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OPHIOLITIC COMPLEXES AND ASSOCIATED ROCKS NEAR THE BORDER RANGES FAULT ZONE, SOUTH CENTRAL ALASKA

by

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INTRODUCTION

The table and text were compiled as part of a comprehensive study of the ophiolitic terranes of Alaska and the northeastern USSR. The study is a cooperative project between the U.S. Geological Survey, Alaska Division of Geological and Geophysical Surveys, and the Far East Branch of the USSR Academy of Sciences. Preliminary results of these investigations are being placed on open file in a folio composed of a series of separately authored reports. It is intended that this report be used in conjunction with OF-92-20A, Geologic map of ophiolitic and associated volcanic arc and metamorphic terranes of Alaska by Patton and others (1992). For information on location and regional geologic setting of the ophiolitic complexes near the Border Ranges fault zone of southcentral Alaska and for definition of the term ophiolite the reader should consult that report.

This present report summarizes geologic and geochemical information about ophiolitic and associated rocks in the northern and western Chugach Mountains, southcentral Alaska. Plate 1 includes a composite lithologic column representing the major geologic units in the ophiolite and summary geochemical plots for the ophiolite and associated island arc volcanic rocks. Brief sources for the data are given on Plate 1, and complete references are given at the end of the text. The text briefly summarizes the field relationships and important geochemical characteristics of the ophiolite belt.

The ophiolitic terrane near the Border Ranges fault includes island arc volcanic rocks and a belt of mafic and ultramafic plutonic rocks of the Peninsular terrane (plate 1, col. G, fig. 9). The belt of ophiolitic rocks referred to in this paper is a subset of the terrane and is a long (> 1000 km), narrow (2-10 km) discontinuous zone of mafic and ultramafic plutonic rocks (plate 1, col. G, figs. 9, 10). The belt is exposed within the Border Ranges fault zone, and in general is in fault contact with the Chugach terrane on the south and Peninsular terrane on the north. The Chugach terrane is composed of a subduction complex (McHugh Complex) of dominantly Cretaceous and Jurassic age, and an accretionary flysch wedge (Valdez Group; Winkler and others, 1981) of Cretaceous age. The Peninsular terrane is composed in large part of the volcanic and sedimentary rocks of an Early Jurassic-Late Triassic(?) island arc. The ophiolitic belt, referred to elsewhere as the Border Ranges Ultramafic/Mafic Complex (BRUMC; Burns, 1985), has been interpreted to be the cumulate fractionates of the Jurassic island arc volcanic rocks and part of the Peninsular terrane.

The cross-section (plate 1, col. G, fig. 11) illustrates the emplacement history of the ophiolitic belt. The magmatic arc ceased activity during middle Jurassic time; sediments were shed to the south near the area of the Border Ranges fault. Renewed plate convergence during Cretaceous time is thought to have caused underthrusting of part of the McHugh Complex beneath the Peninsular terrane. Remnant northward dipping thrust faults, with zones of extensive deformation 2 km wide are common within the Chugach and Peninsular terranes, and locally are present between the Chugach and Peninsular terranes (Burns and others, 1991). During this thrusting event, the southern edge of the Peninsular terrane tilted to the north.

In response to the thrusting, a dense network of near-vertical faults formed, and represent dominantly south side-up, right-lateral displacement (Pavlis, 1982b). This fault system is at least 20 km wide in places and trends along the oroclinal bend of the Chugach Mountains. These faults currently separate almost all lithologic units. Only small segments of intrusive or depositional contacts are observed in the northern Chugach Mountains. Some reactivation along these near-vertical faults has occurred in Tertiary time (Little, 1988; Little and Naeser; 1989). The result of the tectonic movements in the Chugach Mountains is clear exposure of all segments of the Jurassic arc.

PENINSULAR TERRANE

The regional stratigraphy within the southern and southeastern edges of the Peninsular terrane consists of a Jurassic ophiolite and its associated arc volcanic rocks and metamorphic rocks. The various parts have been tectonically dismembered, however, so that no complete sequence is exposed. The composite stratigraphy of the ophiolite consists of, from south to north: 1) minor tectonized harzburgite (interpreted as residual mantle), 2) ultramafic cumulates, 3) gabbronorites, 4) plutonic dike complexes, and 5) thick sequences of andesitic volcanic rocks. Quartz diorite and tonalite intrude both the gabbroic rocks and the andesitic volcanic rocks as dikes and plutons. The gabbroic rocks, quartz diorites, and possibly the cumulate ultramafic rocks intrude metavolcanic and minor metasedimentary rocks, which may represent a subduction complex (Pavlis, 1982a) or part of an old island arc terrane. Field relationships and geochemical data indicate that the mafic and ultramafic rocks are probably genetically related (Newberry and others, 1986); field relationships also indicate that the intermediate-composition plutonic rocks are, in part, contemporaneous with the mafic-ultramafic rocks (Burns, 1985, in press).

OPHIOLITIC ROCKS

Ultramafic rocks:

Minor amounts of harzburgitic dunite, harzburgite, and dunite are present in the southern portions of the Tonsina and the Wolverine complexes (plate 1, col. G, fig. 10). Only small slivers of these rocks are present at the Wolverine complex, and were extensively deformed in accretionary and post-accretionary processes. The rocks in both places have the elongated pyroxene and chromite grains characteristic of mantle rocks. Dikes composed of websterite, orthopyroxenite, and clinopyroxenite are common.

The Eklutna and Red Mountain bodies (plate 1, col. G, fig. 10) are thick cumulate ultramafic complexes (> 1.5 km), and are composed of dunite and chromite-bearing dunite which contain gradually more layers of wehrlite and clinopyroxenite towards the top of the section. At the Eklutna complex, websterite and orthopyroxene-bearing clinopyroxenite layers occur slightly lower than layers containing very calcic plagioclase. In parts of the section that are evolved enough to contain plagioclase, olivine is very rare.

The cumulate ultramafic (intrusive) rocks of the Tonsina complex consist of dunite, clinopyroxenite and websterite. Details of the relationships between these bodies have not been studied.

The Wolverine body contains thin layers (fault slices?) of dunite, clinopyroxenite, wehrlite, altered gabbronorite in an extremely faulted, tectonized, and snow-covered region (Newberry, 1986; Burns and others, 1991).

In dunite, chromite is present most commonly in discontinuous, wispy lenses forming "stringer zones" 1 to 10 m wide. Strike length of most zones range from 10 to 70 m. The largest chromite concentrations are found on Red Mountain on the Kenai Peninsula south of Seldovia. Chromite on Red Mountain occurs as massive layers about 1 m wide and as stringer zones up to 25 m wide with a strike length of over 800 m (Foley and Barker, 1985). Mining of chromite occurred at Red Mountain and other small bodies on the Kenai Peninsula sporadically between 1917 and 1957 (Foley and Barker, 1985). Chromite throughout the ophiolitic belt exhibit high Cr/(Cr+Al) ratios (plate 1, col. F, fig. 8), typical of the composition found in arc complexes, described by Dick and Bullen (1984) as Type III alpine-peridotites .

Cumulate ultramafic rocks in the ophiolitic belt are MgO-enriched. The olivine composition typically ranges from Fo_{95} to Fo_{80}; most olivine has a forsterite content greater than Fo_{88}. Clinopyroxene in dunites, wehrlites, and clinopyroxenites usually ranges from $Mg^{\#}88$ to $Mg^{\#}94$, where $Mg^{\#}$ = molecular $Mg/(Mg+Fe+Mn)$.

The differentiation trend of the ultramafic rocks shown on a $MgO-Al_2O_3-CaO$ diagram (plate 1, col. F, fig. 5) indicates that much ultramafic material crystallized before the initiation of plagioclase crystallization. This type of crystallization, where Mg#s are enriched and plagioclase crystallization is delayed, can be produced with combinations of moderate pressure and/or slight to moderate water content in the magma (Green and Ringwood, 1967; Irvine, 1973; Elthon and others, 1982), a situation presumably common in island arcs but not in mid-ocean ridge magma chambers. One small intrusion within the Kodiak island body (plate 1, number 4 on fig. 5) lies on the typical trend of a shallow level crystallization process, where plagioclase crystallizes early (data taken from Beyer, 1980). However, all other data suggests the major trend of crystallization of the ophiolitic belt follows the path marked "deeper"; the intrusion associated with number 4 is discussed below in the section on gabbroic rocks.

This high-pressure differentiation trend is also reflected in the Al_2O_3 contents in clinopyroxene (plate 1, col. F, fig. 6). As the clinopyroxene becomes more iron-rich in the cumulate ultramafic rocks, the aluminum content gradually increases until the Al_2O_3 ranges from 6 to 8 wt. percent in the ultramafic rocks. This aluminum content is not typical of shallow level crystallization, which displays lower, fairly steady aluminum values in the pyroxenes (contrast Skaergaard trend shown on plate 1, col. F, fig. 6). As very calcic plagioclase begins to crystallize in the ophiolitic bodies, the aluminum content of the pyroxene drops.

Gabbroic rocks:

Gabbroic bodies in the ophiolitic belt are greater than 4 km thick and are composed of gabbronorites, magnetite gabbronorites, and leucogabbronorites. Structural complications restrict accurate size estimates of gabbroic bodies. Lowermost portions contain an a pervasive foliation probably caused by *in situ* crystal growth, and by moderate to high pressure conditions during crystallization. The gabbroic rocks interpreted to represent the upper portions of the gabbroic bodies are isotropic in texture.

Summary plots of major oxide compositions of the gabbroic rocks are shown on plate 1, col. F. The gabbroic rocks follow AFM trends typical of magmatic arcs, and also have the correspondingly low TiO_2 values (plate 1, col. F, figs. 3 and 4). The more mafic gabbroic rocks have SiO_2 near 46 wt. percent and very low TiO_2 (0.6-0.14 wt. percent). The more evolved, Fe-enriched gabbroic rocks contain 39-43 wt. percent SiO_2 and 0.54-1.51 wt. percent TiO_2, owing to abundant magnetite.

Another important characteristic of the gabbroic rocks is the compositions of the coexisting pyroxenes and plagioclase. Relatively iron-enriched pyroxenes (e.g., En_{70}) are paired with calcic plagioclase (e.g. An_{90}), a situation characteristic of moderate to high pressures, like those of arc plutonic rocks (plate 1, col. F, fig. 7). Low pressure tholeiitic differentiation trends, which include Skaergaard data and a trend derived from published analyses of gabbroic inclusions in oceanic basalts, clearly contrast with the differentiation trend of the high pressure calc-alkaline trend. The calc-alkaline trend was determined from published analyses of gabbroic rocks in island arc volcanic rocks. Differentiation trends produced by tholeiitic magma crystallizing at high pressure and calc-alkaline magmas crystallizing at low pressures should lie between the trends shown.

Al_2O_3 contents in the clinopyroxene crystals in the gabbroic rocks range from 2 to 4.5 wt. percent , which is significantly less than the highest values in the ultramafic rocks (plate 1, col. F, fig. 6). These Al_2O_3 contents reflect the crystallization of abundant aluminum-rich plagioclase in the gabbroic rocks.

One very small body of feldspathic wehrlite present among the gabbronorites at Kodiak Island is atypical for the ophiolitic belt (plate 1, number 4 on fig. 5; Beyer, 1980). These rocks are dominated by clinopyroxene and plagioclase, and the three analyses given in Beyer (1980) are compositionally distinct from the other gabbroic rocks. The feldspathic wehrlites have MgO contents of 20 wt. percent, which is similar to the clinopyroxenites in the area. The wehrlites have higher Al_2O_3 contents (5-13 wt. percent) than the clinopyroxenites (< 4 wt. percent). CaO is low in the wehrlites (8 to 11 wt. percent), and higher in the clinopyroxenites (14 - 23 wt. percent). SiO_2 values in the wehrlites range from 36 to 43 wt. percent, like that in dunites. TiO_2 values range from 0.01 - 0.07. These chemical characteristics suggest that the feldspathic wehrlites may be a small, late intrusion that crystallized at shallower pressure than the rest of the ophiolitic belt.

Plutonic dike complexes:

The plutonic dike complexes generally crop out in areas of very rugged topography. The dike complexes consist of multiple intrusions of gabbronorite, hornblende gabbro, and quartz diorite. Up to 6 different sets of intrusions have been identified in one dike complex (Burns, 1983; in press). Intrusions progress from multiple, narrow dikes of fine-grained gabbronorite to progressively wider dikes composed of coarser-grained gabbronorite. Intrusions become progressively more silicic with time, and culminate with intrusions of quartz diorite and tonalite. Ductile deformation textures indicate quartz diorite intruded while the gabbroic rocks were not totally crystallized.

Compositional plots of analyses from the dike complexes indicate that the gabbroic rocks are similar to the other gabbroic rocks in the belt, and that the quartz diorite-tonalite suite is typical of those in arcs (plate 1, col. F, figs. 3, 4, and 5). Specifically, as SiO_2 contents of rocks in the dike complex rise from about 44 to 67 wt. percent, corresponding Al_2O_3 contents drop from 20 to 15 wt. percent, MgO contents drop from 9 to about 1.5 wt. percent, and CaO contents decrease from 10 to 4 wt. percent. TiO_2 in the plutonic dike complex decreases with differentiation from the typical high around 1.5 wt. percent in some early gabbroic rocks to about 0.6 to 0.4 wt. percent in quartz diorites.

Island arc volcanic rocks:

The Talkeetna Formation consists dominantly of flows and tuffs of andesitic composition; only minor amounts of basaltic rocks are exposed. Fossils near the top of the sequence are Early Jurassic in age (Imlay and Detterman, 1973; Detterman and Reed, 1980). These rocks have been interpreted as erupting in an intraoceanic island arc by many workers (for example, Barker and Grantz, 1982). Up to about 6.5 km of volcanic rock is exposed in the central part of the northern Chugach Mountains. The base of the Talkeetna Formation is not clearly observed, due to abundant intrusions of Jurassic quartz diorite and younger rocks, and Cretaceous-Tertiary age faulting. Most of the volcanic rocks are deformed and have been subjected to greenschist facies metamorphism. The most common phenocryst in the volcanic rocks is oscillatory-zoned plagioclase. Both orthopyroxene and clinopyroxene are present as phenocrysts and in the groundmass in less-altered rocks. Orthopyroxene is generally more abundant than clinopyroxene. Magnetite commonly forms 2 - 5 modal percent of the andesites. Hornblende phenocrysts have been noted in only a few of the Talkeetna andesites, and olivine is also rare.

Twenty-three major-oxide analyses of relatively unaltered Talkeetna Formation volcanic rocks are available (Burns and others, 1991; plate 1, col. F). SiO_2 ranges from 48 to 77 wt. percent, while Al_2O_3 drops from 19 to 11 wt. percent, MgO drops from 7 to 1 wt. percent, and CaO similarly drops from 7 to 3 wt. percent. K_2O rises from < 0.5 wt. percent for $SiO_2 < 60$ wt. percent to 2.0 wt. percent at a SiO_2 value of 77 wt. percent. TiO_2 is typically between 0.7 and 1 wt. percent for $SiO_2 < 55$ wt. percent, and decreases to about 0.4 wt. percent at a SiO_2 value of 70 wt. percent. The volcanic rocks fit in the low titanium, island-arc tholeiite field of Hawkins and Evans (1983) (plate 1, col. F, fig. 2).

METAMORPHIC ROCKS

The oldest rocks in the area are amphibolite and schist, with minor amounts of marble. These metamorphic rocks are interpreted to be metamorphosed mafic volcanic rock, chert, siltstone, mudstone, and argillaceous limestone, and are shown as inclusions in the gabbroic rocks on plate 1, column A. The only age on the metamorphic rocks is from a marble containing Permian fusillinids near the Eklutna complex (Clark, 1972; plate 1, col. G). The metamorphic rocks crop out in discontinuous fault-bounded slices near the Border Ranges fault, and form the host rocks for the magmatic arc. The metamorphic rocks are intruded by gabbroic and intermediate composition plutonic rocks of Jurassic age and abundant trondhjemite-tonalite plutons and dikes of Cretaceous age (Pavlis, 1982b; 1983; Winkler, 1990).

The rocks vary in metamorphic grade from pyroxene and amphibole hornfels (or granulite) and amphibolite to upper greenschist facies. The metamorphism occured both because of intrusion of the gabbroic and quartz dioritic magmas, and from increasing depth as the arc formed. Some of the retrograde greenschist facies metamorphism is Cretaceous in age (Pavlis, 1983), and was probably caused by intrusion of the trondhjemite-tonalite suite.

CHUGACH TERRANE

The Chugach terrane has been divided into two major lithotectonic units: an older, melange subterrane exposed discontinuously along its northern inboard edge, and a younger, deformed flysch subterrane which constitutes the majority of the terrane in southern Alaska (Plafker and others, 1976). The older subterrane is thrust over the flysch terrane along the Eagle River thrust fault.

McHugh Complex:

The melange subterrane is known as the McHugh Complex in the Chugach Mountains (Clark, 1973) and the Uyak Formation on Kodiak Island (Connelly, 1978). The McHugh/Uyak Complex is a melange composed of blocks of various ages in a highly deformed matrix. The composition of the matrix varies from dominantly metatuff to dominantly argillite. Chaotic mixtures of light-green metatuff and dark-gray argillite are common and were formed by soft-sediment deformation and shearing of highly incompetent lithologies. Common lithologies for blocks in the McHugh/Uyak Complex include graywacke, chert, pillow basalt, marble, altered diorite, blueshist, and greenschist. The McHugh/Uyak Complex is weakly metamorphosed in the prehnite-pumpellyite or low greenschist facies.

Winkler and others (1981) found that the McHugh Complex in the Valdez Quadrangle is composed of northern, middle, and southern belts, which yield fossils of different ages. The oldest belt crops out discontinuously on the north and contains chert with Late Triassic to Early Jurassic radiolarian faunas. The central and southern belts yielded chert with Late Jurassic to Early Cretaceous, and mid-Cretaceous radiolarian faunas respectively (Winkler and others, 1981). Formation of the McHugh Complex thus may have spanned most of Jurassic and Cretaceous time.

Valdez Group:

The flysch subterrane is referred to as the Valdez Group and the Kodiak Formation and is composed largely of structurally imbricated trench-fill turbidites (Moore, 1973). The Valdez Group consists predominantly of lower-greenschist-facies metagraywacke, argillite, phyllite, and minor greenstone and conglomerate. Sparse marine megafossil collections from the Valdez Group on the Kenai Peninsula are indicative of a Late Cretaceous (Maestrichtian) depositional age (Jones and Clark, 1973).

GENETIC RELATIONSHIP OF THE OPHIOLITIC BELT TO THE ISLAND ARC VOLCANIC ROCKS OF THE PENINSULAR TERRANE

Petrologic and compositional features suggest the plutonic rocks of the ophiolitic belt cooled slowly at moderate to great depths (Burns, 1985). Some of these pressure indicators include the presence of nonzoned crystals and spinel symplectites, the absence or near absence of plagioclase in thick sequences of the ultramafic cumulate rocks, and the high aluminum contents of pyroxenes.

Characteristics of the ophiolitic belt, including moderate to high pressure crystallization, early and abundant crystallization of orthopyroxene, crystallization of abundant gabbronorite instead of gabbro or olivine gabbro, and a thick ultramafic cumulate section, present a striking case for island-arc rather than oceanic origin for the ophiolitic belt (Burns, 1985). The mineral assemblage in the gabbroic rocks and the compositions of the minerals are most similar to phenocrysts and compositions in island arc volcanic rocks, and are not similar those in mid-ocean ridge basalts . The association with nearly contemporaneous, voluminous intrusions of quartz diorite and tonalite also supports the island arc hypothesis.

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