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Chapter 17

Some accreted volcanic rocks of Alaska and their elemental abundances

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INTRODUCTION

Fred Barker

This chapter describes and gives elemental abundances of many of the accreted volcanic rocks and of a few hypabyssal rocks of Alaska. These rocks range from early Paleozoic (or perhaps late Precambrian) to Eocene age. All formed prior to accretion of the terrane containing them and thus were generated either as primary features in the ancestral Pacific Ocean or on terranes or superterranes carried by plates underlying that ocean. Most formed in intraoceanic island arcs and related rifts; one oceanic plateau has been identified; basalts of mid-ocean-ridge (MORB) and of seamount types also are described; other basalts may have been extruded from leaky transforms.

These accreted volcanic rocks are important in terms of continental growth by accretion of oceanic rocks. Various workers have asserted that such growth is by accretion of intra-oceanic island arcs. This assertion, however, must be appreciably modified for the ca. 400,000-km^2 region of southern and central Alaska that is underlain by accreted rocks. Though these rocks

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are not known in sufficient detail to yield a precise figure, I estimate that no more than 70 to 75 percent of this newly formed crust consists of former island arcs and arc-derived epiclastic sedimentary rocks.

Most of the tectonostratigraphic (lithotectonic) terranes of Alaska have minor exposures of volcanic rocks. Accounts of local and regional geology of the state contain cursory to extensive descriptions of such rocks. However, a catalog of such occurrences is not considered appropriate for this volume, and we discuss here only rocks studied by modern methods. The particular terranes containing these rocks are shown on Plate 13 (Barker and others, this volume), whereas all tectonostratigraphic terranes of Alaska are shown on Plate 3 (Silberling and others, this volume).

Though virtually all of the rocks considered in this chapter have been metamorphosed to prehnite-pumpellyite facies or higher grade, the emphasis is on the nature and environments of the protoliths. We also point out that most of these rocks have been subjected to alteration by seawater, by percolating fluids, or by metamorphism during or after accretion. Such processes affect the abundances of such "mobile" elements as K, Rb, Ba, Sr, and others in minor to major ways and obscures their original, magmatic abundances. Interpretations of environments of emplacement by using magmatic compositions thus devolve upon the relatively "immobile" elements such as Ti, Nb, Ta, rare-earth elements (REEs), and others. In addition, the uncertainties of using the various discriminant plots of elemental abundances or ratios as indicators of environments of generation now are well known. The authors of this chapter use geological information in conjunction with such plots where possible.

Analyses of more than 270 accreted volcanic and hypabyssal rocks are given in Tables 1 through 17 (on microfiche, back of this volume). Locations of these rocks are shown on Plate 6 (Barker and others, this volume). Place names not given on the plate may be found on Plate 2 (Wahrhaftig, this volume). The analysis in Tables 1 through 17 (on microfiche) were obtained by the following methods: major elements and Ba, Nb, Rb, Sr, Y, and Zr by x-ray fluorescence; FeO, H_2O, and CO_2 by wet methods; Sc, Cr, Co, and Ni by induction-coupled plasma optical emission spectrometry; rare-earth elements and other remaining elements by instrumental neutron activation. Precision of analyses cannot be given, but is within accepted standards.

SOME PRE–LATE CRETACEOUS VOLCANIC ROCKS OF SOUTHEASTERN ALASKA

G. E. Gehrels

Volcanic rocks of southeastern Alaska range in age from Late Proterozoic or Cambrian to Holocene, and include each intervening geologic period except the Pennsylvanian (Gehrels and Berg, 1992). Despite this surprisingly long and complete record, little is known about the tectonic environments in which the volcanic activity occurred. Hence, in the following discussion I give a general overview of all pre–Late Cretaceous volcanic and metavolcanic rocks in southeastern Alaska, and outine the scant geochemical and (or) petrologic data available. I describe Mesozoic (post-Triassic) rocks of Chichagof and Baranof Islands in the section on the Chugach terrane. The latest Mesozoic and Cenozoic volcanic rocks of southeastern Alaska are discussed by Brew (this volume).

TECTONIC SETTING OF SOUTHEASTERN ALASKA

As described in the chapter on the geology of southeastern Alaska (Gehrels and Berg, this volume), pre–Late Cretaceous rocks of the Alaska Panhandle belong to four terranes. From west to east, these terranes are: the Chugach terrane (mélange and other rocks of Cretaceous sedimentary and rocks of ocean-floor affinity); the Wrangellia terrane (hereafter informally designated Wrangellia; Triassic? basalt and marble); the Alexander terrane (Late Proterozoic or Cambrian through Jurassic sedimentary, volcanic, and intrusive rocks); and the Taku terrane (Permian and Triassic sedimentary and volcanic rocks, and undivided Jurassic and Cretaceous strata of the Gravina-Nutzotin belt).

Most workers agree that all of these terranes were firmly attached to the North American landmass by the end of Cretaceous time, but the timing and processes involved in their displacement, assembly, and accretion remain controversial. The only other relatively certain relationship between these terranes is that the Alexander terrane, Wrangellia, and the Taku terrane are all overlain by Upper Jurassic and Lower Cretaceous strata of the Gravina-Nutzotin belt (Berg and others, 1972, 1978; Barker, this chapter; Rubin, this chapter). The pre–Late Jurassic positions of the terranes relative to each other, and to North America, are as yet poorly constrained. Thus, the pre–Late Jurassic volcanic rocks described in this section, indeed most of the rocks in southeastern Alaska, may well have accumulated far from where they are found today.

The following discussion outlines the volcanic and metavolcanic rocks of southeastern Alaska from oldest to youngest.

LATE PROTEROZOIC OR CAMBRIAN

The oldest volcanic rocks known in southeastern Alaska belong to a greenschist-amphibolite–facies metamorphic complex (Wales Group) that forms the apparent basement to the Alexander terrane (Gehrels and Saleeby, 1987a). These rocks occur in a small area of southern southeast Alaska (Barker and others, this volume, Plate 13) and have been studied only in reconnaissance fashion. Protoliths of the metavolcanic rocks include basaltic-andesitic pillow flows, pillow breccia, and tuff breccia, and rhyolitic tuff and tuff breccia. Small dioritic and granodioritic intrusive bodies of Middle or Late Cambrian age are interpreted to be subvolcanic (Gehrels and Saleeby, 1987b).

ORDOVICIAN TO EARLY SILURIAN

Much of the southern Alexander terrane is underlain by a volcanic-plutonic-sedimentary complex of Ordovician to Early Silurian age, which apparently intrudes and overlies the older metamorphic basement. Volcanic rocks of this complex belong to the Descon Formation. They range from basaltic-andesitic pillow flows and breccia through dacitic breccia, tuff breccia, and tuff, to rhyolitic tuff, pyroclastic breccia, and extrusive dome complexes (Eberlein and others, 1983; Gehrels and Saleeby, 1987b; Gehrels and others, 1987). Coeval plutons range from diorite and subordinate gabbro, through quartz diorite, tonalite, and granodiorite, to granite, quartz monzonite, and quartz syenite. Geochemical analyses have been obtained from various compositional members of the plutonic suite, a basalt-andesite pillow flow, and a rhyolite breccia (Gehrels and Saleeby, 1987b). Major-, minor-, trace-, and rare-earth-element compositions of these rocks are indistinguishable from those of present-day island-arc systems and suggest that the southern Alexander terrane evolved in a convergent-margin environment during Ordovician to Early Silurian time.

DEVONIAN

Devonian volcanic rocks occur in widely scattered localities in the Alexander terrane, but nowhere are they laterally continuous or of great thickness. Lower Devonian volcanic rocks are heterogeneous in composition. Feldspar-porphyritic dacite breccia and basaltic pillow flows and breccia occur on southern Prince of Wales Island (Gehrels and Saleeby, 1987b) and on southern Annette Island (Gehrels and others, 1987); rhyolite flows occur in a very restricted region of east-central Prince of Wales Island (Eberlein and others, 1983); and plagioclase-phyric andesite, possibly correlative with that to the south, occurs on northern Kuiu Island (Muffler, 1967). Middle Devonian rocks occur only in a restricted area of west-central Prince of Wales Island, where they comprise basaltic pillow flows, breccia, and tuff of the Coronados Volcanics (Eberlein and others, 1983). In contrast, volcanic rocks of Late Devonian age occur as thick sections of basaltic-andesitic pillow flows and breccia on northern Chichagof Island (Freshwater Bay Formation, Loney and others, 1975) and western Prince of Wales Island (Port Refugio Formation, Eberlein and others, 1983).

Volcanic and metavolcanic rocks of known, probable, and possible Devonian age occur in several other areas of southeastern Alaska. Such rocks include basaltic flows and breccia of the St. Joseph Island Volcanics (western Prince of Wales Island, Eberlein and others, 1983); unnamed basaltic flows, agglomerate, and tuff of Silurian or Devonian age in the Chilkat Range (Brew and Ford, 1985); and strongly deformed and metamorphosed greenstone and greenschist (Retreat Group and Gambier Bay Formation) of Middle(?) Devonian age on Admiralty and Kupreanof Islands (Lathram and others, 1965; McClelland and Gehrels, 1987).

MISSISSIPPIAN

Mississippian andesitic rocks have been recognized in a small area of northern Kupreanof Island but may be more widespread on Amdiralty Island. These rocks occur on Kupreanof Island as layers and lenses in a disrupted chert-argillite-limestone complex (part of Cannery Formation, see Muffler, 1967).

PERMIAN

Permian volcanic rocks are known in two separate areas of the Alexander terrane, and probably constitute a significant part of the Taku terrane. In the Alexander terrane, they occur on northern Kuiu Island as olivine-rich basalt pillow flows and breccia interbedded with Lower Permian limestone and clastic strata of the Halleck Formation (Muffler, 1967). A similar but less well-known sequence of basaltic(?) volcanic rocks, limestone (marble), and clastic strata occurs in the Chilkat Range and north of Glacier Bay (Brew and Ford, 1985), and may extend northward into the area northwest of Haines (Gehrels and Berg, 1992).

Volcanic rocks of the Taku terrane are predominantly basaltic to andesitic, and range from well-preserved flows and breccia, through moderately deformed greenstone and greenschist, to amphibolite-facies schist and gneiss of uncertain volcanic origin (Berg and others, 1972; Gehrels and Berg, 1992). Fossils have not been found in these strata; their age is constrained only by stratigraphic relations with clastic rocks and limestone-bearing Permian and (or) Triassic fossils. Thus, although such volcanic rocks constitute a significant percentage of the Taku terrane, their age has nowhere been documented. North of Petersburg, these rocks are in unknown contact with a thick(?), but areally restricted, sequence of quartzo-feldspathic schist and gneiss that may have been derived from rhyolite and rhyolitic tuff and could be of Permian age (Monger and Berg, 1987).

TRIASSIC

Triassic volcanic rocks are widespread in southeastern Alaska and occur in the Alexander terrane, Wrangellia terrane, and probably the Taku terrane. The sequence in the Alexander terrane is distinctive in that it consists of a bimodal basalt-rhyolite suite, generally with rhyolite below basalt. These rocks can be traced in a nearly continuous band along the eastern margin of the Alexander terrane and separate subjacent pre-Triassic rocks from overlying Jurassic and Cretaceous strata of the Gravina-Nutzotin belt. A regionally extensive angular unconformity at the base of the Triassic section, a basal conglomerate or sedimentary breccia that displays rapid lateral thickness changes, and facies relations upsection all indicate deposition during a phase of uplift, erosion, and faulting along the eastern (inboard) margin of the Alexander terrane. The bimodal composition of the volcanic rocks and the occurrence of the strata in a narrow band along the eastern margin of the terrane indicate a probable rift origin (Gehrels and others, 1986). However, this hypothesis has not yet been tested by geochemical or petrologic analyses. The Triassic(?) Goon Dip Greenstone and the overlying Triassic(?) Whitestripe Marble (Johnson and Karl, 1985) form a small fragment of the Wrangellia terrane on western Chichagof and northern Baranof Islands. Decker (1980) has indicated that about a 2-km-thick section of the Goon Dip Greenstone is preserved—its base not being exposed. His three analyses show the Goon Dip to lie in the range of major and minor elements given by the Nikolai Greenstone (Barker and others, this chapter) and basalts of the Karmtusen Formation (Barker and others, 1989). Thus, the Goon Dip is presumed to have formed in a back-arc basin, as did the Nikolai and Karmtusen.

Volcanic rocks of the Taku terrane have been described under Permian rocks. However, some of the basaltic rocks within the northern Taku terrane are of Triassic age and are probably correlative with the tholeiitic basalts of Wrangellia. Plafker and Hudson (1980) and Davis and Plafker (1985) report that well-preserved Triassic basalts about 3 km thick on Chilkat Peninsula (northern southeast Alaska) are similar in age and chemistry to the Nikolai Greenstone of southern Alaska. Furthermore, megafossils of the associated limestone are like those of the correlative limestone of Wrangellia. Plafker and others (1989a) recently suggested that northern parts of the "Taku terrane," indeed, are a part of Wrangellia. Because the basaltic rocks on Chilkat Peninsula apparently are correlative with the volcanic and metavolcanic rocks in the Taku terrane to the southeast, it appears likely that the Taku terrane and Wrangellia terrane were contiguous during Late Triassic time (Davis and Plafker, 1985).

The occurrence of similar and coeval rift assemblages in Wrangellia, the Taku terrane, and the Alexander terrane raises the possibility that these three tectonic fragments have been in close proximity since at least Late Triassic time. Gardner and others (1988) note that syenitic intrusions of 309-Ma age stitch together the Alexander and Wrangellia terranes at their mutual contact in the Wrangell Mountains.

METAMORPHOSED MAFIC IGNEOUS ROCKS IN THE SEWARD PENINSULA

B. W. Evans, A. J. Irving, and B. E. Patrick

INTRODUCTION

Low-grade metamorphic rocks of the Nome Group (Till and Dumoulin, this volume) constitute a major part of the bedrock in the Seward Peninsula. Recent fossils finds (Dumoulin and Harris, 1984; Till and others, 1986) have shown that the stratigraphic age of the Nome Group extends from at least Cambrian through Devonian. Whole-rock Rb-Sr isotope data on pelitic schist and granitic orthogneiss are consistent with this age span (Armstrong and others, 1986). The metasedimentary rocks of the Nome Group (pelitic schist, calcareous schist, calcitic and dolomitic marble, graphitic quartzite, and chloritic schist) were deposited in shallow water, apparently in basins and flanking platforms on the rifted lower Paleozoic continental margin of North America. Metagabbros, metadiabases, and probable basaltic lava flow and pyroclastic rocks are particularly abundant in the chlorite schist unit (= Casadepaga Schist) of the Nome Group (Till and Dumoulin, this volume).

Most of the analyzed metabasites are from this unit, which is bounded above and below by marbles of Ordovician age (Till and others, 1986). A few samples are from poor exposures whose structural and stratigraphic relationships are unclear. Thus, the probable age of most of the samples is Ordovician, although no attempt has yet been made to date them radiometrically. In areas of limited deformation, such as south of Teller and near American River (Fig. 1), some metabasites occur in sill-like bodies, and contacts in a few places are seen to crosscut the layering of the metasediments. In these locations, and in the central parts of more massive layers and boudins elsewhere, igneous textures (blastophitic texture, former FeTi-oxide domains, unrecrystallized apatite) are still visible microscopically. In the Teller area, igneous augite, plagioclase, and hornblende survived the greenschist-facies metamorphism. Although contrasting lithologies (more versus less differentiated) occur together in some frost-heaved outcrops, no clear evidence of any primary-layered structure within the former sills has been found.

The rocks of the Nome Group underwent epidote-blueschist and greenschist facies metamorphism in the Jurassic and Early Cretaceous (Forbes and others, 1984; Thurston, 1985; Armstrong and others, 1986). As a result, the metabasites are now composed of various combinations of glaucophane, actinolite, epidote, almandine, paragonite, phengite, chlorite, albite, calcite, quartz, titanite, apatite, and rare sodic pyroxene or chloritoid, with lesser rutile, magnetite, zircon, and pyrite, and rare baddelyite. The growth and preservation of sodic amphibole was a function of both whole-rock composition and metamorphic history.

IGNEOUS ROCK TYPES

Major- and trace-element analyses have been conducted by ICP emission spectrometry on 41 samples of metabasite from the Nome Group rocks on the Seward Peninsula. Major-element

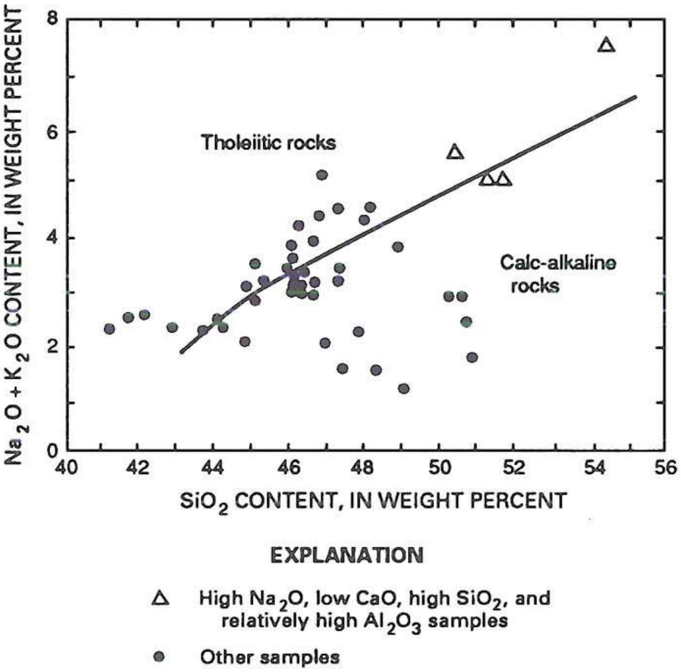

Figure 1. Plot of $Na_2O + K_2O$ versus SiO_2 (weight percent) for Seward Peninsula metabasites. Triangles signify Na-rich, Ca-poor samples (see text). Line separates tholeiitic and alkalic fields.

data on a further six samples were published by Thurston (1985). In addition, data for rare-earth and other trace elements were obtained for 14 of these samples by instrumental neutron activation analysis. The complete data for these 14 are given in Table 1 (on microfiche).

The majority of samples are hypersthene-normative, and can be classified as olivine tholeiite, quartz tholeiite, and olivine basalt (transitional to alkalic basalt); only two samples have more than 0.5 percent normative nepheline. Despite their essentially tholeiitic character many of the samples plot in the mildly alkalic field on an alkalies-SiO_2 plot (Fig. 1). Four samples (designated separately on Figs. 1 and 2) have notably high Na_2O (4.8 to 6.7 weight percent), low CaO (1.3 to 6.9 weight percent), high SiO_2, and relatively high Al_2O_3. These rocks may have experienced spilitic alteration or else may represent plagioclase-enriched igneous protoliths; one of these samples is probably a mafic metasediment. Except for several of these four, all samples plot outside the calc-alkaline field on an AFM diagram and in the tholeiitic field on a SiO_2-FeO^*/MgO plot (Fig. 2).

Mg-values for the Seward Peninsula metabasites range from 0.65 to 0.30 (Fig. 3), and thus, if the protoliths represent magmatic liquids, they show a range of evolved magma compositions relative to typical primary magmas. Many of the more Fe-rich rocks have very high TiO_2 contents (the most Ti-rich sample, now eclogite, contains 7.7 weight percent TiO_2, but more than half of the analyzed samples contain more than 3.5 weight percent TiO_2). Nevertheless, the most evolved (i.e., Fe-rich) compositions also include examples with lower TiO_2 contents (see Fig. 3). TiO_2 correlates fairly well with La/Yb (Fig. 4) and, to a lesser degree, with P_2O_5 and Zr, and shows a broad negative correlation with SiO_2. Relic textures make it clear that many of the samples were rich in igneous FeTi-oxides; the high TiO_2 contents are therefore believed to be an original property of the suite. Low K_2O contents (less than 0.2 weight percent in half the samples) could, on the other hand, reflect loss of potassium prior to or during the metamorphism, or alternatively may imply that some of the protoliths were cumulates.

When normalized to primitive mantle abundances (Fig. 5), the compositions of most Seward Peninsula metabasites are more enriched than "typical" MORB, but have similarities to "enriched" MORB and ocean-island tholeiites. Relative depletions in K, Rb, Ba, Zr, and Hf are also evident from this diagram. Both

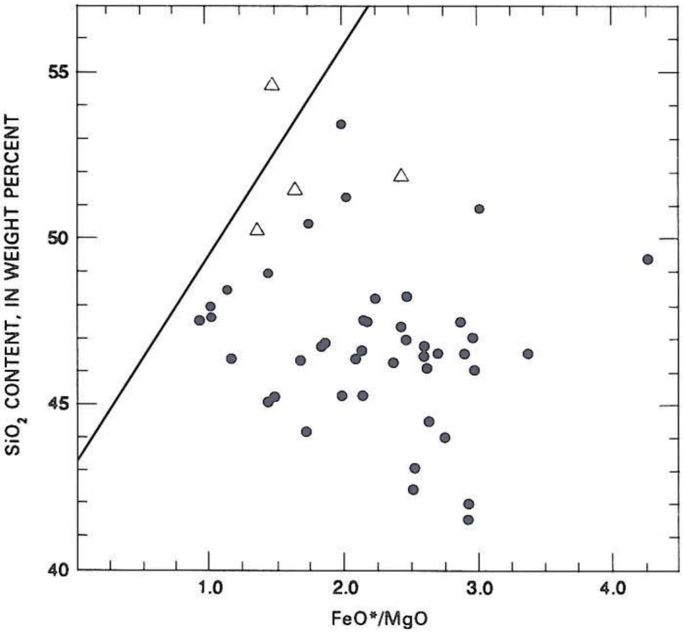

Figure 2. Plot of SiO_2 versus FeO^*/MgO (where $FeO^* = FeO+0.9\ Fe_2O_3$) for Seward Peninsula metabasites. Symbols as in Fig. 1. Line separates calc-alkalic (left) and tholeiitic fields (after Miyashiro, 1974).

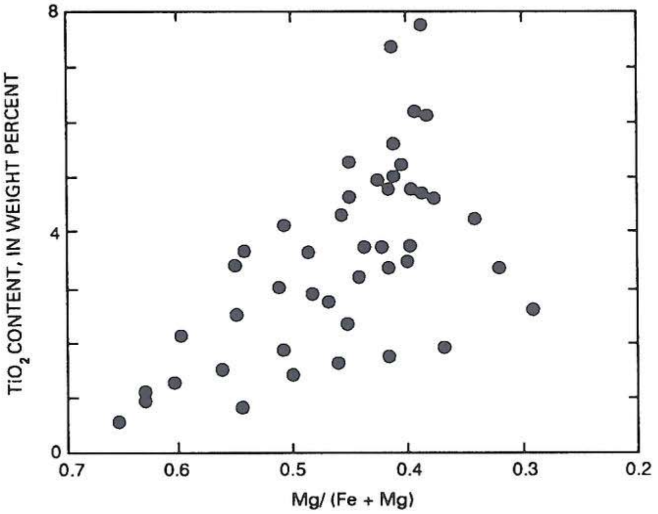

Figure 3. Plot of TiO_2 versus mg (Mg/[Mg+Fe]) for Seward Peninsula metabasites.

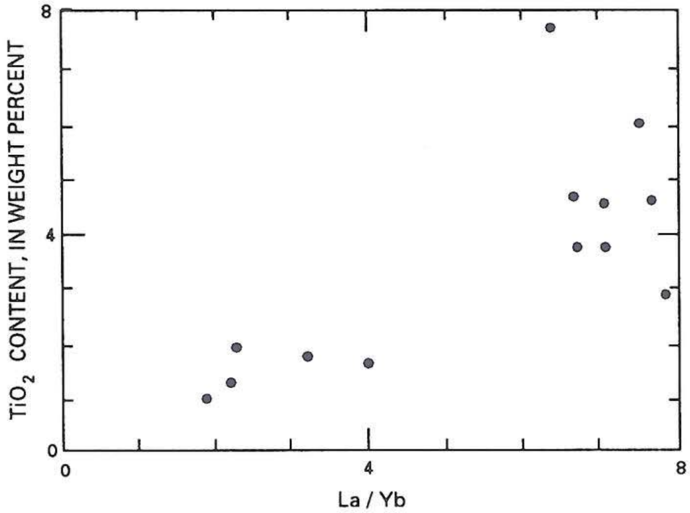

Figure 4. Plot of TiO_2 versus La/Yb for 14 Seward Peninsula metabasites.

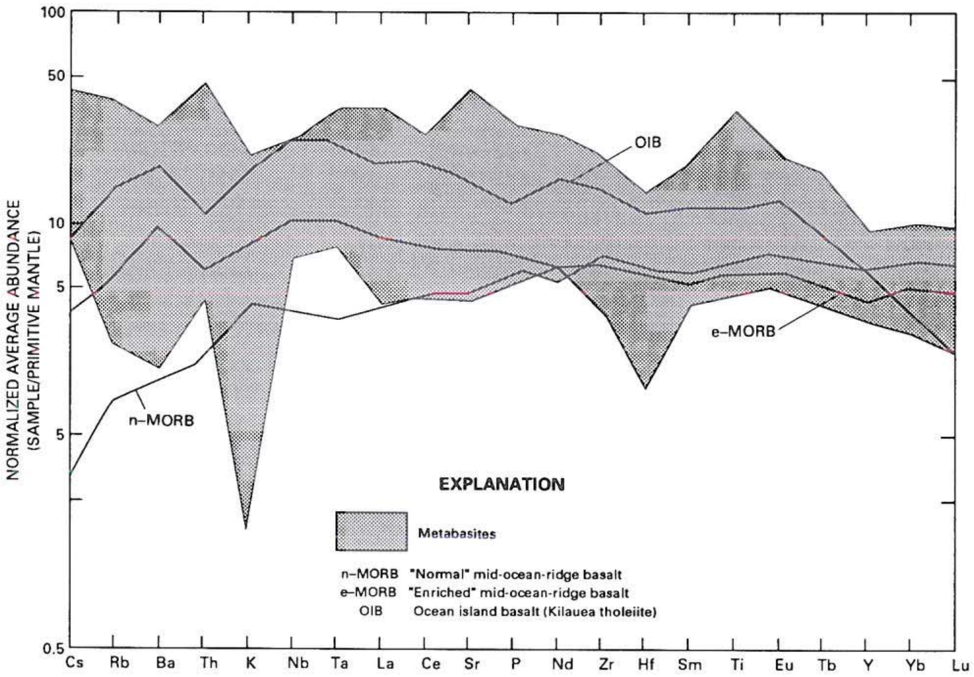

Figure 5. Primitive-mantle-normalized abundance diagram showing range for 14 Seward Peninsula samples and typical patterns for "normal" MORB, "enriched" MORB, and Kilauea tholeiite (OIB). After Sun and Nesbitt (1977), Pearce (1983), and BVSP (1981). Normalizing values from Sun and McDonough (1989).

enrichments and depletions in Sr and Ti are found, and some samples have small Eu anomalies. One interpretation of these chemical characteristics is that the protoliths formed from a variety of liquids and cumulates which were interrelated by addition or subraction of plagioclase, Fe-Ti oxides, and augite. The average composition of relict igneous augite in metagabbros in the Teller area yields a formula $(Ca_{.81}Na_{.02}Fe,Mg_{.17})$ $(Fe,Mg_{.95}Al_{.02}Ti_{.03})$ $(Si_{.92}Al_{.08})O_6$, with Mg/(Mg+Fe) = 0.70. Overall the data are consistent with relatively low-pressure differentiation processes such as would be expected in a subvolcanic dike and sill complex.

Most conventional trace-element discriminant diagrams for these rocks show wide scatter, presumably as a result of both cumulus processes and subsequent alteration. The rocks apparently can be distinguished from island-arc tholeiites on the basis of Ti/V ratios (Fig. 6) and their lack of depletion in Nb, Ta, and Ti (Fig. 5). Consideration of all the geochemical characteristics of the Seward Peninsula metabasites as well as their geological setting leads us to conclude that they represent basaltic magmatism associated with a rifted continental margin or shallow oceanic plateau.

ANGAYUCHAM TERRANE

J. S. Pallister and F. Barker

GENERAL DESCRIPTION

The Angayucham terrane derives its name from the Angayucham Mountains of the south-central Brooks Range, where as much as 8 to 10 km (composite thickness) of structurally interleaved pillow basalt, diabase, basaltic tuff, and chert are exposed (Pallister and Carlson, 1988). Basalt-chert sequences are exposed in a V-shaped outcrop belt that extends from the Angayucham Mountains to the east, past Coldfoot, then southwest through the Kanuti ophiolite to the Ruby Mountains (Barker and others, this volume, Plate 13). Similar rocks are exposed 20 to 100 km to the south and east in the Tozitna terrane (Jones and others, 1987; and see Patton and others, this volume, Chapter 21).

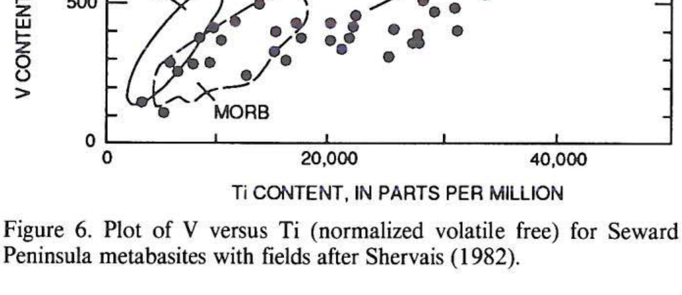

Figure 6. Plot of V versus Ti (normalized volatile free) for Seward Peninsula metabasites with fields after Shervais (1982).

These basaltic-chert terranes are near the top of the sequence of thrust sheets in much of western and northern Alaska and western Canada. Emplacement is generally related to Late Jurassic to Early Cretaceous accretion of the oceanic rocks onto the Brooks Range continental margin (Roeder and Mull, 1978; Jones and others, 1986; Pallister and others, 1989; Patton and others, this volume, Chapter 21). Pillow basalt and chert form the lower and more widely exposed of two lithologic assemblages; the upper assemblage is composed of basal ophiolite rocks (amphibolite, peridotite, and gabbro) of Jurassic age (Patton and others, 1977). Viewed together, the two assemblages appear to comprise an inverted ophiolite sequence; however, they are separated by thrust faults, and the lower basalt-chert assemblage contains fault slices that yield a variety of ages. Sections constructed across fault slices of the basalt-chert assemblage in the central Angayucham Mountains show a telescoped age progression from highly disrupted block mélange of Paleozoic and Mesozoic rocks on the north, through Triassic to Jurassic basalt-chert sequences to the south (Pallister and Budahn, 1989).

BASALT-CHERT ASSEMBLAGE

Thick piles of pillow basalt flows containing sills and dikes of diabase form the bulk of the Angayucham terrane. Intercalated basaltic tuff, red argillite, and lenses of radiolarian chert are common; fault-bounded sequences of chert and tuff are as thick as several hundred meters. The pillow basalts are nonvesicular to amygdaloidal; pillows are typically 30 cm to more than a meter in diameter; and pillow breccias are locally abundant. Two areas within the basalt-chert assemblage have been studied in detail. The central Angayucham Mountains were mapped by Hitzman and others (1982) and by Pallister and Carlson (1991), and the basalts were the subject of a petrologic and geochemical study by Pallister and others (1989). The basalt-chert sequence near Coldfoot was studied by Barker and others (1988).

The central Angayucham Mountains are underlain by prehnite-pumpeyllite facies pillow basalt, subordinate diabase and basaltic tuff, and minor radiolarian chert. The basalts are separated from higher grade metamorphic and crystalline rocks of the Brooks Range successively by a narrow belt of tectonic block–mélange along the northern flank of the Angayucham Mountains and then by a broad, low-relief belt of Paleozoic phyllite, greenschist, and minor blueschist (Patton and Miller, 1966, 1973; Hitzman and others, 1982).

Major-element analysis indicate that many of the basalts are hypersthene-normative olivine tholeiites. Classification based on immobile trace elements confirms the tholeiitic character of most of the basalts and suggests some had primary compositions that were transitional to alkali-basalt (Table 2, on microfiche). Although field and petrographic features of the basalts are similar, trace-element characteristics allow definition of geographically distinct suites. A central outcrop belt along the crest of the mountains is made up of basalt with relatively flat rare-earth element (REE) patterns. This belt is flanked to the north and south by basalts enriched in light rare earth elements (LREE). Radiolarian and conodont ages from interpillow and interlayered chert and limestone indicate that the central belt of basalts is Triassic in age, the southern belt is Jurassic in age, and the northern belt contains rocks of both Paleozoic and Mesozoic ages (Pallister and Carlson, 1988).

The abundance and thickness of pillow basalt and interlayered pelagic sedimentary rocks provide clear evidence that the Angayucham terrane formed in an oceanic setting. None of the basalts have trace-element characteristics of island-arc basalt. Data for most of the basalts cluster in the "within-plate basalt" fields of trace-element discriminant diagrams and lack the Nb and Ta depletions that characterize modern arc basalts (Fig. 7). The Triassic and Jurassic basalts are geochemically most akin to modern oceanic-plateau and island basalts (Pallister and others, 1989).

Field evidence also favors an oceanic plateau or island setting. The great composite thickness of pillow basalt probably resulted from obduction faulting, but the lack of fault slabs of gabbro or peridotite suggests that obduction faults did not penetrate below oceanic layer 2, a likely occurrence if layer 2 was anomalously thick, as in the vicinity of an oceanic island. The presence of basaltic tuff interbeds indicates proximity to an explosive basaltic eruptive center.

The juxtaposition of submarine basalts of differing chemical affinity and age adjacent to higher grade Paleozoic metamorphic rocks of the Brooks Range to the north may be explained by obduction of internally complex (thickened) oceanic crust formed in an ocean plateau and island setting. Emplacement and rotation of thrust plates to steep attitudes occurred during the Late Jurassic and Early Cretaceous accretion of the Brooks Range passive margin. Earlier workers, however, suggested that this juxtaposition was a result of extensional faulting.

Pillow basalt, diabase, chert, and argillite are thrust and folded into duplex structures near Coldfoot (Barker and others, 1988). Peak metamorphism was to epidote-amphibolite facies; originally glassy basalts were most reactive and were converted to blue-green amphibole-sodic plagioclase-epidote-magnetite assemblages. Intrusive and stratigraphic relations and dated radiolarian cherts suggest that the mafic rocks range from Mississippian to latest Triassic or Jurassic in age. Diabase sills and massive to cumulus-banded gabbro occur at or near the base of several large pillow lava sequences in the Coldfoot area. Intrusive relations indicate that these hypabyssal and plutonic rocks are stratiform bodies emplaced at shallow levels within preexisting oceanic crust; contact relations and geochemical affinities suggest that the intrusive rocks represent subvolcanic feeders for overlying pillow lavas.

The Coldfoot basalts are similar to those of the Angayucham Mountains in having the trace-element characteristics of modern within-plate basalts. Barker and others (1988) suggest that they formed in an oceanic intraplate setting (oceanic plateau or seamount) by the mixing of parent magmas having trace-element characteristics of both "normal" mid-ocean-ridge basalt (MORB) and within-plate or "plume-type" MORB.

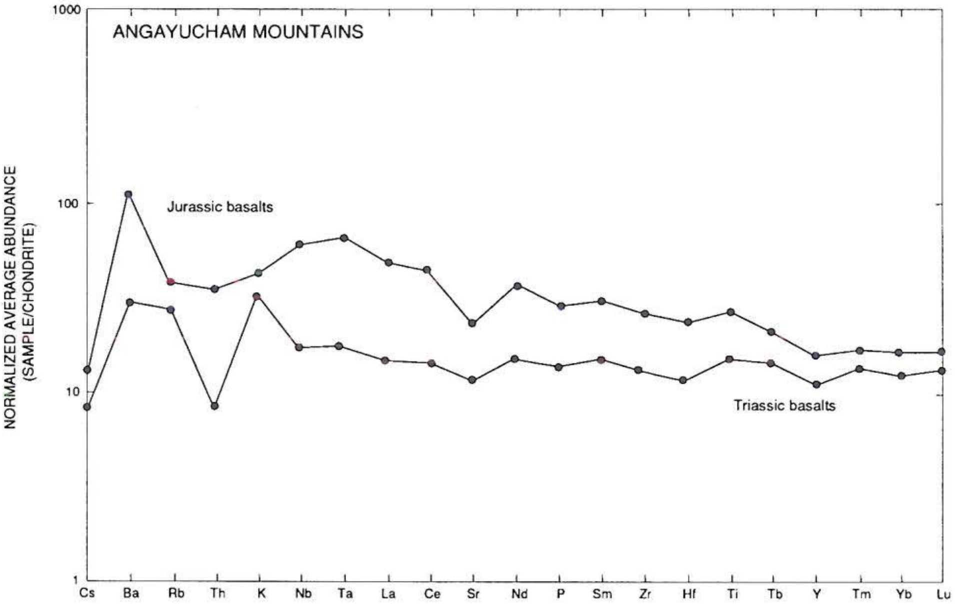

Figure 7. Spidergram of Triassic and Jurassic basalts of western Angayucham terrane (after Thompson and others, 1983) showing chondrite-normalized abundances of selected elements arranged in order of decreasing compatibility and mobility—to yield a smooth pattern for "normal" mid-ocean-ridge basalts (N-MORB).

SOUTHERN YUKON-TANANA TERRANE

W. J. Nokleberg and J. N. Aleinikoff

The southern margin of the Yukon-Tanana terrane in the eastern Alaska Range comprises, from north to south, the Lake George, Macomb, and Jarvis Creek Glacier subterranes (Jones and others, 1987; Aleinikoff and Nokleberg, 1985; Nokleberg and Aleinikoff, 1985). These terranes are interpreted as forming various stratigraphic/structural levels of a Devonian and Mississippian continental-margin arc (Aleinikoff and others, 1981, 1986) that formed along the western margin of North America (Nokleberg and Aleinikoff, 1985). To the north, in the deeper levels of the terrane, the Lake George and Macomb subterranes consist of a sequence of medium- to coarse-grained, multiply deformed, pelitic, mylonitic schists intruded by Devonian schistose quartz diorite, granodiorite, and granite (Aleinikoff and Nokleberg, 1985). To the south, in the higher levels of the terrane, the Jarvis Creek Glacier subterrane consists of Devonian metavolcanic and metasedimentary mylonitic schist and minor phyllonite (Nokleberg and Aleinikoff, 1985). Metavolcanic schists are derived mainly from andesite and quartz keratophyre, and from lesser amounts of dacite and basalt. Metasedimentary schists are derived from fine-grained clastic, calcareous, and volcanogenic sediments. In some areas, volcanogenic massive sulfide deposits occur extensively in the terrane (Nauman and others, 1980; Nokleberg and Lange, 1985). A submarine origin is indicated for these deposits by the interlayering of metavolcanic rocks and sulfide lenses and pods with fine-grained thinly layered metasedimentary rocks. Both suites of metavolcanic and metasedimentary rocks are multiply deformed and metamorphosed, pervasive, younger, middle to upper greenschist facies minerals to the south, and a few areas of older, relict lower amphibolite–facies minerals to the north.

Farther south, the Hayes Glacier subterrane (Nokleberg and Aleinikoff, 1985), consisting of Devonian metasedimentary and metavolcanic phyllonites, is derived from many of the same protoliths as the Jarvis Creek Glacier subterrane. The Hayes Glacier subterrane of the Yukon-Tanana terrane differs from the Jarvis Creek Glacier subterrane in having more black to dark gray carbonaceous pelitic rocks, sparse small volcanogenic massive sulfide deposits, and few metavolcanic and volcanically derived rocks. Stratigraphic and structural relations indicate that these subterranes represent, from north to south, successively higher levels of a single, now highly metamorphosed and deformed, Devonian submarine igneous arc (Nokleberg and Aleinikoff, 1985).

Thin metamorphosed volcanic flows and tuffs of the southern margin of the Yukon-Tanana terrane occur in layers as much as a few meters thick, intercalated mostly with quartz schist and pelitic schist. Estimate of the original thickness is precluded because of intense multiple deformation. These rocks are light to dark gray-green and consist of plagioclase and some quartz microphenocrysts set in a groundmass of thoroughly metamorphosed aggregates of plagioclase, quartz, actinolite, chlorite, epidote, and opaque minerals. The samples chosen for geochemical study were picked on the basis of relict igneous features in thin section, because in outcrop, protolith features are obscured by multiple metamorphism and deformation. Abundant relict igneous features in thin section consist of microphenocrysts of plagioclase with normal and oscillatory zoning, phenocryst outlines for plagioclase, complicated twinning in plagioclase, embayed (resorbed) outlines for quartz phenocrysts, and a massive character to the unit, indicating a probable flow origin. These criteria, however, do not totally exclude the possibility that some samples contain a minor intercalated clastic component.

Major-element whole-rock chemistry of 14 samples of metamorphosed volcanic flows and tuffs in the southern part of the Yukon-Tanana terrane is listed in Table 3 (on microfiche) and displayed in the plot (Fig. 8) of FeO^*/MgO versus SiO_2 (where $FeO^* = FeO + 0.9\ Fe_2O_3$). A wide range of major and minor oxides occurs. SiO_2 ranges from 53.2 to 79.7 percent with an average of 70.1 percent. Two samples are andesite (as defined by SiO_2 = 53 to 63 percent), four are dacite (SiO_2 = 63 to 69 percent), and eight are rhyolite (SiO_2 = 69 percent or more). On a plot of FeO^*/MgO versus SiO_2 (Fig. 8), the suite exhibits limited iron enrichment for low SiO_2-content samples. The suite is about equally divided between the tholeiitic and calc-alkaline fields. Silica variation diagrams, not published here, show two important features. First, for the "immobile" oxides—CaO, FeO^*, MgO, and TiO_2—relatively smooth variations approximate a calc-alkaline trend. Second, there is an almost random pattern for the more "mobile" elements—K_2O and Na_2O—indicating extensive metasomatism either during submarine volcanism and (or) metamorphism.

Origin as a Devonian and Mississippian submerged continental-margin arc is suggested by the marine character, calc-alkaline trend, and abundant quartz detritus in the associated metasedimentary rocks (Nokleberg and Aleinikoff, 1985; this chapter). In addition, preliminary common lead-isotopic studies on sulfide samples from the volcanogenic massive sulfide deposits (LeHuray and others, 1985), and similar studies on feldspars from the metaplutonic and metavolcanic rocks (Aleinikoff and others, 1987), indicate a continental component derived from an Early Proterozoic source. A continental margin setting also is indicated by the abundant quartz-rich schist containing detrital zircons derived from an Early Proterozoic source(s) (Dusel-Bacon and Aleinikoff, 1985; Aleinikoff and others, 1986).

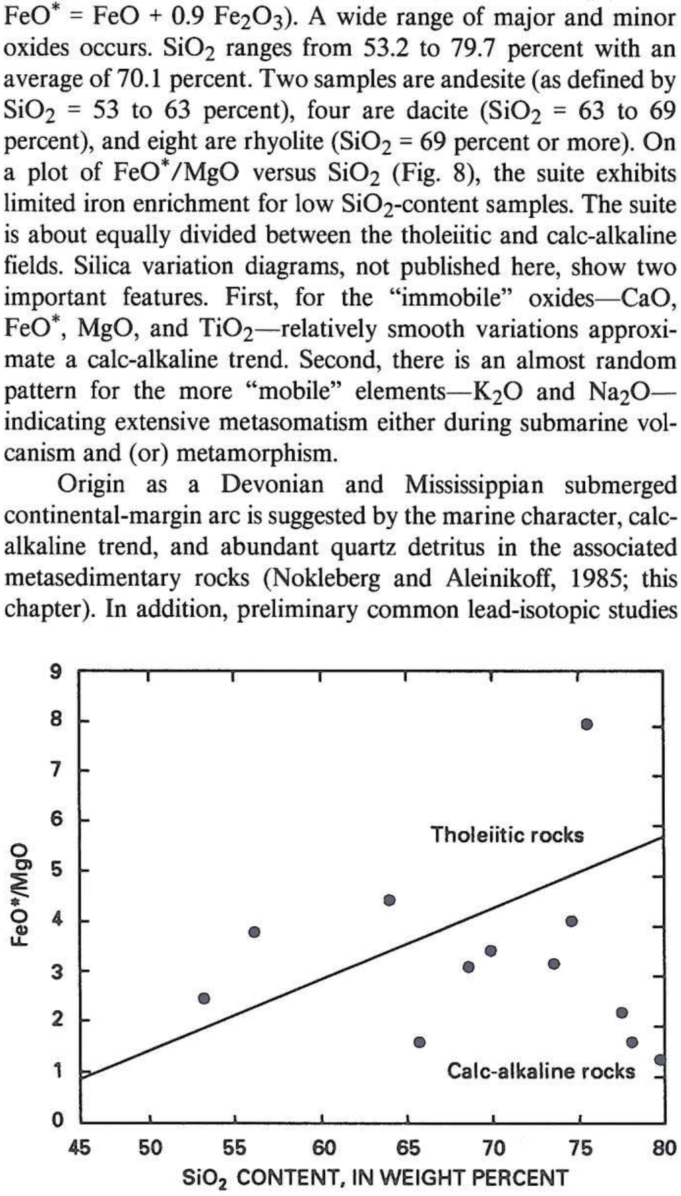

Figure 8. FeO^*/MgO versus SiO_2 (weight percent) of Devonian metavolcanic rocks from the Jarvis Creek Glacier and Hayes Glacier subterranes of the southern Yukon-Tanana terrane, eastern Alaska Range. Tholeiitic-calc-alkaline boundary after Miyashiro (1974).

WRANGELLIA TERRANE

F. Barker, W. J. Nokleberg, G. Plafker, and W. P. Leeman

The Wrangellia terrane, also known as "Wrangellia," was defined by Jones and others (1977). It is exposed in the Wrangell Mountains, eastern Alaska Range, St. Elias Mountains, southeastern Alaska at Chichagof and Baranof Islands, and near Haines, Queen Charlotte Islands, and Vancouver Island. This terrane consists largely of Devonian (Vancouver Island) and late Paleozoic (Alaska) intraoceanic island arcs, Permian limestone, Triassic back-arc-basin basalt, and Triassic limestone (see, e.g., Richter, 1976; MacKevett, 1978; Nokleberg and others, 1985; Brandon and others, 1986; Barker and others, 1989). In the Mount Hayes Quadrangle, Nokleberg and others (1985) have divided Wrangellia into the Slana River subterrane, which is like the type-Wrangellia terrane of the Wrangell Mountains and Nabesna Quadrangle; and into the Tangle subterrane, which is a deeper water facies of type-Wrangellia terrane.

Jurassic and (or) Cretaceous flysch and Early Cretaceous island-arc volcanic rocks formed on the northeast flank of Wrangellia prior to emplacement onto North America. These rocks are termed the Gravina-Nutzotin belt (Berg and others, 1972) and their volcanic rocks are described below. Oceanic volcanic and sedimentary rocks that accreted to the southwestern margin of Wrangellia are discussed in the section (this chapter) below on the Chugach terrane. We next consider the Paleozoic island arc, termed the Skolai arc; and the Triassic arc-rift basalts, the Nikolai Greenstone.

THE SKOLAI ISLAND ARC

The oldest exposed rocks of the Wrangellia terrane in the Wrangell Mountains, eastern Alaska Range, and Kluane Range, Yukon, are the remnants of an intraoceanic island arc of Late Mississippian or Early Pennsylvanian to Early Permian age. This island arc, first recognized by Bond (1973) and Richter and Jones (1973a), is informally termed the Skolai island arc. It consists of the Station Creek Formation of the Skolai Group of the Wrangell Mountains (Smith and MacKevett, 1970; MacKevett, 1978); the Tetelna Volcanics, and the Slana Spur Formation of the eastern Alaska Range (Bond, 1973, 1976; Richter, 1976; Jones and others, 1977; Nokleberg and others, 1985), and the Strelna Metamorphics of Plafker and others (1989b) found in the Chitina Valley region and along the southern margin of this part of

Wrangellia. The stratigraphic relations of these sparsely fossiliferous formations are not entirely clear—as one might expect of island-arc rocks. The Station Creek Formation probably is correlative with most of the Tetelna Volcanics; the Tetelna is overlain by the Slana Spur Formation in western Nabesna Quadrangle (Richter, 1976); but in the Mount Hayes Quadrangle to the west relations of the Tetelna Volcanics and Slana Spur Formation are poorly known (Nokleberg and others, 1985). The Strelna Metamorphics of Plafker and others (1989b) is described below.

Rocks of the Skolai island arc are the oldest exposed in this part of Wrangellia, with the possible exceptions of the quartz-feldspar schist of the Nabesna Quadrangle (Richter, 1976) and the orthogneiss and gabbro of the eastern Wrangell Mountains (MacKevett, 1978). The diorite-gabbro-tonalite complex of Richter (1976) that intruded the Tetelna Volcanics yielded four $^{206}Pb/^{238}U$ ages on zircon of 290 to 316 Ma (Barker and Stern, 1986; Beard and Barker, 1989), indicating that Tetelna volcanism, at least, may have commenced in latest Mississippian (e.g., prior to 330 Ma) or earliest Pennsylvanian time.

Like the axial regions of other island arcs, the lower part of the Station Creek Formation and the Tetelna Volcanics consists largely of massive and pillowed to brecciated basalt and andesite flows 3 m to more than 100 m thick. Intercalated mud flows (lahars), pyroclastic breccias, fine- to coarse-grained volcaniclastic to limy sedimentary rocks, and lapilli tuffs also are present. Exposed thicknesses range from approximately 420 to 1,400 m (Bond, 1973, 1976; Richter, 1976; MacKevett, 1978; Nokleberg and others, 1985). The upper part of the Station Creek and the Slana Spur Formations consist of interlayered silty to conglomeratic volcaniclastic to calcareous sedimentary rocks, lapilli tuff, pyroclastic breccias, and basaltic to dacitic flows (Nokleberg and others, 1982). Thickness of these strata ranges from less than 300 to 2,300 m (Bond, 1973; Richter, 1976). They were metamorphosed, probably during accretion in mid-Cretaceous time, to prehnite-pumpellyite or greenschist facies, and locally to hornfels or amphibolite facies. These rocks, however, were penetratively deformed only near large faults.

Tables 4 and 5 (on microfiche) list 52 new analyses of various volcanic and hypabyssal rocks from the McCarthy, Nabesna, and Mount Hayes 1:250,000-scale Quadrangles and from southwestern Yukon. Ten of these are basalt (SiO_2 <53 percent), 20 are andesite (SiO_2 = 53 to 63 percent), seven are dacite (SiO_2 = 63 to 69 percent), and seven are low-K rhyolite. These analyses show much scatter in K_2O, Na_2O, CO_2, Rb, Sr, and other elements—even though samples free of weathered crusts, calcite or epidote veinlets, and amygdules were collected—that resulted from exposure to seawater and (or) metamorphic fluids. On an FeO^*/MgO versus SiO_2 plot (Fig. 9) samples of the arc from the McCarthy and Nabesna Quadrangles show little iron enrichment and are essentially calc-alkaline. Most samples from the Mount Hayes Quadrangle also show a calc-alkaline signature (Fig. 10). These rocks show moderate to pronounced light-REE enrichment, having La abundances 20 to 90 times chondrites. About half the samples show small negative Eu anomalies. REEs show no correlation with SiO_2. A spidergram of average Station Creek and Tetelna basalts compares moderately well with that of average calc-alkaline arc basalt of Pearce (1982), as shown in Figure 11—except that Nb and Ta of these Alaskan rocks show greater abundances. We judge that these Skolai island-arc rocks probably are of Gill's (1981) medium-K orogenic andesite class.

Strelna Metamorphics

Background. The term Strelna Metamorphics of Plafker and others (1989b), refers to the metamorphosed rocks formerly called the Strelna Formation by Moffit (1938), that are exposed along the southern margin of Wrangellia within and adjacent to the Chitina Valley and to the nonplutonic part of the Haley Creek terrane (Winkler and others, 1981) between the Copper River and Richardson Highway in the northern Chugach Mountains.

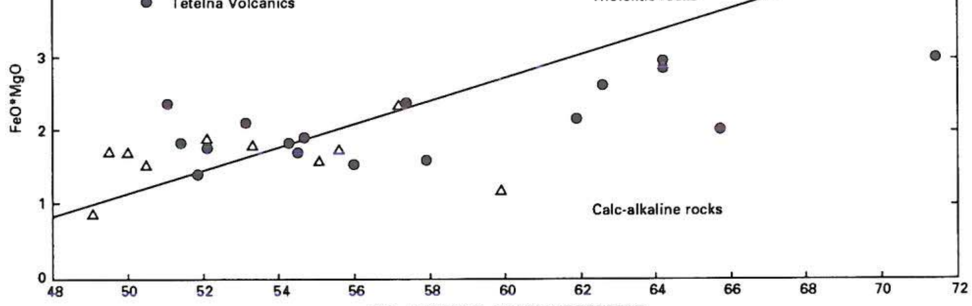

Figure 9. Plot of FeO^*/MgO versus SiO_2 of rocks from the Station Creek Formation and Tetelna Volcanics, Wrangellia terrane. Tholeiitic-calc-alkaline boundary after Miyashiro (1974).

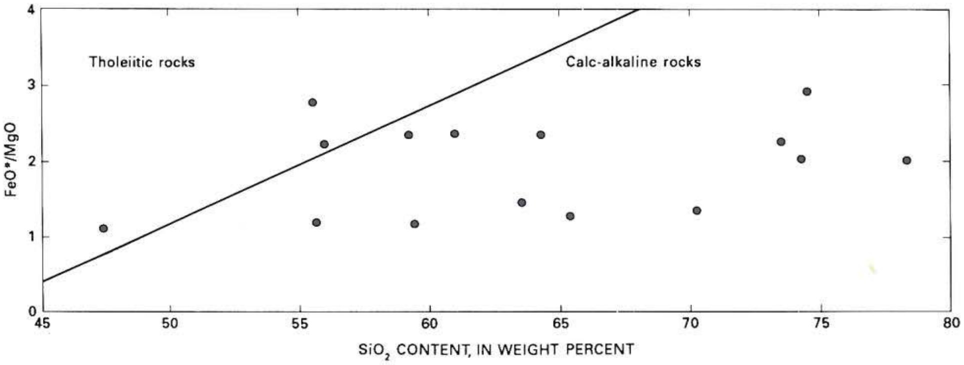

Figure 10. Plot of FeO*/MgO versus SiO_2 of volcanic rocks from the Pennsylvanian Tetelna Volcanics and Pennsylvanian and Permian Slana Spur Formation in the Slana River subterrane of the Wrangellia terrane, eastern Alaska Range. Tholeiitic-calc-alkaline boundary after Miyashiro (1974).

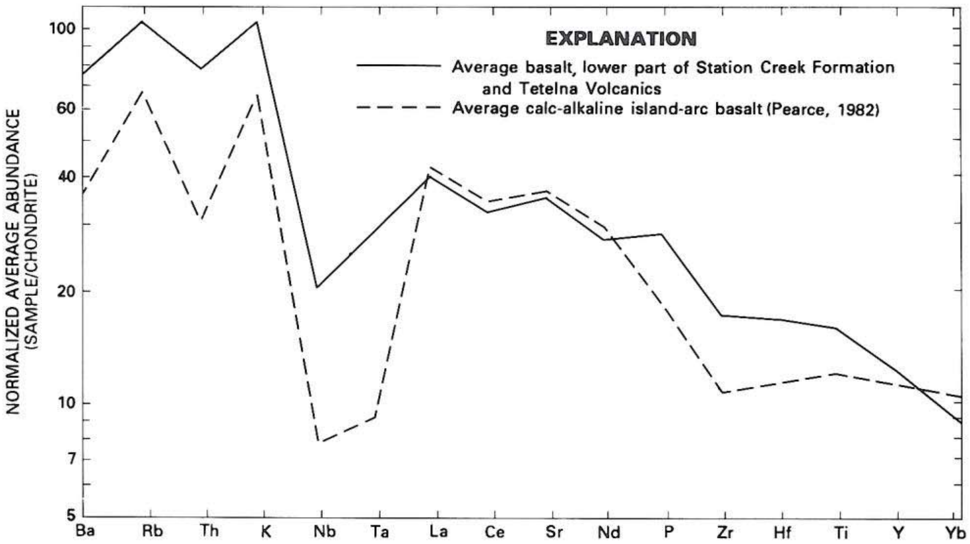

Figure 11. Spidergram of average basalt (samples having SiO_2 = 49.1 to 52.1 percent) of lower part of the Station Creek Formation and the Tetelna Volcanics, Wrangellia terrane, and spidergram of average calc-alkaline island-arc basalt (Pearce, 1982). Normalizing values from Thompson and others (1983).

Correlative rocks extend in a nearly continuous belt southeastward through adjacent parts of Canada (Campbell and Dodds, 1985), and possibly into the Yakutat Bay region (Barker and others, this volume, Plate 13). Within this belt, uplift has exposed deeper levels of basement rocks that consist of penetratively deformed greenschist- and amphibolite-facies metaandesite, metagraywacke, metachert, and many linear units of marble and schistose marble that are at least in part of Early Pennsylvanian age. The metamorphic rocks are intruded by abundant foliated plutonic rocks of the Late Jurassic Chitina Valley batholith (MacKevett, 1978) and an older suite of gneissic plutonic rocks, some of which are of Middle Pennsylvanian age (Aleinikoff and others, 1988). Geochemical data are available for only two samples of metabasite from the Strelna Metamorphics form the vicinity of the Copper River in the northern Chugach Mountains and two from the inferred correlative rocks near Yakutat Bay (Table 6, on microfiche).

Copper River area. Two analyzed samples of greenschist derived from volcanic rocks consist mainly of albite, quartz, epidote, and chlorite ± actinolite (samples 84APR213 and 84ANK155). Their mode of occurrence indicates that the volcanic rocks included massive flow units and thinner bedded units that were probably tuff or breccia intercalated with sedimentary rocks. Geochemically, they are tholeiites (50.1 to 52.1 percent SiO_2, 14.0 to 15.3 percent Al_2O_3, 5.3 to 8.7 percent MgO, 1.51 to 1.88 percent TiO_2) with a slight negative REE slope, La 9 to

12 × chondrites, and Lu 15 to 19 × chondrites. Though not plotted here, both samples lie within the tholeiite field on a plot of FeO^*/MgO versus SiO_2; they plot on a Th-Hf/3-Ta diagram as N-type MORB. On a Ti-Zr-Y diagram and similar discrimination diagrams, these samples plot in low-K tholeiite to ocean-floor basalt fields.

Yakutat area. In the Yakutat area our two samples of the Strelna(?) Metamorphics are tectonized, banded amphibolites that are cut by two generations of in-situ partial melt of trondhjemite. Though both samples show relatively high Al_2O_3 (17.5 to 18.0 percent), one is magnesian and low in incompatible elements (MgO = 8.25 percent, La = 5.3 ppm, Nb < 5 ppm, Zr = 107 ppm), and the other is of typical MgO and is enriched in incompatible elements (MgO = 5.65 percent, La = 31 ppm, Nb = 28 ppm, Zr = 217 ppm).

Interpretation. The Strelna Metamorphics are interpreted as representing a probable marine sequence of mixed quartzofeldspathic, pelitic, calcareous, and cherty rocks and variable amounts of mafic volcanic rocks that accumulated along the oceanward flank of a volcanic arc (Plafker and others, 1989b). These rocks are tentatively correlated with the less-metamorphosed and dominantly andesitic sequence that comprises the lower part of the Skolai arc (Station Creek Formation), although direct linkage with that unit cannot be demonstrated because of intervening faults.

NIKOLAI GREENSTONE: AN ARC-RIFT THOLEIITE

The Middle and (or) Upper Triassic Nikolai Greenstone is found in the Wrangell Mountains, eastern Alaska Range, and the Kluane Ranges of Yukon. Two occurrences of probable correlatives in southeastern Alaska are mentioned by Gehrels (this chapter). The Nikolai is a prominent formation of the Wrangellia section. It consists of 1,000 to 3,000 m of ferrotholeiite and local, intercalated volcaniclastic sedimentary rocks. The Nikolai unconformably overlies rocks of the Skolai arc; in many areas it conformably overlies approximately 100 m of unnamed Middle Triassic (Ladinian) chert, siltstone, and shale that bear a distinctive *Daonella* bivalve fauna; and it is disconformably overlain by the upper Karnian Chitistone Limestone (see summary of Jones and others, 1977; and Nokleberg and others, this volume, Chapter 10) or by younger rocks. The Nikolai typically shows a basal volcanic conglomerate approximately 70 m thick; but locally, in the McCarthy and Nabesna Quadrangles, interlayered pillow basalt and argillite are found (Richter, 1976; MacKevett, 1978). In these two quadrangles, this formation is largely aa and pahoehoe flows 5 cm to 20 m thick, which show amygdaloidal and typically oxidized tops. The Nikolai Greenstone of the Tangle subterrane, however, consists of a lower member of largely pillow basalt and an upper member of subaerial flows. Sills, dikes, and plugs of cogenetic gabbro and diabase are emplaced in or cut Nikolai flows; furthermore, Nokleberg and others (1982, 1985) also report that mafic to ultramafic sills containing abundant cumulus phases are found in, or subjacent to, the Nikolai Greenstone in the Mount Hayes Quadrangle. The Nikolai is correlative with the Karmutsen Formation of Vancouver Island and Queen Charlotte Islands (summary description by Barker and others, 1989).

Basalts of this formation typically are dark green-gray where fresh and brown, purple, or reddish where oxidized. They are massive and of ophitic texture; do not show penetrative deformation except near major faults; typically contain saussuritized labradorite phenocrysts and fresh or altered clinopyroxene phenocrysts; show serpentinized relicts of olivine; have altered matrices of chlorite, epidote, serpentine, Fe-Ti oxides, actinolite, and other minerals; and contain amygdules of quartz, calcite, chlorite, epidote, pumpellyite, prehnite, zeolites, and copper. Metamorphism mostly attained greenschist facies, but many samples show preprinting or overprinting of prehnite-pumpellyite or (and) zeolite facies (Richter, 1976; MacKevett, 1978; Nokleberg and others, 1982, 1985).

We present nine new major-minor-element analysis of the Nikolai Greenstone from the McCarthy and Nabesna Quadrangles and Kluane Ranges in Table 7 (on microfiche), and 18 from the Tangle subterrane of the Mount Hayes Quadrangle in Table 8 (on microfiche). These basalts, like those of other accreted oceanic rocks, show perturbed abundances of K_2O, Rb, Sr, Ba, and other mobile elements, but REEs (except Ce in some submarine rocks), high-field-strength elements (Sc, Ti, Y, Zr, and Nb), and transition elements (Cr, Mn, Fe, Co, and Ni) were largely or wholly immobile. Basalts of the Nikolai are ferruginous, most show FeO^*/MgO ratios greater than 1.5, and so are tholeiitic (see Miyashiro's discriminant, 1974). These FeO^*/MgO ratios are so high, except perhaps those of samples 82-25 and 78ANK155A, as to preclude origin directly from the mantle—that is, fractionation occurred prior to emplacement (see, e.g., Crawford and others, 1987). However, these basalts are not chemically homogeneous: like the correlative Karmutsen basalts of southern Wrangellia (Barker and others, 1989), they are of three types (Tables 7 and 8, on microfiche): (1) light-REE-depleted arc-type basalt, showing relatively low abundances of Ti, P, and Zr, and high abundances of Mg and Ni, as in sample 82-25; (2) a heavy-REE-depleted type, also low in Zr, as in samples 82-10 and 82-24; and (3) abundant, light-REE-enriched basalt, showing La at 20 to 30 times chondrites and heavy REEs at 10 to 19 times chondrites, and relatively high Ti, P, and Zr—compositions like those of back-arc-basin basalt (BABB) or mid-ocean-ridge tholeiite (MORB).

Three samples of the Nikolai Greenstone (Table 7, on microfiche) were analyzed for Sr and Nd isotopic ratios. These results, as calculated for a crystallization age of 220 Ma, are as follows:

Sample No.	$^{87}Sr/^{86}Sr$	$^{143}Nd/^{144}Nd$	ϵNd_o
82-9	0.70412	0.51264	+5.5
82-21	0.70369	0.51262	+5.2
82-25	0.70401	0.51255	+3.9

The $^{87}Sr/^{86}Sr$ ratios may be slightly higher than the primary or magmatic values, owing to interaction of these rocks with seawater or metamorphic fluids containing Sr of higher 87–86 ratios. Because Nd is relatively immobile in postmagmatic processes, the ϵNd_O values probably are magmatic. These Sr and Nd initial ratios are close to those of the mantle array. We note that ϵNd_O of +3.9 of sample 82-25, which is of the light-REE-depleted type of basalt, differs significantly from ϵNd_O of the other two samples—indicating that 82-25 came from different mantle than did the other, light-REE-enriched samples.

By analogy with the results of Barker and others (1989) on the origin of basalts of the Karmutsen Formation, we suggest that the Nikolai Greenstone originated by: (1) mixing of residual island-arc tholeiitic (IAT) magma, as exemplified by sample 82-25 (Table 7, on microfiche), and having ϵNd_O of +3.9 (as mentioned above), and a rift magma, as exemplified by the melts that were parental to samples 82-10 and 82-24 (Table 7, on microfiche), to produce a hybrid liquid; an (2) major fractionation of olivine, pyroxene(s), and plagioclase from this hybrid liquid to give the relatively abundant light-REE-enriched basalt (of ϵNd_O of +5.2 and 5.5 in two samples). Tectonic events causing extrusion of the 1- to 3-km-thick Nikolai pile, by further analogy with the Karmutsen Formation, were (1) rifting of the Skolai arc, (2) formation of a new frontal arc, (3) formation of a back-arc basin or rift and mixing and emplacement of arc-type and rift-type magmas as suggested above. Vallier (1986) has suggested the possibility that the frontal arc of this model, coeval with Nikolai and Karmutsen basalts, is found in the island-arc volcanic rocks of the Wild Sheep Creek and Doyle Creek Formations of the Wallowa terrane, Idaho and Oregon.

GRAVINA-NUTZOTIN BELT

C. M. Rubin and F. Barker

DEFINITION

The Gravina-Nutzotin belt, named and defined by Berg and others (1972), is a distinctive lithostratigraphic package of rocks that formed on the margins of the Alexander and Wrangellia terranes in Late Jurassic and Early Cretaceous time. The Gravina-Nutzotin belt exends from Ketchikan through southeastern Alaska to the vicinity of Haines, intermittently through the southwest Yukon Territory (Kindle, 1953; Muller, 1967), and into the easternmost Alaska Range (Richter and Jones, 1973b; Richter, 1976; MacKevett, 1978).

GRAVINA-NUTZOTIN BELT IN SOUTHEASTERN ALASKA

C. M. Rubin

Background

In southeastern Alaska the Gravina-Nutzotin belt consists of marine basinal volcanic and sedimentary strata that range in age from Oxfordian (Late Jurassic) to early Albian (Early Cretaceous). Age constraints, however, are scant. On Annette and Gravina Islands (southern southeastern Alaska), Gravina-Nutzotin belt volcanic and hypabyssal rocks locally intrude and appear to unconformably overlie Triassic strata of the Alexander terrane (Berg, 1972; Berg and others, 1988; Rubin and Saleeby, 1987b; Gehrels and Berg, this volume), and on Kupreanof and southern Admiralty Islands the Gravina-Nutzotin belt appears to lie disconformably on Triassic rocks of the Alexander terrane (Muffler, 1967; Loney, 1964). On Chilkat Peninsula, possible Gravina-Nutzotin belt flysch disconformably overlies upper Norian (Upper Triassic) chert of the Taku terrane (Plafker and others, 1989a). Elsewhere the boundary is marked by either a high-angle fault or, as on the Cleveland Peninsula (Ketchikan area), a northeast-dipping thrust fault (Rubin and Saleeby, 1987a). As the eastern boundary of the Gravina-Nutzotin belt is approached, there is a general increase in deformation and in grade of metamorphism; however, the nature of the boundary between the Gravina-Nutzotin belt and most parts of the Taku terrane is not well understood. At Berners Bay (55 km north of Juneau), Gravina-Nutzotin belt strata lie unconformably on metamorphic rocks that have been assigned to the Taku terrane (Redman, 1986) because they are on strike with the Taku rocks of Chilkat Peninsula to the north. However, these rocks have not been dated, and the correlations should be considered tentative.

Ketchikan area

The volcanic part of the Gravina-Nutzotin belt consists of phyric to aphyric, massive to pillowed, basalt and basaltic andesite lavas and silicic flows, which are locally known as the Gravina Island Formation (Berg, 1973; Berg and others, 1988; Rubin and Saleeby, 1987b). Metamorphic grade ranges from greenschist to amphibolite facies; deformation and metamorphic grade increase toward the east and northeast. The mafic volcanic rocks consist of flows, pillow breccia, mud-flow deposits or lahars, tuff, and pyroclastic breccia. This submarine volcanic sequence has a structural thickness of approximately 8 km. The mafic flows typically are dark gray and contain abundant phenocrysts of clinopyroxene and minor ones of hornblende and plagioclase. These rocks show minor to pervasive alteration of both the clinopyroxene and hornblende phenocrysts and the fine-grained matrix to chlorite and white mica. Augite porphyry dikes and sills intrude the volcanic section and are probably cogenetic with the extrusive rocks. Hornblendite xenoliths are common in the volcanic flows and augite porphyries. Elongate bodies of porphyritic diorite and quartz diorite of varied texture intrude the volcanic rocks and probably formed as subvolcanic feeders. The silicic volcanic rocks consist of quartz-phyric dacite flows and tuff. The average of selected elemental abundances of six basalts of the Gravina Island Formation gives SiO_2 at 49.1 percent, Al_2O_3 at 16.2 percent, total Fe as Fe_2O_3 at 9.6 percent, TiO_2 at 0.59 percent, P_2O_5 at 0.12 percent, La at 5.7 ppm, Zr at 51 ppm, Hf at 1.02 ppm, and Nb at 10 ppm.

The sedimentary part of the Gravina-Nutzotin belt consists of interbedded tuffaceous turbidites, argillaceous turbidites, and minor impure carbonate, conglomerate, lithic sandstone, and breccia. The turbidites are typically dark to pale gray finingupward sequences of tuffaceous argillite, lithic sandstone, and mudstone. Clasts from the channel-fill deposits consist of leucoquartz diorite to leucodiorite, argillite, and volcanic clasts in an argillaceous matrix.

Admiralty Island–Lynn Canal area

To the north, the volcanic parts of the Gravina-Nutzotin belt belong to the Douglas Island Volcanics and Brothers Volcanics and the correlative Bridget Cove Volcanics of Irvine (1973; Barker, 1957; Ford and Brew, 1973, 1977; Knopf, 1911; Lathram and others, 1965). These rocks consist of massive to pillowed basalt and andesite lavas, breccia, tuff, and volcanic mudflows. The mafic rocks are typically dark greenish gray and contain abundant phenocrysts of diopsidic augite and minor phenocrysts of plagioclase and magnetite (Irvine, 1973). The existence of olivine phenocrysts is inferred from chlorite pseudomorphs (Irvine, 1973). These rocks show minor to pervasive alteration of both clinopyroxene and matrix to chlorite, albite, calcite, and epidote. The exposed structural thickness of this section is approximately 9 km (Lathram and others, 1965; Loney, 1964). The sedimentary section of the Gravina-Nutzotin belt in this area consists of argillite and massive wacke with minor conglomerate; its estimated structural thickness is approximately 900 to 2,400 m (Loney, 1964).

The average elemental abundances of mafic metavolcanic strata of the Gravina-Nutzotin belt exposed on Douglas Island (immediately west of Juneau) are SiO_2 at 46.9 percent, Al_2O_3 at 13.1 percent, total Fe as Fe_2O_3 at 10.7 percent, TiO_2 at 0.74 percent, and P_2O_5 at 0.32 percent (Ford and Brew, 1987). Correlative metavolcanic strata, exposed at Berners Bay (Lynn Canal), have similar elemental abundances: SiO_2 at 48.2 percent, Al_2O_3 at 13.1 percent, total Fe as Fe_2O_3 at 10.7 percent, TiO_2 at 0.7 percent, and P_2O_5 at 0.41 percent (Ford and Brew, 1987). These geochemical data indicate a basalt to a high K-basalt protolith for the mafic metavolcanic rocks exposed on Douglas Island, Glass Peninsula, and Berners Bay.

The Gravina-Nutzotin belt volcanic-sedimentary package probably represents marine pyroclastic and volcaniclastic deposition within an arc-related basinal environment. The volcanic arc complex was constructed upon the Alexander terrane, and perhaps also on the Taku terrane during Late Jurassic to Early Cretaceous(?) time. Deformation probably occurred between early Albian time and 91 Ma, because of the presence of Albian ammonites in Gravina-Nutzotin belt strata on Etolin Island and crosscutting epidote-bearing plutons that yield Pb-U zircon ages of 91 to 94 Ma (Berg and others, 1972; Rubin and Saleeby, 1987b).

GRAVINA-NUTZOTIN BELT OF EASTERN ALASKA RANGE

F. Barker

In the Nutzotin Mountains of the eastern Alaska Range and in the adjacent Wrangell Mountains (Richter and Jones, 1973b; Richter, 1976) the lower, unnamed, sedimentary part of the Gravina-Nutzotin belt comprises predominant, shallow- to deep-water marine argillite, graywacke, and mudstone, and of minor conglomerate, impure limestone, local nonmarine sandstone, and other rocks. This section, whose base is not exposed and which lies in fault contact with older rocks, ranges in age from Tithonian (Late Jurassic) to Valanginian (Early Cretaceous) and is more than 3,000 m thick. This turbidite package, derived from Wrangellia (as known from paleocurrent directions, D. L. Jones, oral communication, 1983) and deposited on the margin of that oceanic complex, grades upward into the Chisana Formation (Richter and Jones, 1973b). The lowermost 600 m of the Chisana section consists of interbedded submarine lahars, basalt and andesite flows, tuff, volcaniclastic sedimentary rocks, and marine argillite, graywacke, and conglomerate. The upper part of the Chisana Formation, which is more than 2,500 m thick, consists of interlayered basalt and andesite flows, lahars, pyroclastic breccia, tuff, and volcaniclastic graywacke and conglomerate. The rocks are partly marine and partly continental. The Chisana is unconformably overlain by Upper Cretaceous continental sedimentary rocks (Richter and Jones, 1973b).

The flows, sills, and dikes in the Chisana Formation typically are dark greenish gray. They contain abundant phenocrysts of plagioclase (mostly labradorite) and minor ones of clinopyroxene and hornblende. These rocks show minor to pervasive alteration of both phenocrysts and their fine-grained matrices to albite, chlorite, calcite, and smectite. Lahars in the lowermost 600 m of the section are as thick as 100 m, contain blocks as large as 20 m, and are proximal to their volcanic source. Sedimentary xenoliths are common in the extrusive rocks. Pillow lava also is found in the lowermost 600 m of the marine section. A stock of hornblende diorite, heavily altered to albite, calcite, and chlorite, cuts the Chisana volcanic rocks and is believed to be cogenetic.

Table 9 (on microfiche) gives new major-minor-element analyses of ten basalts and six andesites of the Chisana Formation and of the associated diorite. The Chisana samples are Al_2O_3-rich, averaging 18.6 percent; even the three samples showing 20.6 to 22.1 Al_2O_3 have Eu/Eu^* ratios of about 1.07 to 1.2, so accumulation of plagioclase in these is only moderate. Because of disturbance of mobile elements (e.g., K_2O ranges from 0.13 to 1.82 percent), we use the FeO^*/MgO versus SiO_2 diagram (Miyashiro, 1974) to classify these rocks as tholeiitic transitional to calc-alkaline (Fig. 12). In Figure 13, spidergrams show average basalt of the Chisana plots—except for high Nb, P, and Sr—between Pearce's (1982) average tholeiitic and calc-alkaline island-arc basalts. The Chisana suite shows mild to pronounced light-REE enrichment, with La at 13 to 75 times chondrites. Lu is 6.5 to 12 times chondrites; nine samples show small to moderate positive Eu anomalies; and REE abundances do not correlate with SiO_2.

These basalts and andesites of the Chisana Formation form what Barker (1987) called the Chisana arc, a short-lived feature that formed on the northeast margin of the so-called (composite) Wrangellia-Alexander superterrane. This arc apparently formed

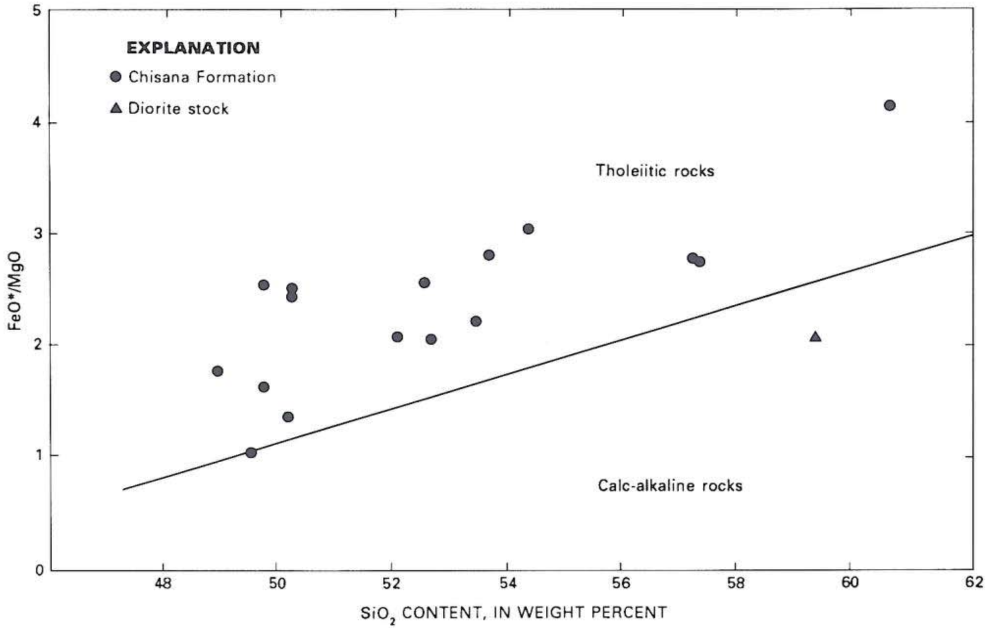

Figure 12. Plot of FeO*/MgO versus SiO_2 of rocks of the Chisana Formation and associated diorite stock, Gravina-Nutzotin belt, Nutzotin Mountains. Tholeiitic-calc-alkaline reference line from Miyashiro (1974).

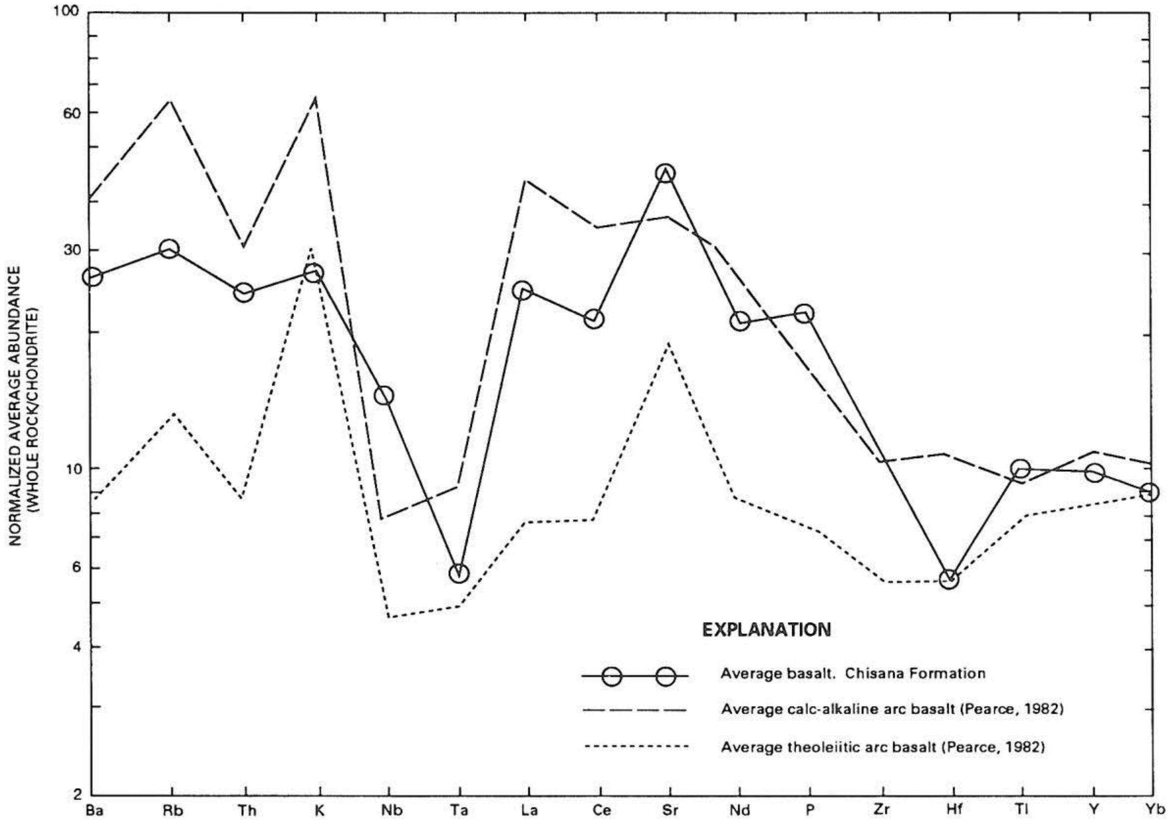

Figure 13. Spider diagram of average basalt of the Chisana Formation, Gravina-Nutzotin belt, and average tholeiitic basalt and calc-alkaline basalt of Pearce (1982).

in response to subduction, as this superterrane moved toward, and finally impinged on North America.

PRE–LATE CRETACEOUS VOLCANIC ROCKS OF THE BRISTOL BAY REGION, SOUTHWESTERN ALASKA

S. E. Box

Several terranes underlying broad areas of western Alaska have a major component of volcanic rocks of pre–Late Cretaceous age. They are the Koyukuk, Tozitna, Innoko, Togiak, Goodnews, Tikchik, and Nyack terranes (Jones and others, 1987; Silberling and others, this volume; and Patton and others, this volume, Chapter 7). None of these terranes shows evidence of a Precambrian continental basement or shows any associated quartzofeldspathic sedimentary rocks of continental derivation until late Early Cretaceous time. Their individual geologic histories suggest that these terranes originated by igneous processes in an oceanic-plate setting and were structurally thickened both during oceanic amalgamation events and during Early Cretaceous accretion against the older continental rocks of interior Alaska (Box, 1985a, b; Patton and others, this volume, Chapter 7; Decker and others, this volume). The geology and geochemistry of volcanic rocks from the northern part of this region (Koyukuk and Tozitna terranes) are discussed by Patton and others in this volume and will not be discussed further here. In this report the petrology, geochemistry, and stratigraphic context of the volcanic rocks of the southern part of western Alaska (Togiak, Goodnews, Tikchik, and Nyack terranes) are summarized by terrane. A broader interpretation of the tectonic histories of these latter terranes is given in Box (1985a, b) and Decker and others (this volume).

The Togiak terrane can be broadly divided into a lower unit of Late Triassic ophiolitic rocks depositionally overlain by an upper unit of Lower Jurassic through Lower Cretaceous volcanic rocks. The partly disrupted ophiolitic section consists of a 2-km-thick pillow basalt sequence that grades downward by increasing intrusion into a sheeted diabase sill complex. The sill complex is faulted against unlayered gabbroic intrusive rocks that grade in some places into layered gabbros and are faulted over serpentinized harzburgites and dunites. The pillow basalts are interbedded with red radiolarian cherts of Late Triassic age. The pillow basalts grade upward through a thick sequence of basaltic breccia and epiclastic strata into the upper unit of Lower Jurassic through Lower Cretaceous volcanic, pyroclastic, and epiclastic strata, which includes indications of shallow-marine deposition. Important unconformities of late Early Jurassic and latest Jurassic age occur within the upper unit.

The petrology and geochemistry of the two broad units of the Togiak terrane are distinct. Amygdaloidal pillow lavas and diabase sills of the lower unit are aphyric to sparsely porphyritic with a subophitic texture of intergrown plagioclase and clinopyroxene. Rocks are generally basaltic but range upward in SiO_2 content to basaltic andesites. TiO_2 contents are generally above 1.5 percent and K_2O contents are low (0.04 to 0.73 percent), and the rocks plot in the tholeiitic field on an AFM diagram. The rocks generally plot in a MORB-OIB field on Ba versus Nb and K_2O versus Nb plots (Fig. 13). Because of their relatively high TiO_2 and Nb contents, the basalts of the lower unit are more like lavas of ocean islands, seamounts, or elevated parts of mid-ocean ridges ("E-MORB") than typical lavas of the deeper parts of the mid-ocean ridges ("N-MORB"; Sun and others, 1979; BVSP, 1981; Thompson and others, 1984). In contrast, the lavas of the upper unit are strongly plagioclase-phyric and contain minor clinopyroxene, hornblende, and orthopyroxene, and rare biotite phenocrysts. They range from basalts to high-silica andesites; andesites are predominant. TiO_2 contents are moderate (0.65 to 1.6 percent), K_2O contents are moderate (0.5 to 2.2 percent), and the rocks fall in both the tholeiitic and calc-alkaline fields of the AFM diagram. The rocks show strong enrichment of alkaline elements relative to high-field-strength elements (e.g., Ba versus Nb and K_2O versus Nb plots in Fig. 14), the primary distinguishing characteristic of convergent-margin volcanism (Gill, 1981; BVSP, 1981; Thompson and others, 1984). The igneous history of the Togiak terrane records a Late Triassic (and older?) episode of nonarc, ocean-island volcanism succeeded by an Early Jurassic to Early Cretaceous period of island-arc volcanism.

The Goodnews terrane is a structurally complex assemblage of pillowed basalt flows, mafic and ultramafic rocks, cherts, limestones, and fine tuffaceous sedimentary rocks ranging from Late Devonian to Late Jurassic in age. The terrane was amalgamated against the Togiak terrane in two stages (late Early Jurassic and latest Jurassic), prior to Early Cretaceous accretion against the Precambrian continental rocks of the Kilbuck terrane (Box, 1985a, b; Decker and others, this volume). Volcanic and plutonic rocks of the Togiak terrane overlapped rocks of Goodnews terrane rocks after each amalgamation event. Preamalgamation volcanic flows of Permian age are widespread in the Goodnews terrane (Hoare and Coonrad, 1978); however, the bulk of these volcanic rocks are only known to be of pre–Early Cretaceous age.

Our geochemical database for lavas of the Goodnews terrane consists of major-element analyses from six samples, and trace-element data (XRF analyses only) from four samples. Flows are generally pillowed, and in some places are vesicular. They are generally aphyric or weakly prophyritic and have intergrown plagioclase and clinopyroxene. All flows are basalts, have moderate TiO_2 contents (0.9 to 1.5 percent), low K_2O contents (0.01 to 0.17), and plot in the tholeiitic field on an AFM diagram. On Ba versus Nb and K_2O versus Nb diagrams (Fig. 14), these rocks plot in the MORB-OIB field. Given the limited database, I feel confident only in coming to the general conclusion that these rocks were erupted in a nonarc oceanic-plate setting.

No geochemical data are presently available for volcanic rocks from the Nyack or Tikchik terranes. Petrographic and lithologic data from the Nyack terrane indicate that it is generally similar to the Togiak terrane in the predominance of plagioclase phyric flows and abundance of interbedded volcaniclastic strata of Middle and Late Jurassic age. The general lithologic assemblage of the Tikchik terrane—a structurally complex assemblage of basalt, chert, and limestone—resembles that of the Goodnews terrane. Tikchik flows consist of scattered occurrences as well as a thick section of mafic flows and volcanic breccias that are bracketed in time by Permian and Triassic calcareous strata. This thick section includes both aphyric and plagioclase and (or) clinopyroxene porphyries. We infer that Tikchik lavas represent nonarc, oceanic-plate volcanism by analogy with flows of the Goodnews terrane.

PENINSULAR TERRANE

TALKEETNA FORMATION

F. Barker and J. S. Kelley

The Peninsular terrane of southern Alaska contains a remnant of an intraoceanic island arc (A. Grantz, unpublished data, 1961; Moore and Connelly, 1977; Barker and Grantz, 1982)—termed the Talkeetna island arc—that now is exposed as

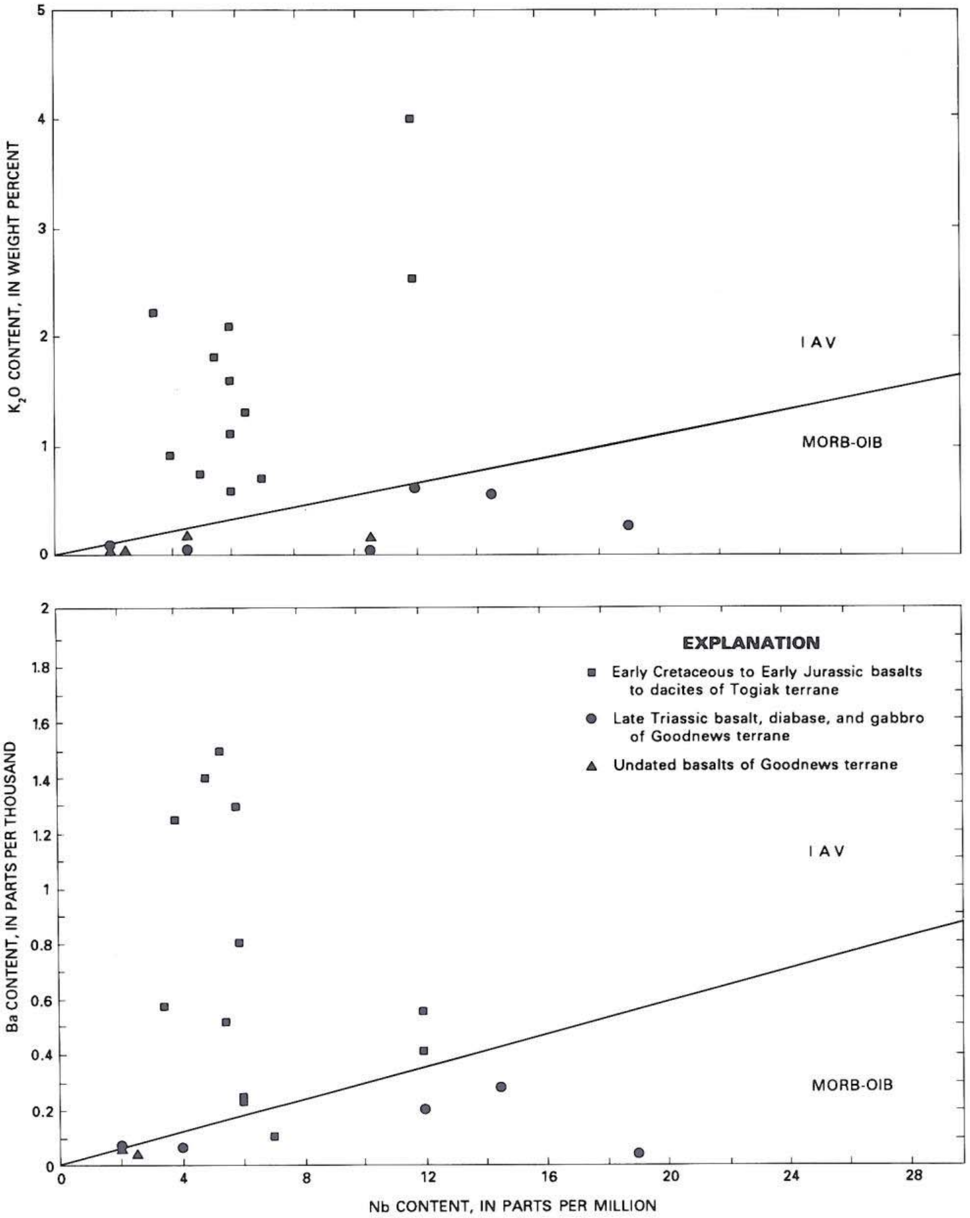

Figure 14. Plots of K_2O and Ba against Nb for samples from the Togiak and Goodnews terranes of southwestern Alaska. Line separating island-arc volcanic rocks (IAV) from mid-ocean-ridge basalt (MORB) and ocean-island basalt (OIB) from Thompson and others (1984) for the K_2O versus Nb, and from Gill (1981) for Ba versus Nb.

the Talkeetna Formation and related plutonic rocks. The Talkeetna Formation (see, e.g., Martin, 1926; Grantz, 1960a, b; Imlay and Detterman, 1973; Detterman and Hartsock, 1966; Detterman and Reed, 1980; Winkler and others, 1981) is exposed in the Talkeetna Mountains, the northern Chugach Mountains, and in the Alaska-Aleutian Range west of Cook Inlet; is of Early Jurassic age (early Sinemurian or older to late Toarcian in the type area); is at least 2,000 m and probably more than 3,000 m thick; and consists of marine and nonmarine pyroclastic breccia, lahars, tuff, silty to cobbly graywacke, flows and sills of basalt and andesite, and other rocks. Older rocks have not been recognized in the Talkeetna Mountains but may be present.

Older parts of the Talkeetna island arc, however, are found well to the southwest of the type area. Martin and others (1915) and Kelley (1980, 1984, 1985) report that 4,000 to 5,300 m of lower Hettangian to lower Sinemurian (earliest Jurassic) rocks are found on Kenai Peninsula between Port Graham and Seldovia. Deep-water marine andesitic to dacitic pyroclastic flows, volcaniclastic turbidites, tuffs, and other rocks range upward to shallow marine and nonmarine volcaniclastic sedimentary rocks and thin beds of coquina and coal. Informally termed the Pogibshi sequence by Kelley (1985), these rocks consist of lower offlap and upper onlap deposits. They overlie Norian (Upper Triassic) to Early Jurassic(?) argillite, limestone, and volcaniclastic rocks. Cowan and Boss (1978) report that 600 m of Talkeetna island-arc rocks are exposed southwest of the Kenai Peninsula in the Barren Islands.

The oldest known evidence of activity in the Talkeetna Island arc is found in the Norian rocks of Afognak and Kodiak Islands and the Alaska Peninsula (Moore and Connelly, 1977; Hill, 1979; Detterman and Reed, 1980). In the latter locality Detterman and Reed (1980) named the Cottonwood Bay Greenstone and the Kamishak Formation.

We present ten new analyses of rocks of the Talkeetna Formation from the well-exposed 1,000 m section of Glacial Fan Creek–Gunsight Mountain, eastern Talkeetna Mountains, and four analyses elsewhere in that range (Table 10, on microfiche). The Glacial Fan–Gunsight section is a heterogeneous one consisting of approximately 40 percent massive mud-flow deposits and pyroclastic breccias, approximately 40 percent airfall and water-laid lapilli tuff and fine-grained breccia, approximately 10 percent flows and sills of basalt and andesite, and the remainder of buff to reddish purple silty to cobbly graywacke. Most clasts of the fragmental rocks are plagioclase-phenocrystic basalt and andesite. Original magmatic phases, except for the relict clinopyroxene, have been altered to albite, epidote, chlorite, calcite, serpentine, zeolites, smectite, Fe-Ti oxides, and other phases. The tuffs contain 20 to 50 percent albitized plagioclase phenocrysts and minor clinopyroxene and (or) embayed quartz set in a matrix of highly altered glass and minerals. The flows are also rich in relict phenocrysts of plagioclase. A plug of 125 m diameter at Glacial Fan Creek also was analyzed (no. B80A-19, Table 10, on microfiche). The two most siliceous clasts (Table 10, on microfiche) contain embayed quartz crystals as well as abundant plagioclase.

The samples comprise three dikes, three flows, three water-laid tuffs, three clasts of breccias, and a sill, as well as the plug—so the number of extrusive cycles represented is not known. Abundances of Na, K, Rb, Sr, and Ba show much variability or mobility, as do Ca and Fe in samples B81A-37 and 79AGx-9, resulting from exposure to seawater and (or) metamorphic fluids. Though classification by alkalies cannot be used, the FeO^*/MgO versus SiO_2 (where $FeO^* = FeO+0.9Fe_2O_3$) plot (Fig. 15) of Miyashiro (1974) indicates that the basalt and andesite are tholeiitic, and the more siliceous rocks are calc-alkaline. On a spidergram of 16 elements (Fig. 16), of which 12 are relatively immobile in alteration processes, the average Talkeetna basalt plots between Pearce's (1982) average island-arc tholeiite and calc-alkaline basalt—a position that agrees with the near-transitional result of Figure 15. The low Nb and Ta, and the generally high Sr abundances are typical of island-arc basalt. Rare-earth elements (REEs) show La at approximately 10 to 28 times, and Lu at 7 to 18 times chondritic values. REE abundances do not correlate with SiO_2, which we interpret to mean that these samples are not related by simple crystal-liquid fractionation of pyroxene, plagioclase, and olivine. The moderately light-REE enrichment may mean that the Talkeetna arc is of medium-K type, as defined by Gill (1981). Average abundances of Zr at 66 ppm, Hf at 1.8 ppm, Ni at 22 ppm, and Co at 34 ppm, as well as least-disturbed(?) K_2O contents of 0.78 to 1.17 percent at 52.4 to 56.5 percent SiO_2 (Table 10, on microfiche), fit the medium-K class better than any other.

SHUYAK FORMATION

M. D. Hill

The oldest known evidence of activity of the Talkeetna island arc of the Peninsula terrane is found in the Norian (Upper Triassic) Shuyak Formation of the Afognak and Shuyak Islands (with possible correlatives at Middle Cape on Kodiak Island); at Port Graham on Kenai Peninsula; in unnamed units at Puale Bay on the Alaska Peninsula (Moore and Connelly, 1977; Connelly and Moore, 1977; Connelly, 1978); and in the Cottonwood Bay Greenstone of the Iliamna region, which is overlain by Norian limestone of the Kamishak Formation (Detterman and Reed, 1980). In the Shuyak Formation, *Halobia*-bearing (early to middle Norian) arc-derived volcaniclastic turbidites intruded by diabase sills structurally overlie a thick sequence of pillow basalts, some with interpillow limestone matrix (Connelly, 1978; Hill, 1979).

At Puale Bay, basaltic flows, agglomerate and conglomerate are interbedded with *Monotis*-bearing limestone and siltstone (Moore, 1967; Imlay and Detterman, 1977; Newton, 1983). In contrast, basaltic andesite to andesite cobbles predominate in conglomerates of uncertain age (probably older than Norian) that are exposed on the small islets 6 to 8 km southwest of Cape Kerkurnoi (Hill, 1979). The undated Middle Cape sequence on Kodiak Island tentatively has been correlated with the Shuyak

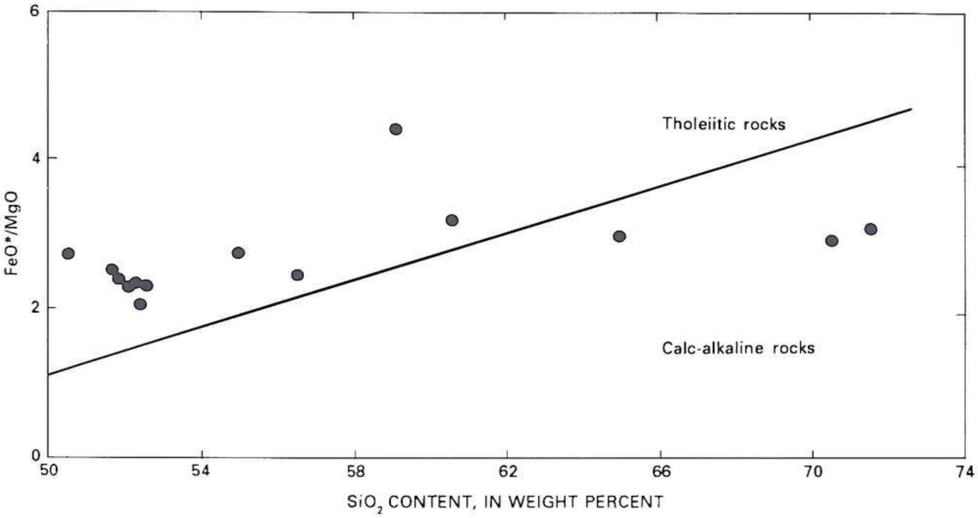

Figure 15. Plot of FeO*/MgO versus SiO_2 of rocks of the Talkeetna Formation, Talkeetna Mountains, Peninsula terrane. Boundary separating tholeiitic rocks from calc-alkaline rocks from Miyashiro (1974).

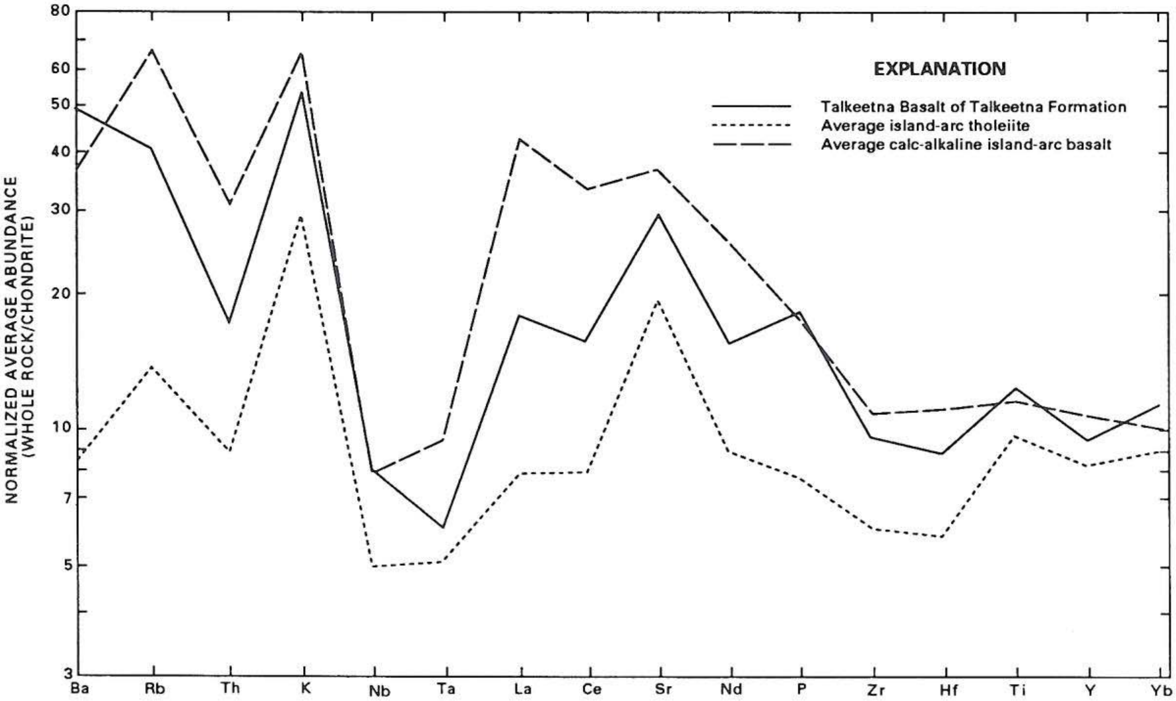

Figure 16. Spidergram of average basalt (samples having SiO_2 = 50.5 to 52.6 percent) of the Talkeetna Formation, Peninsula terrane, and spidergrams of average island-arc tholeiite and calc-alkaline basalt from Pearce (1982).

Formation because of its stratigraphic position (Connelly and Moore, 1977; Connelly, 1978).

Volcanic Geochemistry

The greenstones of the Shuyak Formation are prehnite-pumpellyite–grade metabasalts. Twenty-two analyses are given in Table 11 (on microfiche, with four samples from the Middle Cape sequence on Kodiak Island and six from the unnamed Norian (and older?) strata at Puale Bay. There are two distinct varieties of basalt in the Shuyak Formation—a low-Ti group (0.4 to 1.0 percent TiO_2) and a high-Ti group (1.7 to 3.1 percent TiO_2). The two are not clearly separated in the field, although the high-Ti basalts are more common in the lower part of the sequence. Both groups are subalkaline (high Y/Nb = 2 to 18, and high Zr/Nb = 8 to 29, Table 11A, on microfiche), and cannot be related by low-pressure fractional crystallization (Hill, 1979). The low-Ti suite is LREE—depleted and enriched in Sc, Cr, Co, and Ni (Table 11A, on microfiche); the high-Ti group is LREE-enriched and contains less Sc, Cr, Co, and Ni. On a spider diagram, neither group displays significant depletion of Ta-Nb or Zr-Hf, which is commonly seen in many arc basalts. Hill (1979) described equivocal results for the Shuyak Formation when Ti, Zr, Y, and Ni were used in a discriminant-analysis comparison against basalts from known tectonic environments. This phase of Talkeetna island arc volcanism is more enriched in Fe-Cr-Ni than is common among modern arc tholeiites.

In contrast, the section at Middle Cape contains calc-alkaline dacite to rhyodacite (Table 11B, on microfiche; and Fig. 17) The basalts on the mainland at Puale Bay ("P2-xx" samples in Table 11B, on microfiche and the basaltic-andesite to andesite cobbles of the offshore islets ("P3-xx" samples) are transitional to calc-alkaline in nature (Fig. 17). They include high-alumina compositions, and the low Zr and high Sr contents are typical of arc volcanic rocks.

CHUGACH TERRANE

G. Plafker, M. D. Hill, J. Lull, and F. Barker

TECTONIC SETTING

The Chugach terrane consists of accreted deep-sea sedimentary rocks and oceanic crustal rocks that form a continuous belt approximately 2,000 km long and 60 to 100 km wide in the coastal mountains of southern Alaska (Plafker and others, 1977; Plafker and others, this volume, Chapter 12). Volcanic rocks occur in three main units in the Chugach terrane (Barker and others, this volume, Plate 13). From north to south these units are: (1) Early Jurassic or older coherent blocks and bands of glaucophanic greenschist that include the schists of Raspberry Strait, Seldovia, Iceberg Lake, and Liberty Creek; (2) Late Triassic to mid-Cretaceous mélange of the Uyak Complex, McHugh Complex, Kelp Bay Group, and Yakutat Group; and (3) Upper Cretaceous basaltic volcanic rocks and minor andesitic rocks of the Valdez Group. The volcanic rocks of units (1) and (2) may represent different metamorphic facies of the same mélange protolith.

Basement rocks of the eastern Yakutat terrane are included in this discussion because they are interpreted to be an allochthonous fragment of the Chugach terrane that has been displaced to its present position from the continental margin of southeastern Alaska and (or) British Columbia by movement on the Fairweather fault (Plafker, 1987; Plafker and others, this volume, Chapter 12). Undated pillowed greenstone and related igneous rocks on the Resurrection Peninsula near Seward, previously considered to be correlative with the Valdez Group, have been tentatively assigned to the Paleocene Ghost Rocks terrane south of the Chugach terrane, because of lithologic and paleomagnetic similarities with the Ghost Rocks Formation of Plafker and others (this volume, Chapter 12) of Kodiak Island (Plafker, 1987; and see Hill, this chapter).

Rocks of the Chugach terrane range in age from Late Triassic through Late Cretaceous. The rocks are generally moderately to strongly deformed and locally are multiply deformed. They are variably metamorphosed to glaucophanic greenschist facies and zeolite to amphibolite facies (Dusel-Bacon, this volume, Chapter 15), and they are extensively intruded and locally thermally metamorphosed by Paleocene and Eocene plutons and dikes (Moll-Stalcup, this volume). Terrane boundaries are the Border Ranges fault system on the north and the Contact, Chugach–Saint Elias, and Fairweather faults to the south (Plafker and others, this volume, Chapter 12).

BLUESCHIST-GREENSCHIST UNIT

Glaucophane-bearing blueschist and greenschist of Early Jurassic age and mid-Cretaceous age are exposed intermittently

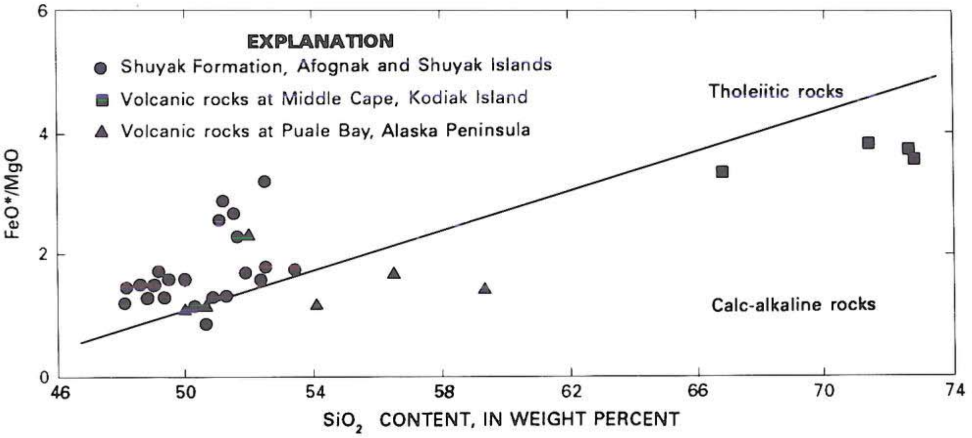

Figure 17. Plot of FeO*/MgO versus SiO_2 of rocks of the Shuyak Formation, unnamed volcanic rocks at Puale Bay and at Middle Cape, Peninsula terrane. Tholeiitic-calc-alkaline boundary from Miyashiro (1974).

along and near the northern margin of the Chugach terrane (Barker and others, this volume, Plate 13), as summarized by Roeske (1986). Although Roeske included the fault-bounded blueschist and greenschist of the Kodiak Islands area as Peninsular terrane, we here consider it to be part of the Chugach terrane, because of its similarities in age and lithology to comparable schists on strike with those of the Chugach terrane, and because of its structural position relative to the Peninsular terrane. The unit consists predominantly of metabasites, including pillows, tuffs, and tuff breccias, and subordinate metachert, metagraywacke, and metapelite. Geochemical analyses are available for the schists of Liberty Creek (three samples) and Iceberg Lake (one sample), which are described below.

Schists of Liberty Creek and Iceberg Lake

Background. The schists of Liberty Creek (Metz, 1976; Plafker and others, this volume, Chapter 12) and Iceberg Lake (Winkler and others, 1981) form elongated, fault-bounded belts of about 280 km^2 and 120 km^2, respectively, in the northern Chugach Mountains.

The schist of Liberty Creek consists predominantly of regionally metamorphosed and multiply deformed, mafic volcanic rocks and minor pelitic rocks. Millimeter-scale crenulated lamination is characteristic. Rarely, the more massive greenschist exhibits faint primary structures suggestive of breccia and possible pillow breccia. Greenschist-facies mineral assemblages (epidote-rich actinolite-albite schist ± chlorite, quartz, calcite, and white mica) are intercalated with sparse bands and lenses from a few millimeters to a few centimeters wide containing variable amounts of very fine-grained blue amphibole (<0.1 mm) that is mainly crossite. Lawsonite has been found at only one locality in the schist of Liberty Creek, but in many places in the schist of Iceberg Lake (Winkler and others, 1981). Highly deformed carbonaceous (graphitic?) phyllite occurs locally as pods and irregular anastomosing layers as much as a few meters thick within the metavolcanic rocks. The lithology and mineralogy of the schist of Iceberg Lake are similar to the schist of Liberty Creek except that the schist of Iceberg Lake contains more chert and pelitic rocks, is coarser grained (0.1 to 0.7 mm), and the blueschist locally contains garnet.

Volcanic Geochemistry. Major- and minor-element analyses of three samples of greenschist from the schist of Liberty Creek and one from blueschist at Iceberg Lake are available (Table 12, on microfiche; and Figs. 18 through 20). The Liberty Creek rocks are basalts but show wide variations in the abundances of silica, CO$_2$, and other mobile elements (49.7 to 58.5 percent SiO$_2$; 0.08 to 2.3 percent K$_2$O; 0.63 to 2.85 percent NaO$_2$) as a result of mineral alteration and the presence of fine veinlets of quartz and calcite. The high-field-strength elements and transition elements were largely or wholly immobile (e.g., 1.03 to 1.93 percent TiO$_2$, and FeO*/MgO is 1.8 to 3.3). Two of the samples plot in the tholeiitic field and the high-silica sample (84ANK152) plots in the calc-alkaline field on an AFM diagram (Fig. 18). All three samples have nearly identical REE patterns that closely match the pattern for average N-type MORB at about 7 to 19 × chondrite with slight depletion of LREE over HREE (Fig. 19). All samples plot in the field of N-type MORB (Wood, 1980) on the Th-Hf-Ta discrimination diagram (Fig. 20).

The sample from the schist of Iceberg Lake (84APr136A, Table 12, on microfiche) is a blue amphibole-bearing pillow basalt (49.0 percent SiO$_2$, 1.0 percent K$_2$O) that is geochemically similar to the least altered samples from the schist of Liberty Creek, except for a slightly higher Na$_2$O content (3.24 percent versus 0.63 to 2.85 percent).

Interpretation. The lithology and geochemistry of the metavolcanic rocks suggest that the schists of Liberty Creek and Iceberg Lake are oceanic tholeiites that were subducted with dominantly pelagic sediments at a convergent plate margin. The blueschist of the Iceberg Lake unit has a metamorphic age of 186 ± 1.5 Ma based on Ar^{40}/Ar^{39} on phengite (Sisson and Onstott, 1986) and K-Ar ages on crossite as old as 175 ± 5 Ma (Winkler and others, 1981)—a date that probably approximates the time of subduction. This age is close to the K-Ar age of 192 Ma reported by Roeske (1986) for glaucophane-bearing blueschist from Kodiak Island. The metamorphic age of the schist of Liberty Creek is assumed to be similar, but has not yet been determined.

The protolith age of the schists of Liberty Creek and Iceberg Lake is not known; their position in the accretionary complex indicates only that they are probably older than the less-metamorphosed, paleontologically dated Upper Triassic to mid-Cretaceous part of the McHugh Complex to the south (Winkler and others, 1981). Transitional blueschist-facies rocks of Early to Middle Jurassic metamorphic ages occur in close association with Upper Triassic oceanic rocks that include paleontologically dated radiolarian chert along the south side of the Border Ranges fault system (Jones and others, 1987). This association suggests the likelihood that the glaucophanic greenschist is a more deeply subducted part of the oldest part of the mélange unit described below.

MÉLANGE UNIT

The mélange unit of the Chugach terrane crops out as a nearly continuous fault-bounded belt as wide as 20 km that extends almost 500 km through the Kodiak Islands (Uyak Complex) and the northern margin of the Kenai and Chugach Mountains (McHugh Complex). Lithologically and, at least partially, temporally equivalent rocks are also exposed in a belt extending from the Tarr Inlet area of Glacier Bay to Chichagof and Baranof Islands (Kelp Bay Group), and as part of the allochthonous Yakutat terrane in the Yakutat Bay area (mélange of the Yakutat Group). In those areas, however, the contact relationships of the mélange have been obscured by structural interleaving with flysch and metasedimentary rocks along strike-slip faults related to the Fairweather fault system. The mélange unit consists of mixed oceanic basalt and sedimentary rocks, arc-derived volcanic and sedimentary rocks, and variable numbers of

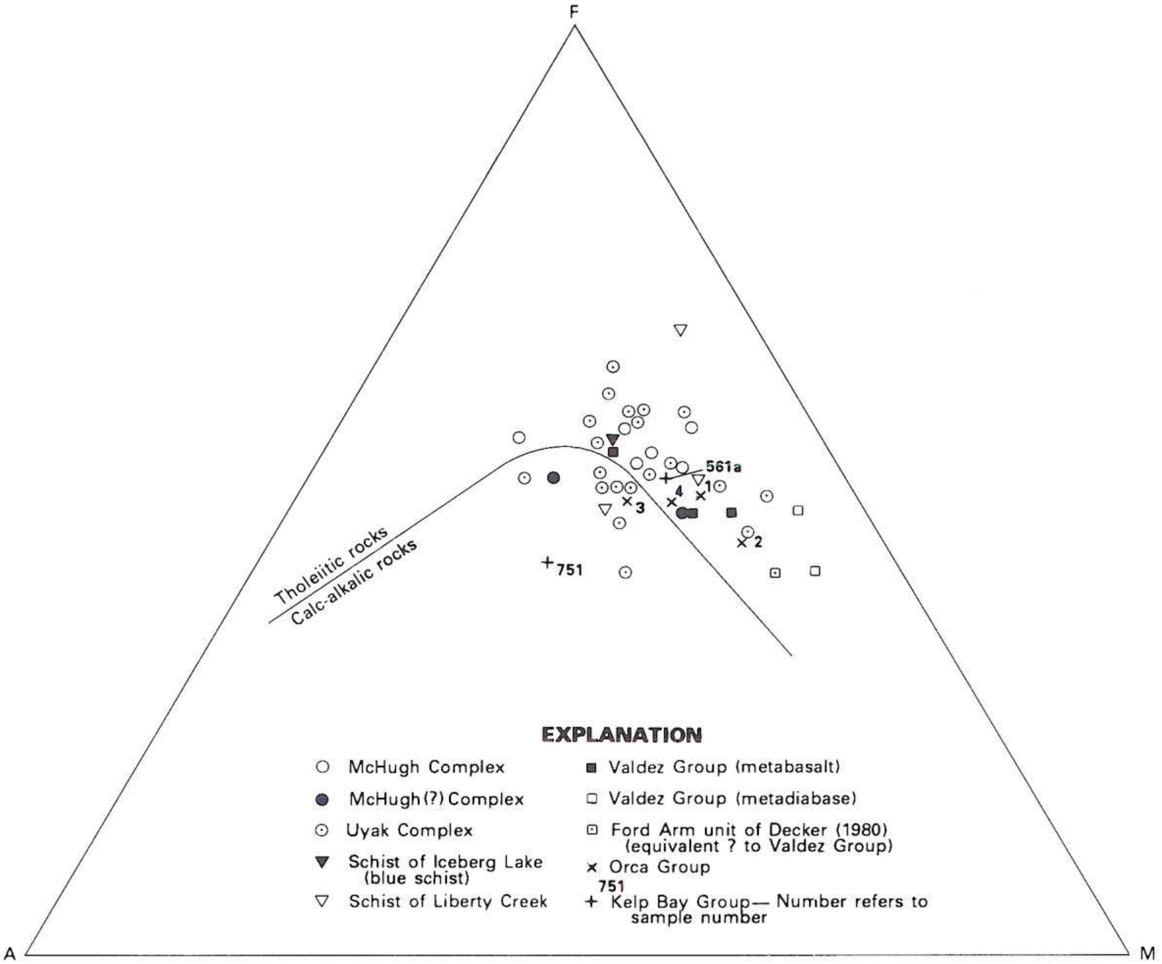

Figure 18. AFM diagram of mafic volcanic and shallow intrusive rocks of the Chugach terrane.

olistostromal blocks (Plafker and others, 1977; Plafker and others, this volume, Chapter 12).

Uyak Complex

Background. The Uyak Complex is a prehnite-pumpellyite-grade tectonic mélange that contains fossils ranging in age from mid-Permian to middle Early Cretaceous. It is exposed on Kodiak, Afognak, and Shuyak Islands (Connelly and Moore, 1977). It contains blocks of chert, greenstone, gabbro and ultramafic rocks, limestone, tuff, argillite, and graywacke (Connelly, 1978). The Uyak Complex is in contact with the Jurassic blueschist-facies Raspberry Schist of Roeske (1986) to the northwest along an unnamed fault that was correlated with the Border Ranges fault by Roeske (1986). Plafker and others (this volume, Chapter 12) believe the contact lies south of the Border Ranges fault. The Uganik thrust separates the Uyak Complex from the Upper Cretaceous (Maastrichtian) turbidites of the Kodiak Formation to the southeast. Connelly (1978) noted that a gently deformed sequence of Upper Cretaceous volcanic and sedimentary rocks (Cape Current terrane) occurs along the Uganik thrust on Shuyak Island (Connelly and Moore, 1977). Similar rocks, much less deformed than the neighboring Uyak Complex or Kodiak Formation to either side, are exposed along the west shore of Raspberry Strait on Kodiak Island, west of Dolphin Point. Two samples in Table 13 (on microfiche) are from that sequence.

Volcanic Geochemistry. The greenstones of the Uyak Complex are prehnite-pumpellyite-grade metabasalts (Table 13, on microfiche). They are subalkaline, and have high Y/Nb (2 to 15) and Zr/Nb (>6). Most samples plot in the tholeiitic field on Figure 21. Hill (1979) found that a discriminant analysis using Ti, Zr, Y, and Ni indicates that 94 percent of the basalts of the Uyak Complex are similar to ocean-ridge basalts. On a MORB-normalized spider diagram (not shown: data in Table 13, on microfiche), these samples display horizontal patterns clustering around 1.0, typical of MORB, for all elements except the highly mobile alkalies and alkaline earths.

The younger Upper Cretaceous(?) basalts within the Uganik thrust belt (V2-lw and V7-lz) are indistinguishable from the basalts of the Uyak Complex (Table 13, on microfiche; Barker

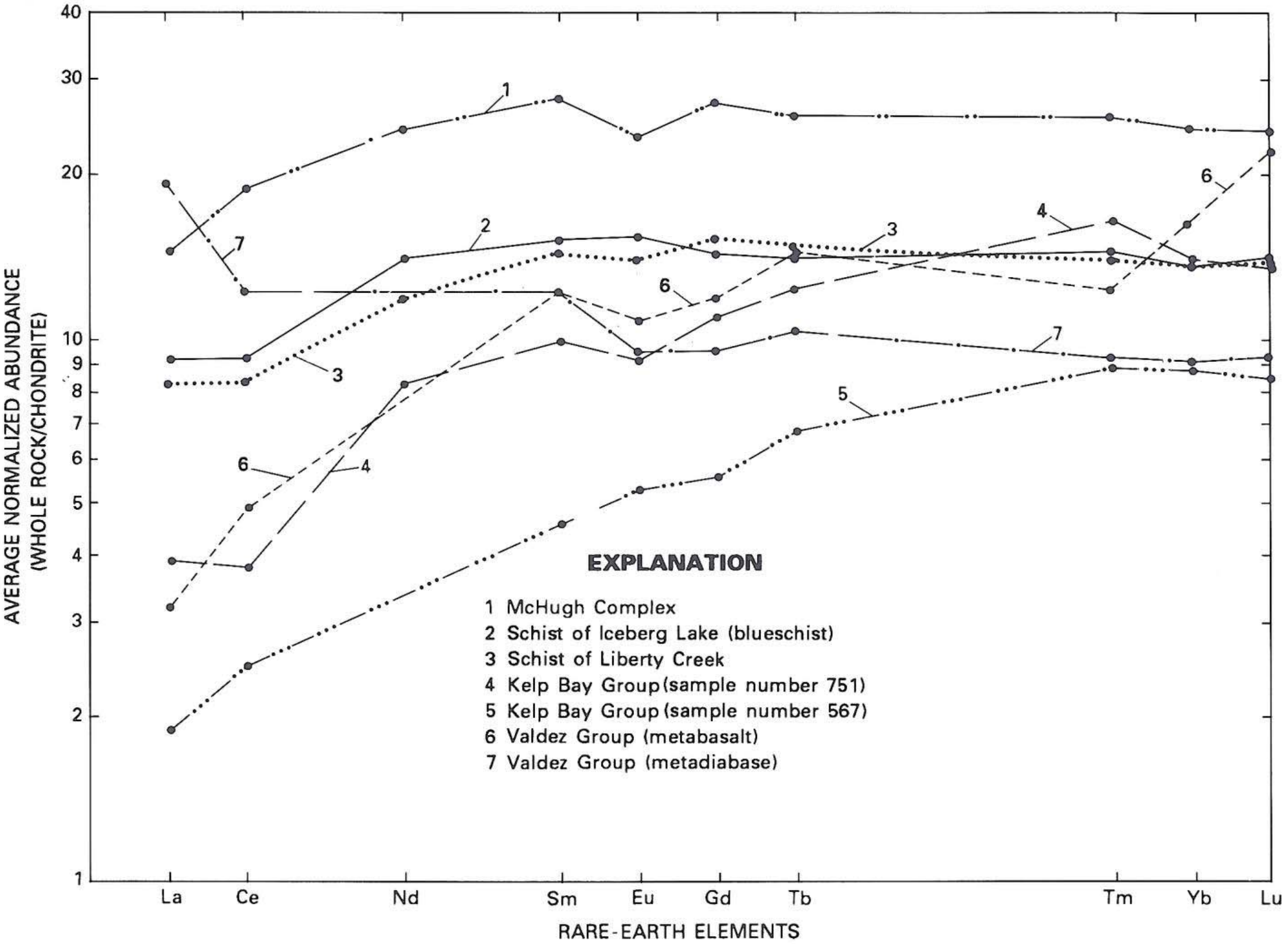

Figure 19. Chondrite-normalized REE distributions for mafic volcanic and shallow intrusive rocks of the Chugach terrane.

and others, this volume, Plate 13). If they formed within topographic lows along the Uganik thrust, they may be more closely related to the Cretaceous(?) and Paleocene Ghost Rocks Formation (discussed below) than to the Uyak Complex.

McHugh Complex

Background. The McHugh Complex as defined by Clark (1973), crops out discontinuously along the northern margin of the Chugach terrane in the Chugach and Kenai Mountains (Plafker and others, 1977). As used here, it also includes the (informal) Seldovia Bay Complex of Cowan and Boss (1978). Along its northern margin, the McHugh Complex is in contact with the Peninsular terrane, Wrangellia terrane, and the Raspberry blueschist unit along vertical, to steeply north-dipping, faults. It is juxtaposed against the Valdez Group on the south along thrust faults that dip moderately to gently northward. Structural style in this commonly massive unit consists of sparse south-verging structures, and an intense penetrative ductile fabric exhibited by pinch-and-swell structure and boudinage, and numerous closely spaced zones of intense cataclasis (Clark, 1973; Cowan and Boss, 1978; Winkler and others, 1981; Nokleberg and others, 1989). The common occurrence of disrupted brittle phacoids at all scales in a sheared argillite-and-tuff matrix imparts a characteristic blocks-in-argillite mélange appearance to parts of the unit. Metamorphism is commonly prehnite-pumpellyite facies except where locally it reaches greenschist facies near its eastern limit of exposure.

The metabasites of the McHugh Complex are dark green to dark greenish gray and characteristically form rough reddish-weathering outcrops. They occur in masses from a few meters to several hundred meters thick, together with variable amounts of chaotically intermixed ribbon chert, tuff, and argillite. The rocks are thoroughly altered to "greenstone," but locally they retain

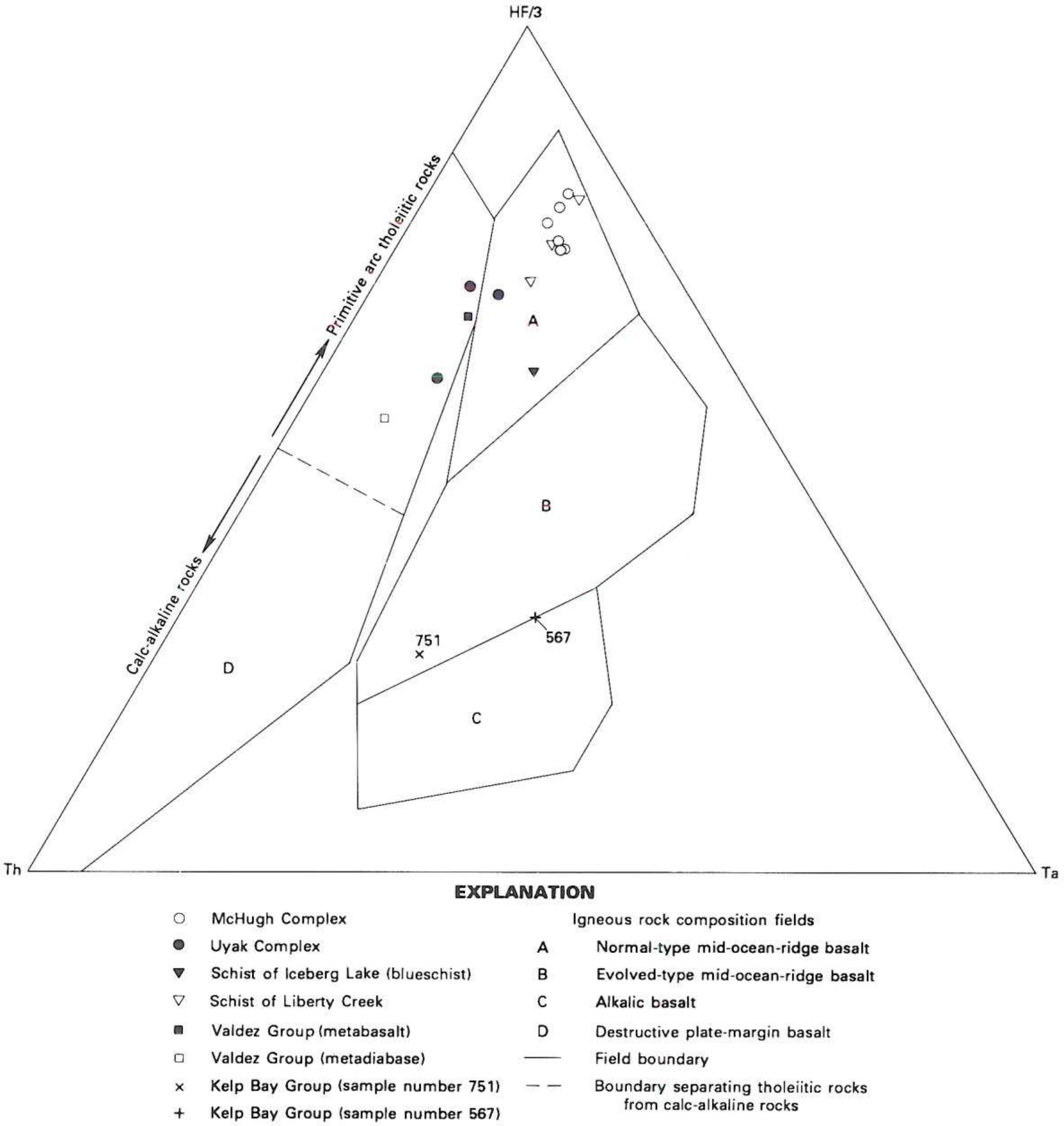

Figure 20. Ternary diagram of (Hf/3)-Th-Ta for selected mafic volcanic and shallow intrusive rock samples of Chugach terrane, showing predominantly normal-type mid-ocean-ridge basalt distribution.

textures and structures indicating that they originally were massive flows, pillow lavas, and pillow breccia. Textures are mainly microporphyritic, intergranular, and microbrecciated. Recognizable minerals in thin section are relict plagioclase, clinopyroxene (commonly as euhedral microphenocrysts), chlorite, sparse epidote, and quartz in a murky optically irresolvable matrix. Crosscutting veinlets consisting of quartz, calcite, serpentine, chlorite, and rare stilpnomelane are numerous.

The McHugh Complex was deposited from Late Triassic to mid-Cretaceous (Albian to Cenomanian) time, as indicated by the age of radiolarian assemblages from chert (Winkler and others, 1981; Nelson and others, 1986; Jones and others, 1987). Olistostromal blocks and clasts within the mélange range in age from Early Pennsylvanian to Jurassic (Nelson and others, 1986).

Volcanic geochemistry. Geochemical data for six analyzed samples of greenstone from the McHugh Complex are summarized in Table 14 (on microfiche) and on Figures 18 through 20. The rocks sampled are basalts that have fairly consistent major- and minor-element compositions (45.5 to 52.2 percent SiO_2, 1.6 to 3.3 ratio of FeO^*/MgO). There are minor variations, however,

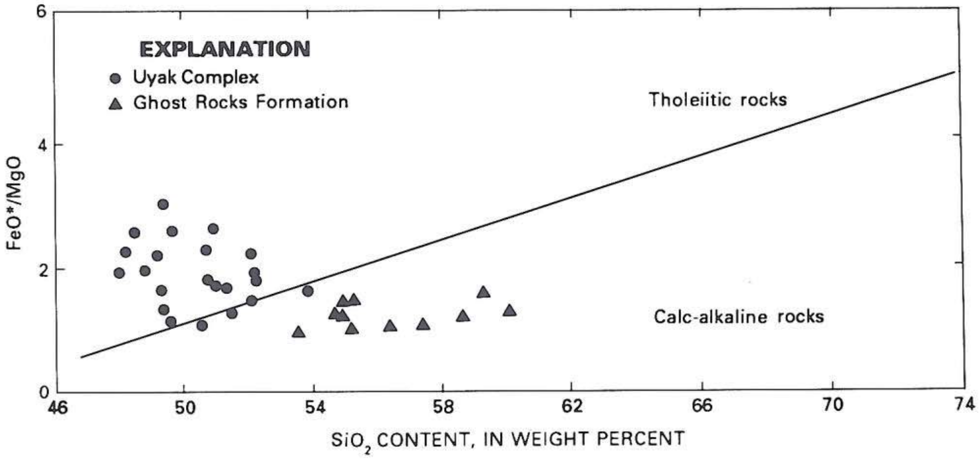

Figure 21. Plot of FeO*/MgO versus SiO_2 of the Uyak Complex and Ghost Rocks Formation, Chugach terrane.

in the alkali elements, probably due to alteration, and in silica and lime contents because of the ubiquitous presence of fine veinlets of quartz and calcite. The samples have low Al_2O_3 (12.82 to 13.64 percent) and moderate to high TiO_2 (1.89 to 2.89 percent). They plot in the tholeiitic field on an AFM diagram (Fig. 18) and on similar discrimination diagrams. The REE pattern is relatively flat at (La 13 to 19 × chondrite and Lu 20 to 28 × chondrite) with a slight depletion of LREE over HREE ($[La/Sm]_n = 0.5$ to 0.6) and a slight negative Eu anomaly (Fig. 19). All samples plot in the field of N-type ocean-ridge basalt (N-MORB) (Wood, 1980) on the Th-Hf-Ta discrimination diagram (Fig. 20) and as ocean-floor basalts on Ti-Zr-Y and Ti-Zr discrimination plots (not shown) of Pearce and Cann (1973). The TiO_2 and REE abundances, however, are relatively high for MORB. The enrichment in HREE relative to LREE suggests derivation from a somewhat depleted mantle source. Geochemically, the McHugh Complex metavolcanic rocks are similar to the metavolcanic rocks in the schists of Liberty Creek and Iceberg Lake, except that their average REE contents are slightly higher.

Kelp Bay Group

Background. Metabasite constitutes an estimated 50 percent of the Kelp Bay Group on Baranof and Chichagof Islands (Loney and others, 1975; Decker, 1980; Johnson and Karl, 1985), and this belt of rocks is inferred to extend northwestward onto the mainland in the Tarr Inlet region of Glacier Bay (Decker and Plafker, 1981). The mélange of the Kelp Bay Group is generally similar to the McHugh Complex in lithology and structural style. It differs in that the Kelp Bay mélange is faulted into a collage of kilometer-scale blocks of lithologically heterogeneous rocks, includes well-foliated rocks ranging from prehnite-pumpellyite facies to greenschist and glaucophanic greenschist facies, and contains kilometer-scale blocks of carbonate and greenstone—some of which are olistostromal in origin (Loney and others, 1975; Decker, 1980; Johnson and Karl, 1985). The age of the matrix appears to be restricted to the Late Jurassic and Early Cretaceous (Decker, 1980; E. Pessagno, written communication, 1987). K-Ar ages of 109 to 91 Ma on sericite and actinolite from the Kelp Bay Group are interpreted by Decker (1980) as dating the time of accretion and initial metamorphism of the unit.

Volcanic geochemistry. Major- and minor-element geochemical analyses are available for two samples (751, 561a) of metabasite from the Kelp Bay Group (Table 14, on microfiche; and Figs. 18 through 20) and 15 additional samples have been analyzed for major and selected minor elements (Decker, 1980). The samples analyzed from the Kelp Bay Group include both intermixed green tuff and massive or pillowed blocks from within the mélange, as well as rocks of all textural grades from massive to schistose. Of the 17 samples analyzed, 15 greenstones are tholeiite (44.6 to 50.6 percent SiO_2, 0.8 to 2.77 percent TiO_2), and two samples of metatuff and metabreccia (661a, 661b) are andesite (57.6 to 59.3 percent SiO_2 and 0.26 to 0.31 percent TiO_2). The samples for which complete analyses are available have FeO^*/MgO ratios of 1.5 to 1.6. On a plot of FeO^*/MgO versus SiO_2 they are in the tholeiitic field (not shown), although on an AFM diagram one plots in the tholeiitic field and one is well into the calc-alkalic field (Fig. 18). The REE pattern is relatively flat (La 3 to 20 × chondrite and Lu 9 to 22 × chondrite); one sample (no. 751) shows significant LREE depletion (Fig. 18).

Yakutat Group

Background. The mélange of the Yakutat Group is similar to that of the Kelp Bay Group in lithology, structure, and matrix age, and it includes abundant lithologically diverse kilometer-scale olistostromal blocks suggestive of a Wrangellian provenance (Plafker, 1987). Most of the unit is typically subgreenschist facies; higher grade rocks occur in schistose fault-bounded slivers near the Fairweather fault, and abundant float of glaucophane greenschist, possibly derived from Yakutat Group mélange, occurs in glacial moraines in the area (G. Plafker, unpublished data).

Volcanic geochemistry. Four samples of tholeiitic metabasalt form the mélange of the Yakutat Group (Table 15, on microfiche) are of two general types. Greenstone from typical mélange northeast of Yakutat (samples 80Apr-43 and 80-APr-44) shows low Al_2O_3 (13.5 to 13.9 percent), moderate TiO_2 (1.4 to 1.9 percent), and mild light-REE enrichment ($[La/Sm]_n \sim 1.2$ to 1.5). Sheared greenstone from west of the Alsek River, samples 78APr-17 and 78APr-18A, are more aluminous (15.6 to 17 percent Al_2O_3), titaniferous (2.3 to 2.4 percent TiO_2), and light-REE enriched ($[La/Sm]_n = 1.3$ to 2.9). Sample 78APr-17, having 0.56 percent P_2O_5, 39 ppm Nb, 2.6 ppm Ta, and 216 ppm Zr, is subalkaline, of enriched MORB composition, and possibly a fragment of seamount basalt. The other three tholeiites appear to be transitional between N-MORB and E-MORB.

Interpretation

Characteristics of the basaltic rocks of the Chugach terrane mélange unit—whether massive, pillowed, tuffaceous, or schistose—suggest predominantly ocean-floor volcanism. Most indicate an origin as normal MORB or as seamounts, an origin that is compatible with their ubiquitous association with pelagic sediments. The compositions of two samples of breccia and tuff from the Kelp Bay Group, which commonly occur intimately interbedded with pelagic sediment within the mélange matrix, suggest possible derivation from a volcanic arc. The Late Jurassic Chitina arc and (or) the Early Cretaceous Chisana arc (see description, this chapter) are possible sources (Plafker and others, 1989b; this volume, Chapter 12). However, G. Winkler (oral communication, 1988) suggested an origin as aquagene tuff. Structural and lithologic data indicate that the complex was probably accreted, disrupted, and mixed with terrigenous sediments at a convergent plate margin (Clark, 1973; Moore and Connelly, 1977). The age distribution of dated radiolarian chert in the western Valdez Quadrangle (Winkler and others, 1981) suggests progressive accretion of slices of the mélange complex ranging from Late Triassic time along the northern margin of the complex to mid-Cretaceous time at the southern margin.

VALDEZ GROUP

Setting

Metavolcanic rocks occur in a discontinuous belt 2 to 8 km wide and 600 km long that defines the southern margin of the Valdez Group and correlative units from the Prince William Sound area to southeastern Alaska (Plafker and others, this volume, Chapter 12). To the north, the metavolcanic rocks are intercalated with structurally higher volcaniclastic flysch that comprises most of the Valdez Group; to the south, the volcanic rocks are in fault contact with rocks of the Prince William and Yakutat terranes. The rocks are polydeformed and polymetamorphosed to metamorphic grades that range from low greenschist facies in the western part of the belt to high greenschist facies, epidote amphibolite facies, and amphibolite facies in the eastern Chugach Mountains and Saint Elias Mountains. The age of the Valdez Group metavolcanic rocks is Late Cretaceous (Maastrichtian and Campanian?), as indicated by fossils in the overlying flysch unit (Tysdal and Plafker, 1978).

Data on the geochemistry of the volcanic rocks were obtained primarily from near the type area of the Valdez Group between Prince William Sound and the Copper River (five analyses), from higher grade schists in the area between Yakutat Bay and the Alsek River (four analyses), and from rocks on Chichagof Island (one analysis) that are tentatively correlated with the Valdez Group. These three areas are referred to below, respectively, as the "western," "Yakutat," and "Chichagof" areas.

Western area

Background. Structural thickness of the metavolcanic rocks is at least 4 km near the western end of the outcrop belt, where it has been studied in detail (Plafker and others, 1986). The rocks consist of green basaltic metatuff that occurs in lenticular beds ranging from a few centimeters to about 15 m thick and 4 km in length, interbedded with metasedimentary rocks, dark green to black metabasalt, amygdaloidal pillow flows, breccia ("greenstone"), and diabase intrusives. Flattened pillow structures are recognizable in some of the more massive volcanic units. Schistose dikes and sills of metadiabase and metagabbro associated with the thicker volcanic units commonly show conspicuous rusty brown alteration zones in outcrop.

The metatuff mainly consists of very fine-grained, sheared chlorite, fibrous actinolite, and epidote ± quartz, pyrite, white mica, and biotite. It commonly is microfolded and may be intimately interlayered with metapelite on a millimeter to centimeter scale. The basaltic rocks are mineralogically similar to the metatuff except that chloritized amygdules are locally abundant. The metadiabase and metagabbor are slightly foliated, equigranular, fine- to medium-grained rocks of diabasic or allotriomorphic granular texture. They consist of pale green actinolite and completely saussuritized plagioclase and as much as 20 percent each of fine- to very fine-grained epidote and chlorite. The diabase in places is cut by millimeter-scale epidote veinlets.

Volcanic geochemistry. Analyses are available for one sample of metatuff, two samples of schistose basalt (greenstone), and two samples of comagmatic metadiabase and metagabbro from the western part of the Valdez Group (Plate 6; Table 15, on microfiche). The samples are LREE—depleted tholeiite (48.5 to 53.7 percent SiO_2 and 0.35 to 1.17 percent TiO_2, $FeO^*/MgO = 0.8$ to 2.1) with low Ba, Sr, and K_2O/Na_2O. They plot as tholeiites with an "iron enrichment" trend on the AFM diagram (Fig. 18), and they straddle the tholeiite-calc-alkaline compositional boundary on a plot of FeO^*/MgO versus SiO_2 (not shown). Two samples with Th contents above detection levels plot in the field of primitive-arc tholeiites (Wood, 1980) on a Th-Hf-Ta discrimination diagram (Fig. 20). On discrimination diagrams of Ti-Zr-Y and Ti—Zr (not shown), the samples plot either in or just outside the low-K arc tholeiite field. REE abundances are low (Fig. 19) and show moderate depletion of LREE relative to HREE (La 1 to 6 × chondrites, Lu 9 to 15 × chondrites, and $[La/Sm]_n = 0.3$ to 0.5); REE contents of the intrusive rocks are systematically lower than for the greenstones. The geochemical data for these rocks are inconclusive in regard to implications about their petrotectonic setting. They could represent contaminated MORB or primitive-island-arc tholeiite.

Yakutat area

The four samples of the Valdez(?) Group are three metabasalts and one meta-andesite. The metabasalts, hornblende-plagioclase amphibolite, and actinolite-albite-chlorite schist are of light-REE-depleted tholeiitic compositions (Table 15, on microfiche). Because their Ta abundances of 0.5 to 0.6 ppm are higher than those of arc tholeiites, we suggest that these rocks probably are offscraped remnants of oceanic crust or MORB. The meta-andesite (sample 78-APr-7), now epidote-actinolite-chlorite-albite-calcite schist, contains 61.5 percent SiO_2, shows moderate light-REE enrichment (La approximately 40 × chondrites), and plots as calc-alkaline on an FeO^*/MgO-SiO_2 diagram (not shown). This rock probably originated as an ash fall from a distant island arc.

Chichagof area

The Ford Arm unit of Decker (1980) is a fault-bounded, undated sequence of flysch locally interbedded with schistose basaltic tuff, flow breccia, and massive flows. The unit is correlated by Decker with the Valdez Group on the mainland, because of its apparent structural continuity and lithology. The one sample (no. 690) for which a complete chemical analysis is available is an actinolite-chlorite-epidote schist that is tholeiitic on AFM (Fig. 18) and FeO^*/MgO versus SiO_2 (not shown) plots, and has a flat REE pattern with La at about 10 × chondrite (Table 15, on microfiche). If this one sample is representative of the Ford Arm unit, the geochemical data (especially the absence of strong LREE depletion) are more compatible if the unit is correlated with MORB tholeiites of the mélange unit rather than with the Valdez Group.

Interpretation

Characteristics of the sedimentary rocks of the Valdez Group suggest that they were deposited mainly in an ocean-floor or trench environment and were derived from a probable Andean type volcano-plutonic arc source (Zuffa and others, 1980; Decker and Plafker, 1981; Nilson and Zuffa, 1982; Plafker and others, this volume, Chapter 11). The basalt and related fragmental volcanic rocks of the Valdez Group are interpreted as the upper levels of oceanic crust upon which the clastic rocks were deposited. The apparent absence of pelagic sediments at the interface and the occurrence of mafic aquagene tuff intercalated on a fine scale with volcanogenic sediments suggest that the oceanic crustal rocks were, at least in part, erupted relatively close to the sediment source.

GHOST ROCKS TERRANE

M. D. Hill and G. Plafker

The Ghost Rocks terrane occurs as a 10-km-wide belt of mafic low-grade metamorphic volcanic rocks and mélange along the southern margin of Kodiak Island and as a thick accumulation of pillow basalt and associated intrusive rocks on the Resurrection Peninsula on the mainland near Seward (Barker and others, this volume, Plate 13; Plafker, 1987; Plafker and others, this volume, Chapter 12). The terrane is juxtaposed against the Chugach terrane to the north along the Contact fault, and against the Prince William terrane to the south along the Resurrection fault. Geochemical data are available only for the Ghost Rocks Formation of Kodiak Island, as discussed below.

GHOST ROCKS FORMATION

The Cretaceous(?) and Paleocene Ghost Rocks Formation (Plafker and others, this volume, Chapter 12) on Kodiak Island consists of pillowed and massive volcanic flows, tuff, sandstone, argillite, diabase, limestone, and conglomerate. Reid (in Moore and others, 1983) showed that the volcanic rocks include both LREE-depleted tholeiitic basalt and LREE-enriched calc-alkaline basaltic andesite to andesite. The data in Table 16, (on microfiche) and on Figure 21, from Hill (1979), are entirely from the latter group, sampled along the north shore of the Aliulik Peninsula on Kodiak Island. The Nd isotope data summarized by Moore and others (1983) provide convincing evidence that the calc-alkaline units of the Ghost Rocks Formation represent hybrid magmas derived by contamination of tholeiitic, MORB-like basalt with sediments of the accretionary prism. Demonstration of this mechanism within the volcanic rocks of the Ghost Rocks Formation and the occurrence of gabbro to quartz diorite plutons within the Ghost Rocks provide further support for the contention made by Hill and others (1981) that Ghost Rocks magma invaded the accretionary prism and was responsible for generating the approximately 60-Ma batholiths on Kodiak, Shumagin, and Sanak Islands. The basalt volcanism, preserved in relatively undeformed rocks of the Upper Cretaceous units within the Uganik thrust, may represent an early state of this Ghost Rocks volcanic activity.

PRINCE WILLIAM TERRANE

G. Plafker and J. S. Lull

INTRODUCTION

The Prince William terrane forms an outcrop belt more than 100 km wide that extends from the Copper River and Prince William Sound areas southwestward beneath the continental shelf and slopes off the Kodiak Island (Jones and others, 1987; Nokleberg and others, this volume, Chapter 10). The terrane basement consists of the upper Paleocene through middle Eocene Orca Group, overlain in the offshore areas by thick, younger Tertiary sedimentary sequences. The terrane is in fault contact with the Ghost Rocks, Chugach, and Yakutat terranes on the north and east; the offshore contact relationships to the south are unknown.

ORCA GROUP

Background

The Orca Group is a structurally complex deep-sea-fan flysch complex interbedded with subordinate oceanic volcanic and minor pelagic sedimentary rocks (Winkler, 1976; Winkler and others, 1981; Nelson and others, 1986). The sedimentary rocks were derived from a dominantly plutonic and high-grade metamorphic source and had a minor contribution from a probable cratonal source. Outcrops of predominantly mafic volcanic rocks as much as several kilometers thick occur in discontinuous belts as large as 150 km long and 12 km wide (Barker and others, this volume, Plate 13). They consist of basalt, including pillowed basalt, and basaltic breccia, tuff, and basaltic volcanogenic sedimentary rocks that locally contain pelagic microfossils and are interlayered with the flysch.

Volcanic geochemistry

Chemical analyses are available for 15 samples of basaltic rocks and four samples of diabase from the Prince William Sound area and the Ragged Mountains area (Table 17, on microfiche): 48.0 to 55.4 percent SiO_2, 11.8 to 20.6 percent Al_2O_3, O.4 to 2.4 percent TiO_2, FeO^*/MgO = 0.9 to 2.0). On an AFM diagram, most samples plot as tholeiitic or close to the field boundary with four samples in the calc-alkalic field (Fig. 22). On plots of FeO^*/MgO versus SiO_2 (not shown), the samples straddle the tholeiite-calc-alkalic boundary, but most plot in the tholeiite field. High CaO (13 to 14 percent) in three samples is probably due to veinlets and amygdules of calcite.

Based on minor-element geochemistry, four distinct types of mafic volcanic rocks can be recognized in the Orca Group. Type one (six samples) is best characterized as enriched (transitional) MORB (La 23 to 52 × chondrites, Lu 9 to 14 < chondrites, $[La/Sm]_n$ = 1.4 to 2.2) and the samples plot as E-MORB and ocean-island basalts on the Th-Hf-Ta and Ti-Zr-Y discrimination diagrams (not shown). Type two (three samples of basalt, four samples of diabase) is normal MORB. REE patterns for the basalt show a flat trend (La 17 × chondrites, Lu 17 to 18 × chondrites, $[La/Sm]_n$ = 1.0) and a slight negative Eu anomaly. REE abundances for the diabase are slightly lower than for the basalt (Fig. 23), show slight LREE depletion (La 9 to 12 ×

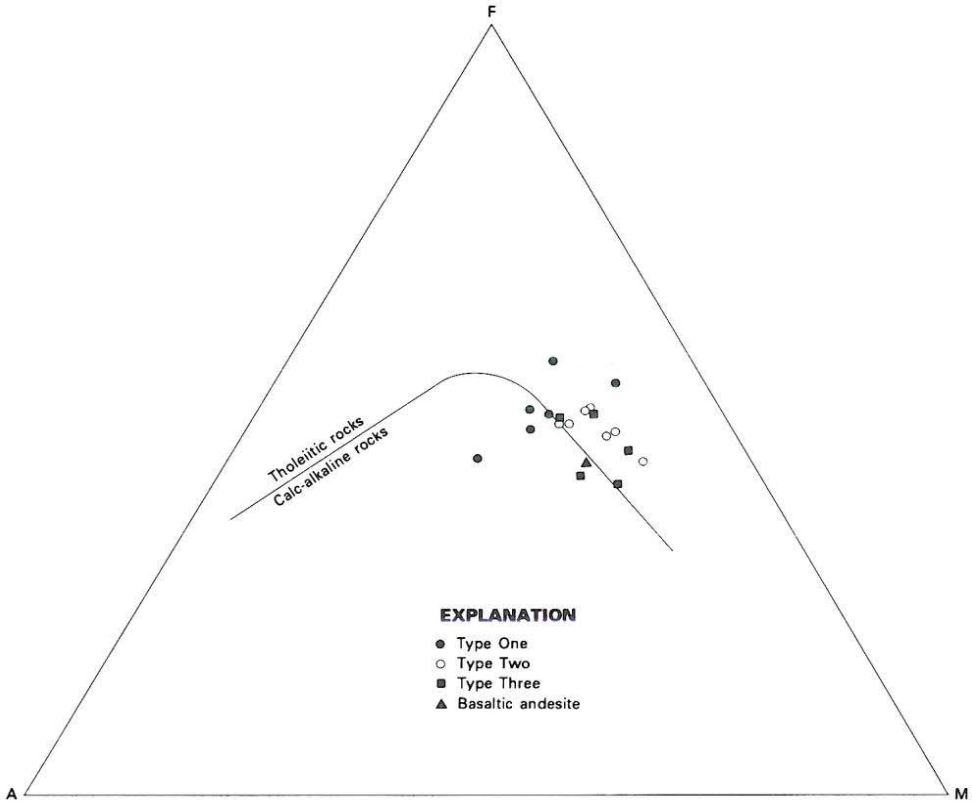

Figure 22. AFM diagram of mafic volcanic rocks of the Orca Group, Prince William terrane.

chondrites, Lu 13 to 16 × chondrites, $[\mathrm{La/Sm}]_n = 0.7$ to 0.9), and no Eu anomaly. This trend is nearly identical to the average MORB trend of Sun and others (1979). Type two basalts and diabase plot as ocean-floor basalt on a Ti-Zr-Y discrimination diagram and as N-MORB on a La/Ta plot (not shown). Type three basalts (five samples) are low-Ti (TiO_2 <1 percent) and low-Zr (<40 ppm) basalts similar to arc tholeiites. REE abundances are low and depleted in LREE (La 2 to 7 × chondrites, Lu 6 to 18 × chondrites, $[\mathrm{La/Sm}]_n = 0.3$ to 0.4), although one sample shows LREE enrichment ($[\mathrm{La/Sm}]_n = 1.8$). On a Ti-Sr-Y diagram, type three basalts plot within and just outside the low-K arc tholeiite field. Type four is represented by one sample of "arc" calc-alkalic andesite from southwest Prince William Sound. The REE pattern shows slight LREE enrichment (La 20 × chondrites, Lu 13 × chondrites, $[\mathrm{La/Sm}]_n = 1.4$) and a slight negative Eu anomaly. This sample plots in the field for calc-alkalic basalt on both the Ti-Zr-Y and the Hf-Ta discrimination diagrams (not shown).

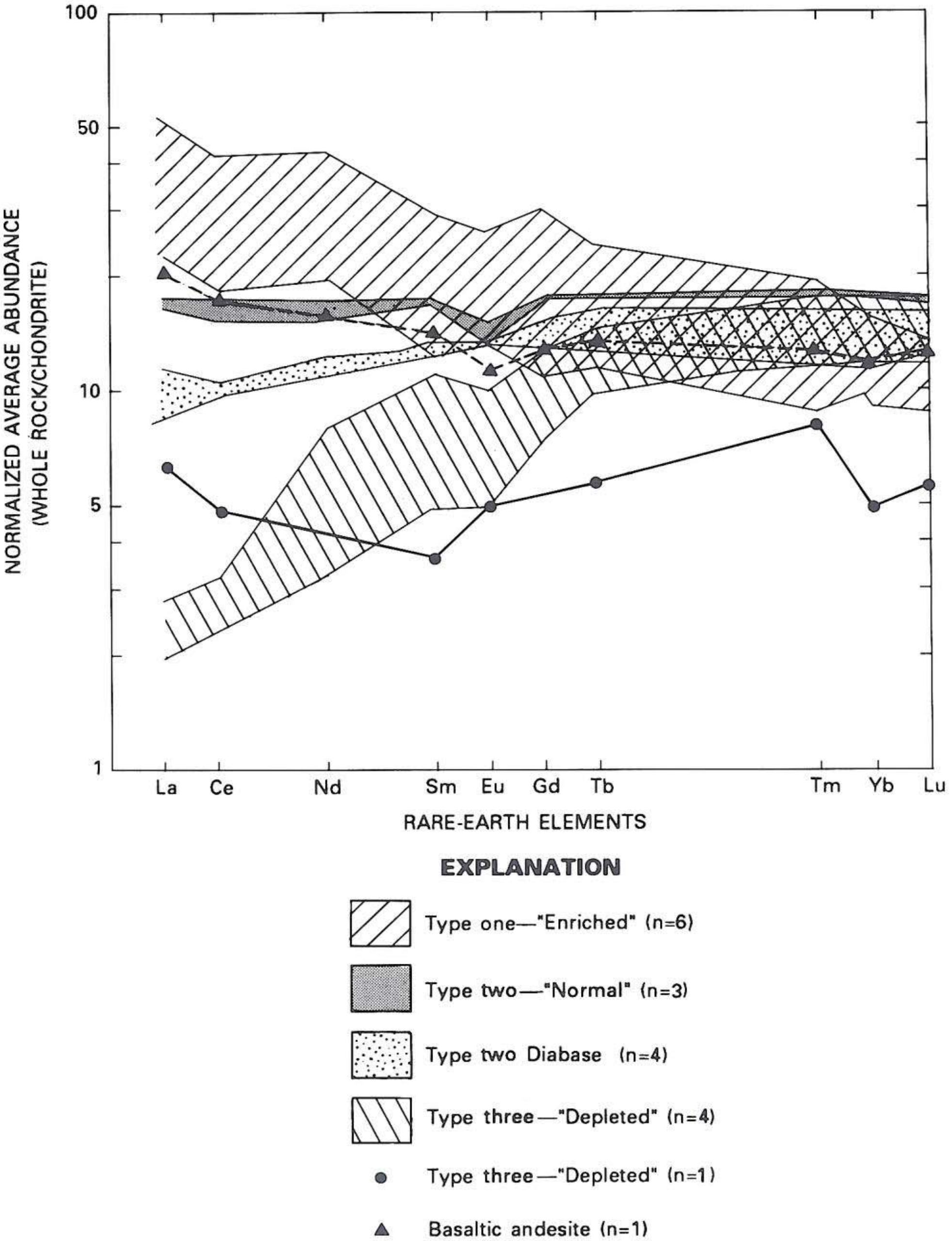

Figure 23. Chondrite-normalized REE distributions for mafic volcanic rocks of the Orca Group, Prince William terrane.

Interpretation

The geochemical data, in conjunction with geological factors, suggest eruption as submarine ridges or volcano chains within reach of submarine fans built out from the continental margin. The basalts may have erupted from leaky transforms along the continental margin (Tysdal and Case, 1979) or from the Kula-Farallon ridge that was rapidly approaching the continental margin during Orca time (Plafker and others, this volume, Chapter 12). The thermal and mechanical regime within fracture zones and near ridge-transform intersections favors ineffective magma mixing and less total melt production, giving rise to more diverse magma types and the formation of both LREE-enriched and LREE-depleted lavas (Batiza and Vanko, 1984). Such a regime gives one possible explanation for the chemical diversity of basalts of the Orca Group.

PALEOGENE BASALT OF THE YAKUTAT TERRANE

G. Plafker and F. Barker

BACKGROUND

The Yakutat terrane is a composite allochthonous terrane 600 km long and 200 km wide along the northern Gulf of Alaska margin. It is bounded on the east and north by the Fairweather and Chugach–Saint Elias faults, on the west by the Kayak Island zone, and on the south by the Transition fault system (Plafker, 1987). Oceanic crust of early Eocene and possibly Paleocene age underlies the western two-thirds of the block. A dominantly clastic sequence of early Eocene to Quaternary age overlies the oceanic basement. Dredge samples of basalt found in this clastic sequence have been described by Davis and Plafker (1985). We summarize in the following paragraph.

VOLCANIC GEOCHEMISTRY

Eight samples of this continental-slope basalt were collected just north of the Transition fault (Davis and Plafker, 1985). These rocks are altered flows, hyaloclastites, and pillow breccias that are aphyric to moderately phyric (>10 percent phenocrysts). Plagioclase is the common phenocryst phase, diopsidic augite is minor in amount, and olivine is rare. These basalts are of two chemical types: one shows depletion of light REE, Ti, Nb, and Zr, and is of MORB type; the other shows enrichment of light REEs and LILE and is of ocean-island or seamount type. Davis and Plafker infer that these basalts originated at and near the Kula-Farallon spreading center, were accreted to the continental margin at British Columbia or (and) Washington at ca. 48 Ma, and were carried northwestward by transform faulting.

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