes that lie to the northeast of the fault (Tempelman-Kluit, 1979). This fault zone separates rocks of the Stikinia and Cache Creek terranes on the southwest from rocks of the Yukon-Tanana metamorphic terrane and the Cassiar miogeoclinal terrane to the northeast. According to Tempelman-Kluit (1979), development of the Yukon-Tanana metamorphic terrane, including its "piggy-back" mafic-ultramafic nappes, is related to collision of an offshore island-arc complex (Stikinia, Cache Creek, and other terranes) with the North American miogeoclinal margin in Early Jurassic (also see Monger and others, 1982). This interpretation suggests that the mafic-ultramafic nappes were rooted beneath the forearc of a former arc terrane, which presently lies south of the Salcha-Seventymile belt.

Livengood

Ultramafic and associated plutonic rocks crop out along a narrow but nearly continuous 95-km-long belt that trends southwestward across the Livengood and Tanana quadrangles in east-central Alaska (locality 19 on Fig. 1). These rocks extend along the boundary between the Cretaceous flysch deposits of the Manley terrane and the weakly metamorphosed Paleozoic rocks of the Livengood terrane. Sporadic outcrops continue on strike for another 100 km to the southwest where they have been included in the Manley terrane by Jones and others (1987) (Fig. 1). The complexes have a total outcrop area of about 150 km² and are composed predominantly of completely serpentized ultramafic rocks. In the vicinity of Livengood, where they have been studied in greatest detail, Loney and Himmelberg (1987) report that the ultramafic rocks are largely serpentized harzburgite and minor dunite. The serpentinite is locally intruded by lenticular bodies and dikes of altered diorite and gabbro.

The structural setting of the ultramafic complexes is unclear. In the Livengood quadrangle, Chapman and others (1971, 1985) interpret the contact with the Cretaceous flysch deposits of the Manley terrane as depositional, whereas Foster and others (1983) conclude that the contact, at least at the northeast end of the belt, is a fault. Coney (1984) contends that the ultramafic rocks dip steeply northwestward and were emplaced against the flysch deposits by southeastward overthrusting in late Mesozoic time.

The age of the ultramafic complexes in the Livengood belt is uncertain, but probably pre-Ordovician. Near Livengood diorite and gabbro intruding the

ultramafic rocks yield K-Ar hornblende ages of 518 to 633 Ma (D. L. Turner, written commun., 1987). These K-Ar ages confirm a previous pre-Late Devonian age assignment by Foster (1966) based on the presence of serpentinite clasts in nearby conglomerates containing Late Devonian fossils. To the southwest in the Tanana quadrangle, Chapman and others (1982) assigned the ultramafic complexes a probable Late Cretaceous age on the basis of their apparent intrusive relationship with the enclosing Cretaceous sedimentary rocks. However, Loney and Himmelberg argue that, although the ultramafic rocks in the Tanana quadrangle may have undergone higher temperature recrystallization, they appear to be an extension of the older Livengood ultramafic belt and should be assigned to the Livengood terrane rather than to the Manley terrane as indicated by Jones and others (1987) (Fig. 1).

SOUTHERN ALASKA

Alaska Range

Small ultramafic bodies are scattered along the central and eastern Alaska Range for at least 500 km, but a clear pattern of their age and origin is not apparent. Possibly the best known body in the central Alaska Range occurs in the Chulitna district (locality 20 on Fig. 1), where an Upper Devonian ophiolite sequence of serpentinite, gabbro, pillow basalt, and radiolarian chert is well documented in the Chulitna terrane (Jones and others, 1980). Nearby in the Talkeetna quadrangle (locality 21 on Fig. 1), Reed and Nelson (1980) have identified several dunite and serpentinite bodies of uncertain age. The serpentinite occurs as a narrow fault sliver about 5 km in length along a prominent fault zone parallel to and just northwest of the Denali fault. In addition, "alpine-type" dunite and serpentinite are exposed discontinuously for 25 km in a thick, lithologically and structurally complex unit (chiefly marine flyschoid sedimentary rocks) of middle and late Paleozoic age.

Farther east in the central Alaska Range, at least 24 ultramafic bodies are exposed along a belt about 50 km long and 15 km wide that extends from the Maclaren Glacier to beyond Rainbow Mountain (locality 22 on Fig. 1; Hanson, 1964; Rose, 1965 and 1966; Stout, 1976; Nokleberg and others, 1982). The bodies consist mainly of locally serpentinitized dunite and peridotite and of gabbro. Nokleberg and others (1979) suggest that these ultramafic bodies are the lower cumulus portion of a Triassic ophiolite. Subsequent work by Nokleberg and his colleagues (1981) suggest that the mafic-ultramafic rocks together with adjoining belts of Nikolai Greenstone represent rift-type magmatism along a Triassic spreading center. Farther to the east, near Slate Creek, Matteson (1973) has documented several small bodies of Cretaceous (122 Ma) biotite-hornblende pyroxenite, hornblendite, and gabbro, that intrude Upper Jurassic and Lower Cretaceous Mentasta Argillite (Richter, 1967).

In the eastern Alaska Range (locality 23 on Fig. 1; Richter, 1976), at least five alpine-type ultramafic bodies, chiefly serpentinite, serpentinitized peridotite, and dunite, are scattered north of the Denali fault from the Canadian border to Mentasta Pass. The largest, near Mentasta Pass, is a thin body about 12 km long in Devonian phyllite. One of the bodies apparently intrudes a Cretaceous and Tertiary conglomerate, and on this basis Richter (1976) has assigned these bodies to the Cretaceous. A nearby body of serpentinitized peridotite and dunite in the Carden Hills is associated with gabbro and anorthosite in a metamorphosed Paleozoic volcanic-

volcaniclastic sequence and has been assigned a probable Paleozoic age by Richter (1976)

Baranof-Chugach-Kodiak belt

A belt of ultramafic and related mafic complexes extends for more than 1,600 km in an arc from southern Baranof Island, along the north and west sides of the Chugach Range and then southwestward to Kodiak Island. The belt is generally coincident with the Border Ranges fault, a major structure along the northern side of the Chugach terrane that can be traced from northern Baranof Island to Kodiak Island. Between Tonsina and Kodiak Island, where most of mafic-ultramafic complexes occur, the Border Ranges fault generally separates the subduction complexes of the Chugach terrane on the south and east from the island arc assemblages of the Peninsular terrane to the north and west. The subduction complexes of the Chugach terrane include the Jurassic and Cretaceous McHugh complex of the northern Chugach Mountains (Clark, 1973; Winkler and others, 1981; Plafker and others, 1985); the Cretaceous Seldovia Bay complex of the southern Kenai Peninsula (Cowan and Boss, 1978); and the Cretaceous Uyak complex of Kodiak Island (Connelly, 1978). These complexes are heterogeneous assemblages of deformed and fragmented, weakly metamorphosed argillite, graywacke, radiolarian (meta)chert, greenstone, and local marble and tuff. They include rocks of diverse ages from Triassic to Cretaceous, but their age of emplacement is generally considered to be Cretaceous--probably slightly older than, but possibly partly contemporaneous with, the Late Cretaceous accretionary flysch that makes up most of the Chugach terrane. A series of thrust faults generally emplace the subduction complexes onto the Late Cretaceous flysch. In the Peninsular terrane a volcanic arc is represented by the Lower Jurassic Talkeetna Formation, which consists of andesite, andesitic tuff, basalt and volcaniclastic sedimentary rocks and is extensively exposed just north of the Border Ranges fault from at least Tonsina to the southern Kenai Peninsula. The Talkeetna Formation's Jurassic calc-alkaline plutonic equivalents are well documented on Kodiak Island (Kodiak-Kenai belt of Hudson, 1983) and from Tonsina southeastward to Baranof Island (Hudson's Tonsina-Chichagof belt); Hudson also indicated that the belts are probably continuous along the northern flank of the Chugach Range, where several Jurassic intermediate-composition plutons are known (Clark, 1971a, b; Magoon and others, 1976; Winkler and others, 1981; Pessel and others, 1981; Burns and others, 1983; Little and others, in preparation; and Pavlis, in preparation).

The mafic-ultramafic complexes, which are distributed along the Border Ranges fault between Tonsina and Kodiak were generally thought to be remnants of oceanic crust that formed the basement of the subduction complexes of the Chugach terrane (Beyer, 1980; Toth, 1981). However, recent investigations (Winkler and others, 1981; Pessel and others, 1981; Burns and others, 1983; Burns, 1985) suggest that they have arc affinities and are more closely associated with the Peninsular terrane. Several mafic-ultramafic complexes lie within the subduction complexes of the Chugach terrane but their emplacement in that terrane is thought to be the result of Cretaceous and Tertiary tectonics (Burns, oral commun., 1986).

Near Tonsina, an ultramafic complex about 3 km by 20 km in outcrop extent is composed of layered dunite, harzburgitic dunite, wehrlite, websterite, and clinopyroxenite and occurs in a fault block along with Jurassic (about 175 Ma) layered gabbro and leucogabbro (locality 25 on Fig. 1; Hoffman, 1974; Winkler and

others, 1981, Coleman and Burns, 1985). Several smaller ultramafic bodies, including serpentinite, pyroxenite, and peridotite, are scattered for about 100 km east of Tonsina (Metz, 1975; MacKevett, 1978; MacKevett and Plafker, 1974; Herreid, 1970). Various ages ranging from Pennsylvanian to Jurassic have been suggested for these bodies, but most of them are fault-bounded, and their proposed ages are largely inferred. Page and others (1986) suggest that the ultramafic portion of the Tonsina complex may be part of a late Paleozoic arc upon which the Jurassic Talkeetna arc and associated plutonic rocks are superposed. Burns (1983, 1985), on the other hand, has suggested that some of the ultramafic rocks in the Tonsina complex are mantle rocks and thus may be older basement on which the Jurassic arc was built.

Near the Tonsina ultramafic complex, an extensive and probably cogenetic Jurassic (153 to 171 Ma) layered gabbro body is exposed along the foothills of the Chugach Range. It extends discontinuously westward to the Jurassic Wolverine complex, a body of layered dunite, clinopyroxenite, gabbro, and peridotite that crops out for a distance of about 8 km near Palmer (locality 26 on Fig. 1; Clark, 1972; Burns, 1985). About 30 km southwest of Wolverine, near Anchorage, the Eklutna complex, which is mainly weakly serpentinitized wehrlite, dunite and pyroxenite, occurs in an elongate, fault-bounded body about 3 km by 15 km in areal extent between a metamorphic complex to the northwest and the McHugh Complex to the southeast (locality 27 on Fig. 1; G.L. Winkler, unpublished map, 1987; Rose, 1966; Clark and Bartsch, 1971a,b).

Several ultramafic bodies have long been known near Seldovia at the southern tip of the Kenai Peninsula (Guild, 1942; Toth, 1981). Red Mountain--the largest of these bodies--is a roughly oval area of layered dunite and clinopyroxenite (wehrlite) about 7 km in length. The body is faulted into the Cretaceous melange of the Seldovia Bay complex along a nearly vertical shear of serpentinite (locality 28 on Fig. 1), between the Border Ranges fault and a prominent thrust fault that forms the eastern limit of the Seldovia Bay complex (Cowan and Boss, 1978; Magoon and others, 1976). Toth (1981) suggests that the Red Mountain body formed at an oceanic spreading center as part of an ophiolite sequence in a Late Cretaceous episode of subduction. More recently Burns (1983, 1985) argued that the Red Mountain body formed in an island arc as a cumulate counterpart of volcanic rocks. In addition to the well-known ultramafic bodies in the Seldovia Bay complex, Forbes and Lanphere (1973) have identified serpentinite and associated chert and pillow basalt at the southeast side of a narrow fault block of quartz-sericite schist, marble, greenschist, and blueschist--the Seldovia schist terrane of Cowan and Boss (1978). They have dated the metamorphism within the Seldovia schist terrane as Late Triassic to Early Jurassic (about 190 Ma) and connect the event to an ophiolite-related subduction zone.

Several ultramafic bodies occur on western Kodiak Island near the Border Ranges fault (locality 29 on Fig. 1). The ultramafic rocks, mainly dunite, ortho- and clinopyroxenite, and gabbro (Hill and Brandon, 1976) occur as kilometer-size "slabs" in the Uyak complex, a chaotic assemblage of chert, argillite, wacke, and greenstone (Connelly, 1978). The Uyak complex is thrust to the southeast over Upper Cretaceous turbidites of the Kodiak Formation. Connelly (1978) interpreted the Uyak complex and the ultramafic blocks within it as a subduction complex of probable Late Cretaceous age. Hill and Brandon (1976) suggested that the ultramafic rocks may represent the lower portion of a dismembered ophiolite; Burns (1983, 1985) interpreted the ultramafic bodies as a part of the Peninsular terrane that represents a portion of an island arc ophiolite.

At the southeastern end of the Baranof-Chugach Kodiak belt on Baranof Island, several small serpentinite bodies ("tectonic inclusions") occur in metamorphosed phyllitic rocks of the Kelp Bay Group (locality 24 on Fig. 1; Loney and others, 1975). The association of these serpentinites with the greenstone, radiolarian metachert, phyllite, amphibolite, and metagabbro of the Kelp Bay Group suggests that they may represent part of an ophiolite assemblage (Berg and Jones, 1974). The nearby dunite-clinopyroxenite body at Red Bluff Bay (locality 40 on Fig. 1; Guild and Balsley, 1942; Loney and others, 1975)--sometimes grouped with the zoned ultramafic complexes--is probably best included with the serpentinites on Baranof Island (Irvine, 1974). Although it is larger than the serpentinite bodies, the Red Bluff Bay body is similarly bounded by faults and is associated with phyllonite and greenschist of the Kelp Bay Group.

Prince William Sound

Ophiolites are exposed over extensive areas on the Resurrection Peninsula and on Knight Island in Prince William Sound (localities 30 and 31 on Fig. 1). The complex on the Resurrection Peninsula near Seward consists of pillow basalt, a thick sequence of basaltic sheeted dikes and gabbro, and serpentinitized ultramafic rocks that include clinopyroxenite, dunite, and harzburgite in a composite body about 8 km wide by 27 km long (Miller, 1984; Tysdal and others, 1977). The Resurrection Peninsula complex is faulted into Upper Cretaceous flysch and interbedded volcanic rocks of the Valdez Group in the Chugach terrane (Miller, 1984). The complex on Knight Island is strikingly similar to the one on Resurrection Peninsula and consists mainly of gabbro and pods of ultramafic rocks associated with a basalt sheeted-dike sequence. However, the Knight Island complex, which is exposed over an area about 13 km in width and 34 km in length, is interbedded with lower Tertiary Orca Group flysch of the Prince William terrane. Both complexes lack only basal tectonized peridotite and associated deep marine sediments to be complete ophiolite sequences. The relationship of the two complexes to each other is ambiguous. Miller (1984), in agreement with Tysdal and others (1977), assigned a Cretaceous age to the Resurrection Peninsula complex and a Tertiary age to the Knight Island complex but noted that the similar petrology suggests a similar origin.

SOUTHEASTERN ALASKA

A narrow belt of distinctive ultramafic bodies, variously called Alaska-type or (concentrically) zoned ultramafic complexes, extends for about 560 km along the length of southeastern Alaska, southwest of the Coast Range batholith. At least 35 such bodies occur (Taylor, 1967); the best known are on Duke Island (locality 32 on Fig. 1; Irvine, 1974), at Union Bay (locality 33; Ruckmick and Noble, 1959), on the Blashke Islands (locality 34; Himmelberg and others, 1986), at Snettisham (locality 35; Thorne and Wells, 1956), and near Klukwan (locality 36; MacKevett and others, 1974). Several similar bodies are known elsewhere in the Americas, and an analogous belt occurs in the Ural Mountains of the U.S.S.R. (Taylor, 1967). The bodies in southeastern Alaska, however, are unique in their consistent petrology, chemistry, textures, and structures--especially remarkable because they are so scattered along the belt and are relatively small. Duke Island, the largest, is about 18 km in maximum outcrop dimension. Several of the bodies are concentrically zoned and have dunite cores; cumulus textures are common, notably at Duke Island, where sedimentary layering and structures are spectacularly displayed (Irvine, 1974). Where the

complete zoned sequence is present, the complexes consist of cores of dunite surrounded by concentric shells of olivine pyroxenite, magnetite pyroxenite, and hornblende pyroxenite. Only partial sequences are exposed in most of the complexes, however, and shells commonly are discontinuous. Most of the bodies intrude gabbro. Lanphere and Eberlein (1966) have isotopically dated several of these ultramafic complexes by K-Ar methods as 100 to 110 Ma.

The pyroxene in the ultramafic rocks of the zoned bodies is consistently high-alumina diopsidic augite. Orthopyroxene and plagioclase do not occur in most of the complexes and occur only rarely in the Blashke Islands complex (Himmelberg and others, 1986). The olivine is highly magnesian. Magnetite is common, and magnetite deposits in the pyroxenite at Snettisham and Klukwan have been explored for commercial amounts of iron. Minor to trace amounts of chromite are ubiquitous in the dunite as disseminated grains, scattered lenses, and pods.

Two hypotheses have been proposed for the origin of these bodies. An earlier hypothesis, cited in numerous publications but put forth in detail by Taylor (1967), is that the complexes were formed from a fractionating series of increasingly ultramafic magmas, each of which intruded its precursor to form the zonal pattern. Taylor further suggested that the magmas may be derived by fusion within the mantle--the lowest-melting-temperature fraction developing first. Alternatively, Irvine (1974), in his detailed study of the complex at Duke Island, suggested that the various ultramafic rock types developed from one magma by differentiation and precipitation of cumulus minerals in a single magma chamber. The zonal pattern is due to subsequent diapiric remobilization of the layered complex in response to regional compression. Irvine also concluded that the ultramafic rocks crystallized from a single alkaline picritic magma, and he and others (Berg and others, 1972; Irvine, 1973; Ford and Brew, 1976) suggested that the zoned complexes are related to a coeval, generally coincident belt of Cretaceous alkaline volcanic rocks. Himmelberg and others (1986), on the other hand, present evidence that the Blashke Island body crystallized from a subalkaline magma.

Whatever the origin of these unusual bodies, the consistency of their petrology and chemistry argues for a non-continental source for their parent magma(s), especially in view of the heterogeneity of the crust in southeastern Alaska. The most likely source is the mantle or, as indicated by Rb-Sr isotope data (Lanphere, 1968), the oceanic crust. Berg and others (1972) suggested that these complexes were emplaced during continental accretion and subduction in southeastern Alaska. Alternatively, Gehrels and Berg (in preparation) propose that the zoned plutons may be related to a post-accretional tensional event. Although many workers believe that Cretaceous continental accretion played an important role in generating or localizing these bodies, the Cretaceous geology of southeastern Alaska suggests a more complicated tectonic history. For example, the region contains 1) belts of 74 to 84 Ma calc-alkaline granodiorite, quartz diorite, and diorite plutons (Brew and Morrell, 1983), 2) the 55 to 65 Ma Coast plutonic complex (tonalite) sill belt just to the east of the belt of zoned ultramafic complexes, and 3) a belt of Upper Jurassic to mid-Cretaceous flysch and basaltic andesite that is nearly coincident with the belt of zoned ultramafic complexes (Berg and others, 1972).

In addition to the zoned ultramafic complexes, numerous other ultramafic bodies occur along the axial and eastern portions of southeastern Alaska. Grybeck and others (1976) and Brew and Grybeck (1984) described numerous ultramafic bodies scattered through the Coast Range batholith in the vicinity of Tracy and Endicott Arms. All of these bodies are only a few tens of meters in maximum

dimension and most are strongly foliated. They have a diverse lithology including dunite, pyroxenite, peridotite, and abundant serpentinite. The bodies occur in several forms--as inclusions within the plutonic rocks of the Coast Range batholith, as fault blocks and slivers within the schist and gneiss roof pendants of the Coast Range batholith, and as intrafolial layers in the schist and gneiss. Several clearly predate the intrusion of the plutonic rocks of the Coast Range batholith; most appear to have undergone the same metamorphism that produced the schist and gneiss within the Coast Range batholith. The origin of these dismembered ultramafic bodies is obscure and possibly diverse. Their variety and distribution suggest that the protoliths of the Coast Range batholith were structurally and tectonically complex.

Numerous small ultramafic, hornblendite, and related(?) gabbro bodies occur along, or just west of the belt of zoned ultramafic complexes (Buddington and Chapin, 1929; Brew and Morrell, 1983). Some of them may be related to the zoned complexes, and others are probably mafic phases of larger intermediate plutons. Elsewhere in southeastern Alaska, an Ordovician (440 to 449 Ma) gabbro, pyroxenite, and hornblendite stock near southern Prince of Wales Island has been reported by Eberlein and others (1983), and on northern Admiralty Island serpentinite bodies have been described by Berg and Jones (1974), who interpret them to be remnants of a dismembered upper Paleozoic or Mesozoic ophiolite suite.

A belt of distinctive Tertiary mafic(-ultramafic) plutons extends from northern Chichagof Island northward through the Fairweather Range. The best known pluton in this belt is the layered gabbro body at Mt. La Perouse and Mt. Crillon (locality 37 on Fig. 1; Rossman, 1963; Brew and others, 1978; Himmelberg and Loney, 1981; Loney and Himmelberg, 1983). At least 6,000 m of layered olivine gabbro and norite, lesser amounts of gabbronorite and troctolite, and rare anorthosite are spectacularly exposed, although nearly inaccessible, in the extremely mountainous terrane. The gabbro includes sparse thin layers of ultramafic rocks and a basal cumulus ultramafic zone containing deposits of Cu, Ni, and Pt-group elements. The gabbro is a layered stratiform body formed in a single magma chamber by differentiation and cumulus processes. Himmelberg and Loney (1981) concluded that the unusually consistent composition of the body throughout its stratigraphic range resulted from repeated injections of similar magma during its cooling history. The body has a pronounced contact-metamorphic zone, in which the low-grade country rocks are upgraded to amphibolite and biotite schist. Hudson and Plafker (1981) bracketed the age of the gabbro between 19 Ma and 41 Ma (with a probable age of 40 Ma) by K-Ar dating metamorphic minerals in the contact aureole; Loney and Himmelberg (1983) determined a K-Ar age of 28 Ma on minerals from the gabbro. Several other bodies of layered gabbro occur near the La Perouse body and as far north as Mt. Fairweather (locality 38; Brew and others, 1978; Plafker and MacKevett, 1970). Tertiary gabbro or norite bodies, at least one of which is layered, and associated tonalite plutons that occur on Yakobi Island (locality 39) and on the northern Chichagof Island probably are related to the layered gabbro pluton near Mt. La Perouse (Loney and others, 1975; Johnson and Karl, 1985; Rossman, 1959).

SUMMARY

The mafic-ultramafic complexes of Alaska are divided in four groups on the basis of their geologic setting and tectonic history: (1) The large mafic-ultramafic complexes of northern and western Alaska are remnants of huge allochthonous sheets of oceanic and mantle rocks that overrode or were "obducted" onto the continental margin in Late Jurassic and Early Cretaceous time. These complexes

together with underlying allochthonous sheets of pillow basalt, gabbro, and chert comprise broad synformal masses or monoclinial slabs resting in thrust contact upon early Mesozoic and older continental and continental margin deposits. (2) In the Alaska Range of central Alaska, the complexes are typically narrow elongate bodies aligned along or near suture zones bounding diverse allochthonous terranes. The structural setting and common association with flyschoid deposits suggest that they represent fragments of former ocean basins that collapsed during accretion. (3) In the Baranof-Chugach-Kodiak belt of southern Alaska the mafic-ultramafic bodies are closely associated with subduction complexes along the Border Ranges fault and are bounded on the south by the Upper Cretaceous accretionary flysch of the Chugach terrane. Emplacement of these mafic-ultramafic bodies is generally attributed to subduction of the oceanic crust along the continental margin in Cretaceous time. (4) The concentrically zoned bodies of southeastern Alaska clearly are intrusive and therefore unlike the mafic-ultramafic complexes of the other three groups, most of which are bounded by faults. However, their Cretaceous age, their homogeneity of composition, and their parallelism with terrane boundaries for a distance of about 560 km strongly argue for a genetic relationship with subduction and (or) accretion.

The bulk of Alaska's ultramafic complexes appear to occur at the structural base of an adjacent volcanic arc terrane (western Brooks Range, Angayucham, and Tozitna-Innoko with the Koyukuk arc terrane; southwestern Alaska with the Togiak arc terrane; and the Baranof-Chugach-Kodiak belt with Peninsular arc terrane). These relationships apparently resulted from the underthrusting of isostatically buoyant crust beneath the forearc limb of an adjacent volcanic arc terrane (a thick pile of continentally derived sediments beneath the Baranof-Chugach-Kodiak belt, and Paleozoic or older continental crust beneath the others). The other ultramafic-mafic complexes (Salcha-Seventymile, Livengood, Alaska Range, Prince William Sound, and in the Coast Range batholith) are either too complex or too poorly understood to speculate on their tectonic setting.

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FIGURE CAPTION

Figure 1 Lithotectonic terrane map of Alaska showing locations of mafic and ultramafic complexes. Terrane map modified from Jones and others (1987) and W. Nokleberg (written commun., 1989)