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OPHIOLITIC TERRANE OF WESTERN BROOKS RANGE, ALASKA

compiled by

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INTRODUCTION

This is one of a series of open-file reports that present the results of a comprehensive study of the ophiolitic terranes of Alaska and contiguous parts of northeast Russia. The study was carried out by the U.S. Geological Survey, the Alaska Division of Geological and Geophysical Surveys, and the Far East Branch of the Academy of Sciences of the USSR between 1989 and 1991. Other reports in this series include a geologic map, a metallogenic map, and reports summarizing the lithology, thickness, age, geochemistry, and geologic setting of each of the major ophiolitic terranes in Alaska and northeast Russia. This report focuses on the ophiolitic terrane in the western Brooks Range of northern Alaska. For information on location and regional geologic setting of this and the other ophiolitic terranes of Alaska, the reader should consult OF 92-20A in this series by Patton and others (1992).

Definition of terms

The term *ophiolite*, as used in this report, follows the definitions of Steinmann (1927) and the Geological Society of America Penrose Conference on ophiolites (Penrose Field Conference, 1972). It refers to an association of mafic and ultramafic rocks that in a complete sequence is characterized from bottom to top by tectonized ultramafic rock, a transitional zone of interlayered ultramafic and mafic cumulates, layered gabbro, massive gabbro, a mafic sheeted dike complex, and pillow basalt. Most workers now regard ophiolite assemblages as allochthonous fragments of oceanic crust and upper mantle that formed along mid-ocean ridges, in small marginal basins, or as basement to island arcs. The western Brooks Range ophiolites clearly have been emplaced or "obducted" onto older continental crust and thus are characteristic of the "Tethyan-type" as defined by Moores (1982) and Coleman (1984). The geologic setting of these ophiolites contrasts with the the "Cordilleran-type" ophiolites in southern Alaska, which are structurally underlain by younger accretionary flysch deposits.

Ophiolitic terranes are defined in this report as fault-bounded belts of oceanic rocks that contain ophiolite complexes. In the western Brooks Range the boundaries of the ophiolitic terrane coincide with the Angayucham lithotectonic terrane of Jones and others (1987).

OPHIOLITIC TERRANE OF WESTERN BROOKS RANGE

The ophiolitic terrane of the western Brooks Range consists of two tectonic packages, as defined by Mayfield and others (1988): the Misheguk Mountain allochthon, a mafic-ultramafic complex typical of the lower and middle parts of an ophiolite sequence, and the Copter Peak allochthon, an assemblage of pillow basalt and chert typical of the upper part (Plate 1). Isotopic and fossil ages indicate that the two allochthons are of different ages, however, and therefore they are not parts of the same ophiolite sequence. The two allochthons are the highest of seven imbricated tectonic slices that overrode the western Brooks Range from south to north (relative to present coordinates) in Early Cretaceous time. They now are preserved in a broad arcuate belt of synformal erosional remnants that extends westward from the central Brooks Range to the Chukchi Sea, a distance of about 350 km (Patton and others, 1992). Five large mafic-ultramafic complexes of the Misheguk Mountain allochthon together with basalt and chert of the underlying Copter Peak allochthon have been mapped from east to west at Siniktanneyak Mountain, Misheguk Mountain, Asik Mountain, Avan Hills, and Iyikrok Mountain (Mayfield and others, 1988)(Plate 1, col. F). The easternmost synformal remnant, the Pupik Hills, is composed entirely of basalt and chert of the Copter Peak allochthon. The oceanic rocks of the Misheguk Mountain and Copter Peak allochthons structurally overlie an imbricated assemblage of miogeoclinal pelagic and continental platform deposits belonging chiefly to the the Ipnavik River allochthon (Plate 1).

Misheguk Mountain allochthon

At Misheguk Mountain the allochthon consists of a mantle suite of tectonized peridotite overlain by a magmatic suite of ultramafic cumulates (transitional zone), layered gabbro, and massive gabbro (Plate 1, col. A)(Harris 1989). The tectonized peridotite in the mantle suite is composed of harzburgite and minor lherzolite overlain by variably tectonized dunite. Serpentinization increases downward and, at the base of the mantle suite, the peridotites are sheared and mylonitized. The transitional zone at the base of the overlying magmatic suite is characterized by tabular dunite bodies that grade upward into mixed ultramafic and mafic cumulates and chromitites. Near the top of the transitional zone clinopyroxene-rich dunite grades into a mixed zone that contains lineated pods of wehrlite, olivine and plagioclase clinopyroxenites, olivine websterite, troctolite, chromitite, and olivine gabbro. The base of the mixed zone, according to Harris (1989), is marked by chromite-rich horizons 0.5 - 10m thick (Plate 1, col. D). The chromite occurs in stringers and veins, irregular massive layers and pods, stockwork veins, and planar and disseminated bands. At Misheguk Mountain some chromitites at the base of the mixed zone contain significant concentrations (10g/tonne) of platinum group metals. The transitional zone grades upward into a layered series composed of gabbro, olivine gabbro, gabbronorite, hornblende gabbro, and lesser amounts of olivine clinopyroxenite, wehrlite, troctolite, and anorthosite. Massive gabbro and subordinate leucocratic intrusives bodies of hornblende diorite, quartz diorite, tonalite, trondjhemite, granodiorite, and biotite granite cap the magmatic suite.

In most places massive gabbro appears to form the erosional top of the ophiolite assemblage, but in the Maiyumerak Mountains (Plate 1, col. F), Bird and others (1985) report that the massive gabbro appears to be succeeded by volcanic rocks composed of sheeted dikes of basalt, minor diorite, and rare rhyolite separated by screens of pillow basalt. The dike complex is in turn overlain by pillowed and massive basalt flows that are lithologically unlike the basalt flows in the underlying Copter Peak allochthon. Geochemical studies by Wirth and others (1987) indicate that at least some of these basalts have trace element abundances similar to island-arc basalts and are unlike the mid-ocean ridge basalt (MORB) or enriched MORB that characterizes the Copter Peak allochthon. These overlying volcanic rocks are as yet undated, but it is conceivable that they are part of the Koyukuk volcanic arc terrane and that the western Brooks Range ophiolites, as has been suggested for the Yukon-Koyukuk ophiolites (Patton and Box, 1989), formed in a volcanic arc setting.

Age Ten K-Ar analyses of hornblende mineral separates from gabbro, diorite, and hornblende pegmatite in the upper part of the Misheguk allochthon yield ages of 147 to 183 Ma and five ^{40}Ar-^{39}Ar analyses yield ages of 169 to 179 Ma (Plate 1, col. C). A comparison of 4 samples dated by both K-Ar and ^{40}Ar-^{39}Ar by Harris (1989) shows an age range of 27 m.y. for K-Ar ages as compared with a range of 4 m.y. for ^{40}Ar-^{39}Ar ages. Harris attributes the spread in K-Ar ages to inaccuracies in measurement of K in low concentrations of K_2O. The ^{40}Ar-^{39}Ar age range of all measured samples (169-179 Ma) is considered the most reliable indication of when the magmatic suite passed through the 530°+/- 40° blocking temperature for hornblende argon (Harrison and McDougall, 1980). According to Harris the ^{40}Ar-^{39}Ar incremental release spectra show no evidence of a later thermal event that would have resulted in argon loss. Therefore, if the newly formed ophiolite assemblage cooled and moved away from a spreading center at or near an average spreading rate, a reasonable crystallization age for the magmatic suite would be Middle Jurassic.

Geochemistry The mineral chemistry of the cumulate mafic rocks is compared using a diagram proposed by Beard (1986) (Plate 1, col. E). According to Beard, calcic plagioclase (An_{85-100}) and moderately Fe-rich olivine (Fo_{60-80}) commonly occur together in arc cumulate gabbros, but not in cumulate gabbros from mid-ocean ridges, ocean islands, or tholeiitic layered intrusions. Analyses by Harris (1989) of the mafic cumulates from the Misheguk allochthon fall in the range of Beard's arc type II, which typically are dominated by olivine-bearing ultramafic rocks and olivine-free gabbronorite. An arc setting is also suggested by Cr-TiO_2 ratio plots by Harris (1989) for tectonized peridotites from the mantle suite. On a discriminant diagram by Pearce and others (1984), these analyses fall in the field of SSZ (supra-subduction zone) ophiolites suggesting that they formed in a volcanic arc setting rather than in a mid-ocean ridge (MOR) setting. According to Pearce and others (1984) the SSZ ophiolite mantle residue is generally more residual (carries less TiO_2) than that of the MOR ophiolites. Chrome spinel compositions from Misheguk Mountain have been plotted by Harris (1989) on a Cr# (100 Cr)/(Cr+Al) vs Mg# (100 Mg)/(Mg+Fe^{2+}) discriminant diagram, which shows the field of abyssal peridotites (after Dick and Bullen, 1986). Abyssal peridotites are defined by Dick and Bullen (1986) as peridotites dredged from the world's ocean ridge system. Their studies indicate that Cr# in peridotites increases as the degree of depletion in the mantle source increases. The wide range of Cr# for the western Brooks Range ophiolites is not typical of mid-ocean ridge-generated ophiolites, which show a relatively restricted range of depletion, but suggests a multiphase melting history more typical of ophiolites generated in an island arc setting.

Metamorphic sole

The basal fault of the Misheguk allochthon is marked by an intensely tectonized zone of sheared and mylonitized serpentinite, amphibolite, and greenschist (Plate 1, col. A). A metamorphic sole such as this is characteristic of most "Tethyan-type" ophiolites as defined by Moores (1982) and Coleman (1984). At Misheguk Mountain Harris (1989) reports the presence of a zone of garnet amphibolite, commonly interlayered with quartz-mica schist, that occurs immediately below the basal fault. The amphibolite grades downward into greenschist, which in turn grades into unsheared pillow basalt of the Copter Peak allochthon. Bulk chemistry suggests that the protoliths of these metamorphic rocks are basalt, chert, and argillaceous rocks of the Copter Peak allochthon. At Iyikrok Mountain the Misheguk allochthon is underlain by a metamorphic sole composed of hornblende-biotite quartzofeldspathic schist, and garnetiferous pelitic schist intercalated with amphibolites (Boak and others, 1987). The protoliths of these rocks are interpreted to be interlayered lithic graywacke, shale, and basalt representing, at least in part, the Copter Peak allochthon. Beneath the sole fault these amphibolite metamorphic rocks grade structurally downward through a thickness estimated to be as much as 200m into greenschist facies assemblages and finally into unaltered basalts typical of the Copter Peak allochthon.

Age Three K-Ar analyses from metamorphic hornblende from the metamorphic sole yield cooling ages ranging from 153 to 157 Ma (Late Jurassic) and four ^{40}Ar-^{39}Ar analyses on metamorphic hornblende yield ages ranging from 158 to 171 Ma (Middle to Late Jurassic) (Plate 1, col. C). These ages are interpreted as reflecting the time of emplacement of the Misheguk allochthon onto the Copter Peak allochthon. The ^{40}Ar-^{39}Ar ages average only 8 m.y. younger than the ages obtained from the magmatic suite in the Misheguk allochthon, suggesting that detachment of the ophiolite slab in the upper mantle and emplacement at higher crustal levels occurred relatively soon after formation at the spreading ridge. Coleman (1981) arrived at a similar conclusion for the Semail ophiolite and Spray (1984) pointed out the close relationship (<10 Ma) between ophiolite crystallization ages and ages from the associated metamorphic soles in the Appalachian-Caledonian ophiolites.

Copter Peak allochthon

The Copter Peak allochthon is composed chiefly of pillow basalt and subordinate andesite intercalated with gray, green, and maroon chert and shale containing Triassic and Jurassic(?) radiolarians (Mayfield and others, 1988). Locally the allochthon contains thrust slices of Devonian carbonate rocks, particularly near the basal thrust.

Geochemistry Harris (1989) obtained 8 whole-rock chemical analyses for samples of basalt from the Copter Peak allochthon. Although these rocks are highly altered, discriminant plots of immobile elements (Y/Nb vs Zr) indicate that they fall into two groups: 1) tholeiitic basalts and 2) basalts transitional between tholeiites and alkali basalts. Plate 1, col. E shows rare earth element (REE) plots and trace-element spiderdiagrams for each of the two groups. The chondrite-normalized REE show enrichment of the light rare earth elements similar to P(plume)-type MORB and to ocean island or seamount basalts. Similarly chondrite-normalized trace-element spiderdiagrams using normalization values of Thompson (1982), show enrichment of the mobile elements on the left side of the patterns and lack of enrichment of the less mobile elements to the right, suggesting the possible influence of enriched mantle plumes and an ocean island or seamount origin.

UNDERLYING CONTINENTAL MARGIN DEPOSITS

Ipnavik River allochthon

In most places the Misheguk and Copter Peak allochthons are structurally underlain by the Ipnavik River allochthon, a mixed assemblage of platform carbonate rocks and pelagic deposits of Devonian to Triassic age (Plate 1, col. A). The top of the Ipnavik River allochthon includes graywacke and mudstone of Early Cretaceous age. The base of the allochthon is commonly marked by as much as 200m of gray platform carbonate rocks of Devonian age belonging to the Baird Group. These are succeeded by as much as several hundred meters of black chert, fine-grained limestone, and shale of Early Carboniferous age (belonging to the Etivluk and Lisburne Groups) and by gray and maroon bedded chert of Late Carboniferous, Permian, and Triassic age (belonging to the Etivluk Group). The Lisburne and Etivluk Groups are widely intruded by diabase sills. The platform carbonates at the base are dated by conodonts and brachiopods; the overlying fine-grained pelagic deposits have been dated by radiolarians, conodonts, and foraminifers.

The continental margin deposits comprising the Ipnavik River allochthon have not been subjected to high-pressure ductile deformation as have the continental margin deposits that structurally underlie the ophiolitic terrane along the southern margin of the Brooks Range. The high-pressure metamorphism along the southern margin of the Brooks Range is generally interpreted to reflect partial subduction of these continental deposits beneath the oceanic rocks of the ophiolitic terrane during collision with the Koyukuk arc (Patton and Box, 1989). A possible explanation for the absence of metamorphism beneath the western Brooks Range ophiolites is that the Misheguk and Copter Peak allochthons were transported north of the metamorphic belt by gravity sliding following isostatic rebound of the subducted continental margin deposits.

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