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Ophiolitic Complexes of the Gulf of Alaska

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OPHIOLITIC COMPLEXES OF THE GULF OF ALASKA
GEOLOGIC SUMMARY

Introduction

This table and text was compiled as part of a comprehensive study of the ophiolitic terranes of Alaska started by the U.S. Geological Survey in 1988. Parts of the study were carried out in cooperation with the Alaska Division of Geological and Geophysical Surveys and the U.S. Bureau of Mines, and some data was collected in cooperation with the Far East Branch of the USSR Academy of Sciences in a collaborative study of the ophiolitic terranes of Alaska and adjoining parts of northeast USSR. 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-- A, 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 of the Gulf of Alaska and for definition of the term ophiolite the reader should consult that report.

In this report geologic and geochemical information about ophiolitic and associated rocks of the Gulf of Alaska region are shown on Plate 1. These rocks include various oceanic crust lithologies that in part comprise the Chugach and Prince William terranes. A composite lithologic column represents the major geologic units exposed between Anchorage and Prince William Sound. Summary plots of geochemical data are shown for the ophiolitic and non-ophiolitic units. Together these igneous rocks represent oceanic crust and upper mantle lithologies. The ophiolite complexes in the Orca Group are the most complete ophiolites in Alaska. Geologic maps and cross sections of two of the best exposed ophiolites in the Orca Group are shown (Resurrection Peninsula and Knight Island). These units, together with the geologic terranes in which they occur, record much of the Mesozoic accretionary history of this part of Alaska. Plate 1 summarizes much of the information available; for specific details and chemical data see the references cited.

TERRANES

Chugach terrane

The Chugach terrane is made up of two fault bounded Mesozoic belts (Jones and others, 1981). The northern belt consists of a discontinuous melange named the McHugh Complex, Seldovia Bay complex, and Uyak Formation (Clark, 1973; Cowan and Boss, 1978; Hill, 1979). The melange of the Chugach terrane is shown as the "Subduction complex of south-central Alaska (Patton and others, 1992. The southern belt consists of accreted Late Cretaceous deep-sea fan turbidites and oceanic or intraoceanic crust of the Valdez Group and Kodiak Formation (Plafker and others, 1977; Lull and Plafker, 1990). The belts extend for more than 2,000 km along the coastal margin of Alaska from southeastern Alaska on the east to near the tip of the Alaska Peninsula on the west. In southern Alaska, rocks of the Chugach terrane record intermittent accretion and deformation beginning in the Early Jurassic and continuing into the latest Cretaceous or earliest Tertiary; Tertiary accretion was accompanied by formation of one or more generations of predominantly south-verging regional structures (Nokleberg and others, 1989). The rocks are variably metamorphosed with blueschist, prehnite-pumpellyite, and greenschist to amphibolite facies present (Miller and others, 1984; Winkler and others, 1981; Winkler and Plafker, 1981). Along its northern margin the Chugach terrane is in fault contact with the Wrangellia and Peninsular terranes along the Border Ranges fault system (MacKevett and Plafker, 1974).

Prince William terrane

The Prince William terrane lies immediately to the south of the Chugach terrane and is separated from it along the Contact fault system (Winkler and Plafker, 1981; Plafker and others, 1986). The Prince William terrane extends from just east of Prince William sound to the continental shelf southwest of Kodiak Island. The only formal stratigraphic unit in the terrane is the Orca Group, an accreted Paleocene to early middle Eocene deep-sea-fan complex with ophiolites and other volcanic units (Plafker, 1969, 1971; Winkler, 1976; Nelson and others, 1985, 1989). The Orca Group is complexly folded and faulted. Geologic data indicate that the Orca Group was accreted to the Chugach terrane by 51 Ma (Plafker and others, 1989).

Fossil ages decrease to the southeast across the regional strike of units in the Chugach and Prince William terranes, from Triassic to early middle Eocene (Nelson and others, 1985, 1986, 1987; Plafker and others, 1985; Blome and others, 1990). Both the Orca and Valdez Groups are intruded by Eocene and Oligocene plutons (Plafker and Lanphere, 1974; Nelson and others, 1985).

Paleomagnetic and fossil data from the two terranes indicate that they originated to the south of their present position. Northward displacements ranging from 13 to 40 degrees have been proposed (Hillhouse and Grommé, 1977; Stone and Packer, 1979; Grommé and Hillhouse, 1981; Hillhouse and others, 1985; Plumley and Plafker, 1985; Plafker, 1987; Bol and Coe, 1987; Blome and others, 1990).

LITHOLOGIC UNITS

McHugh Complex (Subduction complex of South-Central Alaska)

Throughout southern Alaska, the melange of the McHugh Complex is composed of slabs and blocks (up to 40 km long) of various rock types such as chert, basalt, ultramafic rocks, marble, and schist. These lithologies are intermixed in a deformed argillaceous matrix. Paleontologic and radiometric ages of the slabs and blocks range in age from late Paleozoic to mid-Cretaceous (Nelson and others, 1986; 1987; Blome and others, 1990).

Several source terranes have been proposed for the slabs and blocks in the melange. Plafker (1987) suggested that the melange contains exotic blocks derived from the Wrangellia terrane (northeastern part of southern Alaska). Winkler and others (1981, 1984) suggested, based on fossil and radiometric ages, that the Peninsular terrane as well as Wrangellia were likely source areas. Some ultramafic blocks are Cretaceous or younger tectonic emplacements derived from the ophiolite complex of the Border Ranges fault zone (Burns, 1985, 1992; Debari and Coleman, 1989). Nelson and Blome (1991) found no arc geochemical signature, nor any strong chemical similarity of basalts in the McHugh Complex with basalt from the Wrangellia or Peninsular terranes. These analyses (Plate 1, column E) show that basalts from the McHugh appear most similar to mid-ocean ridge basalts (MORB) or oceanic islands (enriched-MORB).

Valdez and Orca Groups

The geology of the Prince William Sound area (Plate 1, column A) consists of two similar lithologic units, the Valdez and Orca Groups (Schrader, 1900). Both groups consist of graywacke, siltstone, and shale, with the finer grained rocks commonly displaying a slaty fabric. The Orca Group (Moffit, 1954) was thought to be somewhat less metamorphosed than the Valdez Group (probably based on the dominance of slate in the latter unit) and by the presence of mafic volcanic rocks and local conglomerate beds. These rocks are now recognized in both groups (Nelson and others, 1985).

Previously, Tysdal and Case (1979), and Winkler and Plafker (1981), described the metamorphism in both groups. Orca Group metamorphism ranged from zeolite and prehnite--pumpellyite facies to low greenschist facies and in the Valdez Group metamorphism ranged from zeolite and low greenschist facies to amphibolite facies. Later workers have recognized that metamorphic grade overlaps in the two units. Miller and others (1984) have recognized that amphibolite (or hornblende-hornfels) facies are present locally in both groups. Goldfarb and others (1986) suggest that both groups range from laumontite to amphibolite facies.

The Orca Group ophiolite complexes include those exposed on the Resurrection Peninsula, Knight Island, Glacier Island, and the pillow basalts on Copper Mountain ophiolites (Helwig and Emmet, 1981; Miller, 1984; Nelson and others, 1985, 1987, 1989--see Plate 1, fig. 12). These ophiolites are the youngest and most complete in Alaska. They consist of an upper pillow basalt unit, a sheeted dike unit, a lower layered gabbro, and minor amounts of ultramafic rock, plagiogranite, and volcanic breccia and tuff. Geophysical surveys (Case and others, 1979a,b; Barnes and Morin, 1990) show continuous gravity and aeromagnetic anomalies that suggest that Knight Island, Glacier Island, and Copper Mountain are connected.

Whole rock K/Ar dates (Plate 1, column C) reported by Miller (1984) probably represent a younger age metamorphic age. Plagiogranite from the Resurrection Peninsula has yielded a 57 Ma U/Pb date on zircon. The plagiogranite cuts the upper layered gabbro and is both intruded by and intrudes the sheeted dike unit (Nelson and others, 1989).

Non-ophiolitic mafic volcanic rocks include mixed sections of pillow basalt, massive flows, tuff and tuffaceous sedimentary rocks, flow breccia, and varying amounts of sandstone, mudstone, chert, and limestone (Nelson and others, 1985). These rocks are exposed on Hinchinbrook Island, near Cordova, and east of the Copper River and are informally named here the Outboard sequence of the Orca Group due to their outer position south of the ophiolites.

Mafic igneous rocks in the Valdez Group are predominantly greenstone and pillow basalt with less abundant sheeted dikes and gabbro. Locally lenticular bodies of chlorite schist may have originally been mafic flows or tuffs (Nelson and others, 1985). Ultramafic rocks occur within the Valdez Group near the head of Port Fidalgo (Nelson and others, 1985) and consist of serpentinized dunite and peridotite.

GEOCHEMISTRY AND TECTONIC SETTING OF THE MAFIC IGNEOUS ROCKS FROM THE PRINCE WILLIAM SOUND AREA

The mafic igneous rocks from the Prince William Sound area are divided into three sequences based on age and lithologic association: (1) a late Cretaceous Valdez Ophiolite Group sequence, (2) a lower (?) Tertiary Ophiolite sequence of the Orca Group, and (3) a younger Outboard sequence of the Orca Group. The stratigraphic and structural relation of the sequences is shown on Plate 1. Petrographic descriptions of the mafic and ultramafic rocks from the Valdez and Orca Groups are presented in Richter (1965), McGlasson (1976), and Nelson and others (1985; 1987).

Valdez Group Ophiolite Sequence

Summary plots of analyses (Nelson, unpub. data) of igneous rocks from this sequence are presented in Plate 1, column E. The mafic rocks plot as tholeiitic on an AMF diagram (fig. 5). Chondrite normalized rare earth element (REE) abundances (fig. 8) are low (<10x chondrite) with a depletion of LREE (light REE) relative to HREE (heavy REE) and a pattern similar to N-MORB (normal-mid ocean ridge basalt) or primitive basalt derived from a LREE depleted source (Wilson, 1989).

Discrimination diagrams and element ratios suggest several tectonic settings. La/Ta ranges from 18-37 (n=8), with an average of about 25, and suggests an N-MORB setting (Woods and others, 1979). Diagrams and data shown in Plate 1, Plafker and others (1989), and Lull and Plafker (1990) indicate N-MORB and N-MORB or arc tholeiite settings for the Valdez Group sequence.

The association of this sequence with a thick section of marine turbidites of the Valdez Group suggests that volcanism occurred near a continental margin and within the depositional region of deep sea fans (Budnik, 1974). The geochemical data indicate that the mafic rocks are similar to N-MORB or primitive island arc basalts. The geochemical characteristics thus appear anomalous in the absence of a general volcanic arc setting. However the mafic rocks may represent an undeveloped immature arc or contamination of a ridge basalt magma by sediment assimilation.

Orca Group Ophiolite Sequence

The three ophiolite complexes in the Orca Group are the youngest and most complete ophiolites recognized in Alaska (Nelson and others, 1989). Several field guides (Nelson and others, 1987; 1989) and other publications describe the lithologies, metamorphism, and regional setting of these ophiolite complexes (Richter, 1965; McGlasson, 1976; Tysdal and others, 1977; Nelson and others, 1985).

Geochemical analyses (Nelson unpub. data) from the Orca Group ophiolite sequence show wider chemical diversity than those of the other sequences, and so are subdivided into four groups: Group 1 includes mafic pillow basalt, sheeted dikes, and gabbro; Group 2 includes plagiogranite[1]; Group 3 includes a diorite and basaltic andesite; and Group 4 ultramafic rocks.

In the SiO_2 vs total alkalis classification of Cox and others (1979) most of the Group 1 rocks are tholeiitic basalt. The diorite and the basaltic andesite samples fall in the basaltic andesite field and the plagiogranites in the granite field. The AMF diagram (fig. 5) shows a strong cluster of most Group 1 rocks along the tholeiite/calc-alkaline field boundary. Three samples are anomalous and are either MgO-rich or FeO^* (total iron as FeO)) rich relative to the others. The diorite and basaltic andesite plot in the calc-alkaline field and the plagiogranites plot in the alkali-rich region.

REE abundances of samples from the ophiolite sequence are variable (fig. 8). Group 1 samples, representing the majority of the mafic samples from the ophiolites, show the most variation; some have relatively flat REE abundances at about 10x chondrite or 40x chondrite. Other Group 1 samples with total abundances less than about 10x chondrite are LREE depleted. Several of the Group 1 samples show relatively smooth flat patterns suggesting that partial melting of source material was extensive (Wilson, 1989). Group 2 plagiogranites show strong LREE enrichment relative to HREE and a prominent negative Eu anomaly. Group 3 samples show a more moderate LREE enrichment relative to HREE.

Plots of major- and minor-element data in discriminant diagrams (fig. 7, 9) show that Group 1 samples include a variety of geochemical types. Compositions range from calc-alkaline, low potassium arc tholeiite, to normal-MORB. Samples from Groups 2 and 3 plot in the calc-alkaline fields. The chemical variability suggests several tectonic environments and the association of both high-Ti and low-Ti values (Sun and Nesbett, 1978) of rocks from Group 1 suggest that the most likely tectonic environment for the formation of the ophiolites was a spreading center near a subduction zone.

Microprobe analyses of (fig. 10, 11) clinopyroxene and plagioclase from four samples of gabbro have mid-ocean ridge compositions (Burns 1992). The trend of differentiation (decreasing Mg number) with no increase in Al_2xO_3 is similar to the low pressure trend (fig. 10) in the Bushveld Complex and oceanic rocks (Burns, 1985). Coexisting pyroxene and plagioclase compositions are indicative of crystallization under low pressure oceanic conditions (Burns, 1985, 1992). One sample (fig. 11) does plot near high pressure calc-alkaline region, however, the sample also plots in the low pressure field on figure 10.

Orca Group Outboard Sequence

Volcanic rocks from the Outboard sequence are exposed on Hinchinbrook Island, in the Cordova area, and east of the Copper River. These rocks may be some of the youngest and last accreted rocks of the Orca Group (Plafker and others, 1985).

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[1]Could also be classified as trondhjemite. Major oxide values: SiO_2 = 74%; Al_2O_3 = 13%; CaO = 3%; Na_2O = 5%; K_2O <.1%

Detailed studies of the turbidites from Hinchinbrook Island by Winkler (1976) suggest that the Orca Group sedimentary rocks were deposited in the middle part of submarine fans. Outboard sequence volcanic rocks on Hinchinbrook Island occur in a fault bounded section within the turbidites where a 2,000m-thick measured section (Nelson and others, 1985) consists of 22% broken pillow breccia, 20% massive basalt flows, 30% pillow basalt flows, and 26% sedimentary rocks. The sedimentary rocks from this section are predominantly dark-gray shale and variously colored mudstone and subordinate limestone and fine-grained sandstone. Other measured sections from the Outboard sequence (Nelson and others, 1985) show wide variations in the percentages of igneous rocks and types of sedimentary rock.

The four samples from the outboard sequence (Plate 1, figs. 5-9) are from massive flows (Nelson, unpub. data). Dikes or mafic intrusive rocks have not been recognized in this sequence.

REE abundances show a narrow range of values (fig. 8) with LREE enrichment relative to the HREE for this sequence. The lack of any significant Eu anomaly suggests that plagioclase fractionation was not a major factor in the formation of these rocks.

Discrimination diagrams (Plate 1, fig. 7, 9) show these samples plot in several ocean crust fields: ocean floor basalt, ocean island, and enriched-MORB. An earlier interpretation based on geologic associations suggested that these rocks formed in seamounts (Tysdal and others, 1976; Winkler, 1976; and Winkler and Plafker, 1981). However, this was probably more of a geomorphic than geochemical interpretation.

The LREE-enriched pattern of the Outboard sequence (compared to the older Valdez and Orca Group ophiolite REE patterns, except plagiogranite) may reflect effects of increasing basaltic magma contamination by sediment assimilation with time, as Moore and others (1983) proposed for correlative volcanic rocks of the Ghost Rocks Formation on Kodiak Island.

Conclusions

1. Basalts from the McHugh Complex occur as blocks in melange associated with Mesozoic chert and appear chemically most similar to MORB and E-MORB or oceanic island basalt.
2. Three igneous rock sequences in the Prince William Sound area recognized on the basis of age and/or lithologic association are: a Late Cretaceous Valdez Group ophiolite sequence consisting of pillow basalt, greenstone, local sheeted dikes, and ultramafic rock; a Tertiary Orca Group ophiolite sequence consisting of several complexes with pillow basalt, sheeted dikes, layered gabbro, and ultramafic bodies; an Orca Group outboard sequence containing mixed sections of mafic volcanic rock and variable kinds of sedimentary rocks.
3. Mafic igneous rocks from the three sequences in Prince William Sound area can be distinguished by their REE abundances and on several chemical discriminant diagrams. Several tectonic environments of formation are indicated for these rocks; chemical data, along with the known geology, suggests that a likely scenario of formation would have involved spreading ridge and subduction zone interaction with possible sediment contamination of mafic magmas.
4. A present day analog for the mafic rock sequences of the Prince William Sound area is the Juan de Fuca ridge where active spreading segments of a ridge, separated by transform faults, are being subducted adjacent to an actively eroding arc.

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