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# Eocene basalts from the Yakutat terrane: Evidence for the origin of an accreting terrane in southern Alaska

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# Eocene basalts from the Yakutat terrane: Evidence for the origin of an accreting terrane in southern Alaska

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## ABSTRACT

**Basalts from the Yakutat terrane, a composite oceanic and continental tectonostratigraphic terrane, are chemically diverse large ion lithophile element (LILE)–depleted and LILE-enriched tholeiites, interpreted as normal mid-ocean ridge and oceanic island basalt, that originated on seamounts near the Kula-Farallon spreading center during the early to middle Eocene. Coeval and geochemically similar basalts, occurring sporadically in a linear belt from southern Vancouver Island to the southern Oregon Coast Range, are correlative with the Yakutat terrane basalts. Both basaltic sequences were accreted to the continental margin during subduction of the Kula-Farallon Ridge and Kula plate about 48 Ma. The Yakutat basalts were emplaced along the coast of Washington or British Columbia. The Yakutat terrane probably originated during the Neogene as a composite terrane when it was sliced off the continental margin and started to move northward along the Queen Charlotte–Fairweather transform fault toward its present location in southern Alaska.**


## INTRODUCTION

Recently it has become widely accepted that much of western North America is composed of numerous structurally bound tectonostratigraphic terranes that may differ considerably in stratigraphy, lithology, and petrochemistry (Jones et al., 1984). One of these terranes, now accreting to southern Alaska, is a relatively small triangular crustal plate, named the Yakutat terrane by Plafker (1983) and Jones et al. (1984). The eastern, relatively undeformed part of this terrane was originally referred to informally as the Yakutat block (Rogers, 1977; Plafker et al., 1978). The Yakutat terrane is characterized by a composite oceanic and continental basement and is structurally bounded on the north by the Chugach–St. Elias fault, on the northeast by the Fairweather fault, on the south by the Transition fault at the base of the continental slope, and on the west by the Ragged Mountain and Wingham Island thrust faults and their inferred offshore extensions (Fig. 1). Structural and seismic data indicate that the Yakutat terrane has been moving with the Pacific plate at a velocity of about 5.8 cm/yr for at least the past 100,000 yr (Plafker et al., 1978; Lahr and Plafker, 1980). Movement prior to that is less well

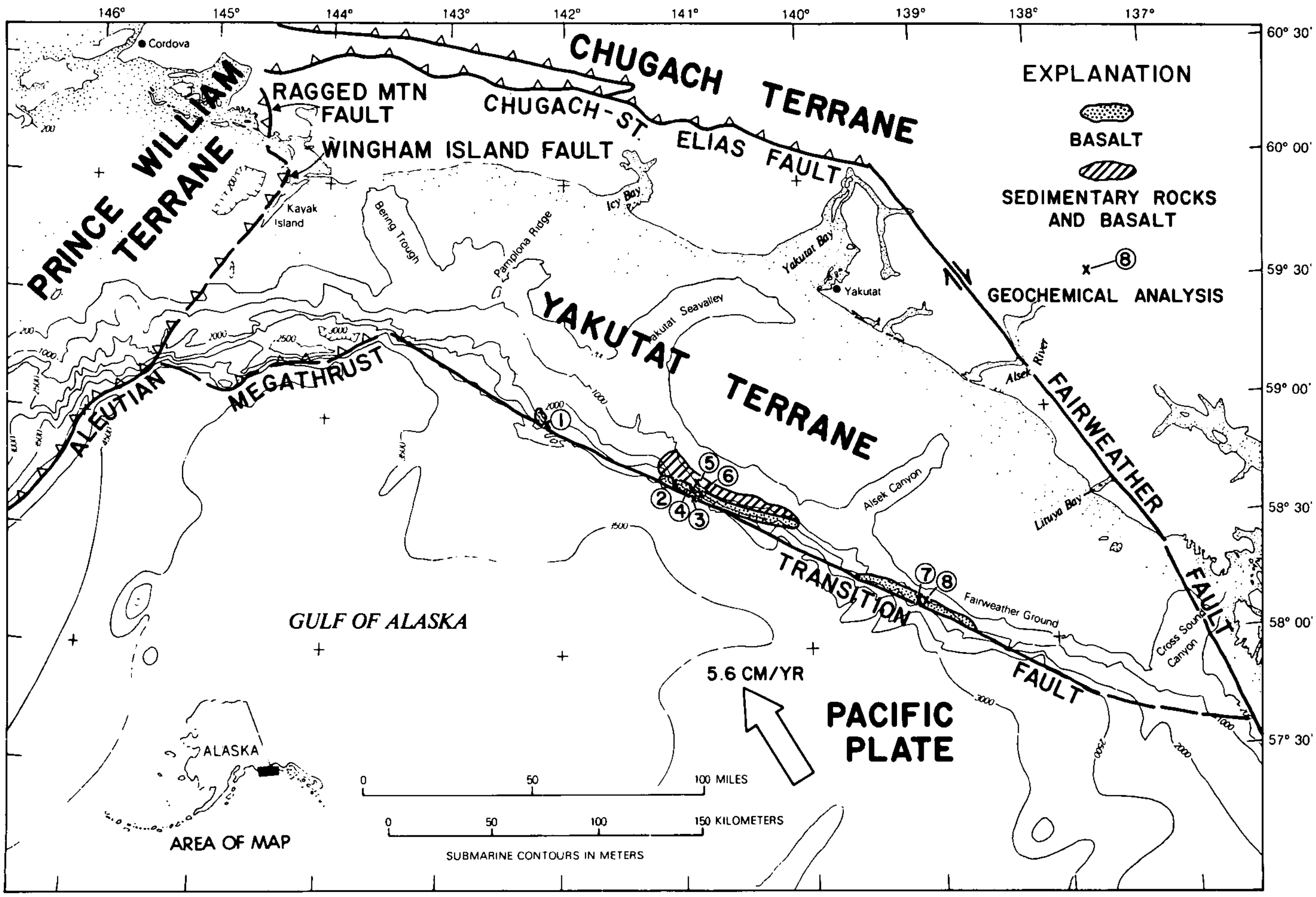


**Figure 1. Map showing Yakutat terrane, basalt distribution on continental slope, and location of geochemically analyzed samples. Modified from Jones et al. (1984) and Plafker et al. (1980).**

agreed upon and ranges from 5° (Plafker, 1983, 1986) to 30° (Bruns, 1983; Keller et al., 1984).

A variety of igneous and sedimentary rocks, from Cretaceous to Tertiary in age, was dredged from the continental slope and outer shelf of the Yakutat terrane between long 138°00′ and 142°30′ W (Fig. 1). Basaltic flows, hyaloclastites, and flow breccias with interbedded clastic marine sedimentary rock, more than 1300 m thick, constitute much of the lower continental slope throughout this area. This unit is largely, if not entirely, of early to middle Eocene age, as determined by radiometric and paleontologic dating (Plafker et al., 1980).

We present here petrologic and geochemical data for basalts from the Yakutat terrane that suggest that these basalts erupted on normal mid-ocean ridge segments and seamounts (and/or leaky fracture zones) at the Kula-Farallon spreading center during the Eocene. A possible common history for basalts in western Washington and Oregon and southern Vancouver Island is suggested by similarities in their age and composition.

## METHODS

Samples described in this report were dredged from the continental slope between long 138°00′ and 142°30′ W, from water depths between 3150 and 200 m. Sample locations are shown in Figure 1. Sampling methods, seismic reflection data, inferred stratigraphy, radiometric ages, and paleontological data were described in detail by Plafker et al. (1980), and petrography and geochemistry of the basalts and mineral chemistry of the clinopyroxenes by Davis and Plafker (1984). Chemical studies on the basalts were performed in the laboratories of the U.S. Geological Survey using X-ray fluorescence (XRF), wet chemical, and instrumental neutron activation (INAA) methods. Precision and accuracy of XRF and INAA methods have been discussed by Fabbi et al. (1976) and Baedecker (1979), respectively.

## BASALTS FROM THE YAKUTAT BLOCK

The dredged samples of basaltic rock from the Yakutat terrane consist of variably altered flows, hyaloclastites, and broken pillow breccias. Intercalated clastic sedimentary rocks derived from a metamorphic-plutonic complex in the upper part of the sequence indicate proximity to a continental margin. Reefal carbonate detritus in the upper part of the sequence suggests that some of these rocks may have been deposited in a shallow marine environment (Plafker et al., 1980). Whole-rock K/Ar ages of two basalt samples, which are believed to approximate the crystallization age because they are consistent with paleontological data, are 50.7 ±5 Ma (sample 79-18D, locality 8, Fig. 1) and 55.2 ±7 Ma (sample 78-22A5, locality 4, Fig. 1). Three other samples, associated with Eocene microfossils, yielded dates ranging from 26.2 ±3 to 38.9 ±3 Ma, which are believed to be too young, probably because of K addition and/or argon loss during alteration (Plafker et al., 1980).

### Petrography

The basalt samples show a wide range of textures, from hyalopilitic and variolitic to intergranular, intersertal, and ophitic. The samples with coarser textures presumably are from the interior of flows but could be from dikes and sills as well. Most of the samples are aphyric or sparsely phyric (<5% phenocrysts), but about one-third are moderately phyric (>10% phenocrysts). Plagioclase, the dominant phenocryst phase, is accompanied by minor pyroxene and less frequently by olivine. The plagioclase phenocrysts are normally zoned calcic labradorite when unaltered, but they are typically altered to zeolite minerals, clays, K-feldspar, and albite. Pyroxene and olivine phenocrysts are largely replaced by chlorophaeite or smectite clays; there are iddingsite rims around some olivines. Groundmass phases are plagioclase, clinopyroxene, and opaque minerals. Unaltered plagioclase microlites are labradorite and andesine. Clinopyroxene is diopsidic augite ($Wo_{38-43}$ $En_{39-49}$ $Fs_{9-22}$) and is typically fresh even in highly altered samples. The presence of abundant vesicles (>20%) in about one-fourth of the samples, as well as iddingsite rims of olivines, may indicate eruption into shallow water or subaerial eruption for some of the basalts. A large variety of secondary minerals, including zeolite minerals, clays, chlorite, epidote, calcite, and secondary feldspars, is present as mineral and glass replacement or as veinlets and amygdules.

### Major-Element Chemistry

All of the basalts from the Yakutat terrane are altered to some degree. Some are extremely altered, and consequently the major-element chemistry is highly variable. $Na_2O$ ranges from 2.8% to 5.6%, $K_2O$ from 0.08% to 1.7%, $H_2O$ from 2.9° to 7.6°, and $Fe_2O_3/FeO$ from 0.23 to 3.45. The addition of large quantities of secondary alkalies makes some of the samples appear alkalic and nepheline normative, whereas immobile trace-element data and clinopyroxene compositions clearly identify them as tholeiitic. Hence, only the less mobile trace elements and Ti have been considered in identifying the plate-tectonic affinities of these basalts. However, major-element chemical analyses, recalculated to total 100% on a volatile-free basis, are presented in Table 1[1], and compositions are shown on a $TiO_2$ vs. total FeO/MgO variation diagram in Figure 2.

### Trace-Element Chemistry

The trace-element abundances in the basalts from the Yakutat terrane also show considerable diversity (Table 1; see footnote 1). Large, low-valence cations like Rb, Ba, and Sr that are highly susceptible to submarine weathering are most variable. Large, high-valence cations (Zr, Nb, Y, Ti) are better indicators of basalt origin because they are less mobile during secondary alteration processes (e.g., Winchester and Floyd, 1976). Various combinations of relatively immobile elements have been used to discriminate among basalts from different geologic environments (e.g., Pearce and Norry, 1979; Winchester and Floyd, 1976; Wood, 1980). The basalts from the Yakutat terrane have been plotted on Ti/100-Zr-3Y, Th-Hf/3-Ta, $TiO_2$ vs. Y/Nb (not shown), and Zr vs. Nb (Fig. 3) diagrams; about half the samples plot consistently as typical mid-ocean ridge basalt (MORB), and the rest plot as oceanic island and/or intraplate basalt.

The rare earth element (REE) data also reveal two distinct groups (Fig. 4a). One group shows light-REE–depleted, chondrite-normalized patterns typical of mid-ocean-ridge basalt, whereas the other group shows light-REE–enriched patterns with steeper slopes that are typical of oceanic island tholeiite (Basaltic Volcanism Project, 1981). Similar diverse groups of light-REE–enriched and light-REE–depleted lavas have been reported from young seamounts on the flanks of the East Pacific Rise (EPR) (Batiza, 1980; Batiza and Vanko, 1984). The lavas from seamounts near the EPR are predominantly light-REE–depleted normal MORB, but they also show light-REE–enriched tholeiites and sometimes even small volumes of alkalic basalt erupted from the same volcano. Light-REE–enriched lavas are more common on older crust as the seamount drifts away from the spreading center, or on seamounts formed outside the spreading center. The trend toward light-REE enrichment is typically accompanied by an increase in alkalies and elements like Ti, Zr, Y, and Nb, whereas the heavy-REE abundances remain nearly the same (Batiza and Vanko, 1984).

## EOCENE BASALTS FROM OREGON AND WASHINGTON

Tholeiitic pillow lavas and flow breccias with intercalated marine sediments, similar to the Yakutat basalts and also largely of Eocene age, occur in a north-south–trending belt from the tip of Vancouver Island to the southern Coast Range of Oregon. Extensive submarine pillow tholeiites that grade locally into subaerially erupted alkalic basalts, described

[1]Table 1, Chemical Analyses of Basalts from the Yakutat Terrane, GSA Supplementary Material 8628, is available on request from Documents Secretary, Geological Society of America, P.O. Box 9140, Boulder, CO 80301.

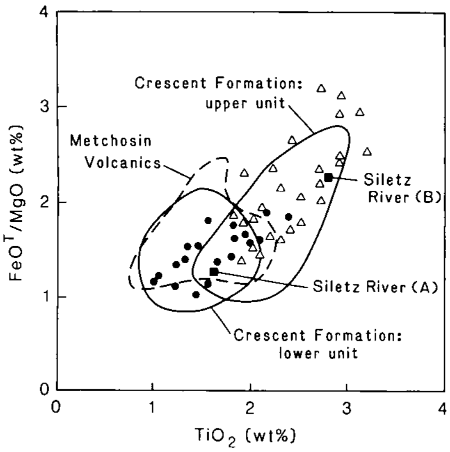


**Figure 2. $TiO_2$ vs. $FeO^T/MgO$ discrimination diagram for Yakutat basalt (circles) showing Black Hills, Crescent Formation, and Siletz River basalts for comparison. Basalts of lower and upper unit of Crescent Formation and flows and pillows of Metchosin Volcanics are shown as fields. Data for Crescent Formation from Glassley (1974) and for Metchosin Volcanics from Muller (1980). Basalts from lower unit of Siletz River Volcanics (squares) represent averaged analyses of (A) older part and (B) younger part of lower unit. Data from Snavely et al. (1968). Black Hills basalt data (triangles) are from Globerman (1980). Note that all samples that fall outside field defined by Crescent Formation basalts are described by Globerman as extremely altered.**

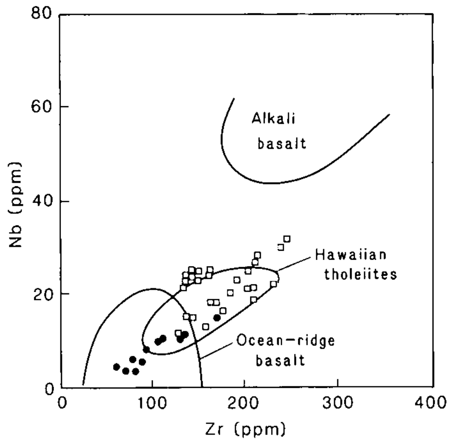


**Figure 3. Zr vs. Nb discrimination diagram showing that Yakutat basalt (circles) and Black Hills basalt (squares) have very similar Zr/Nb ratios. Normal MORB compositions predominate in Yakutat basalt, whereas oceanic island compositions predominate in Black Hills basalt. Data for Black Hills basalt from Globerman (1980); tectonic fields from Bass et al. (1973).**

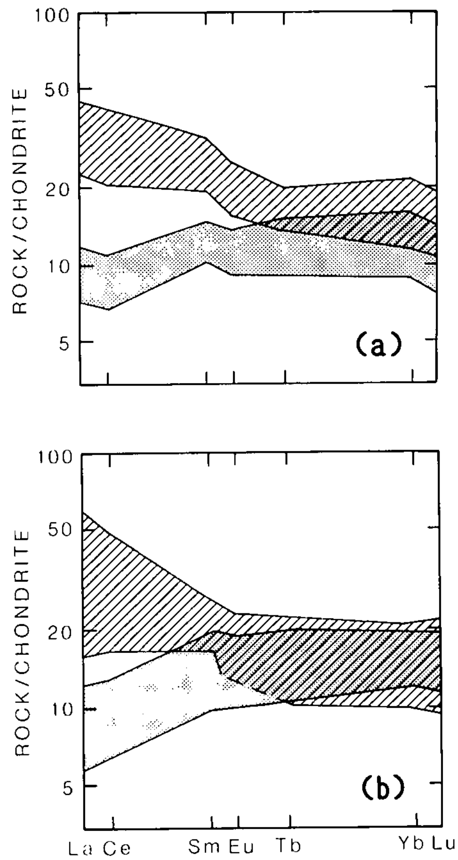


**Figure 4. Chondrite-normalized REE distribution of (a) Yakutat basalt, showing two distinct groups, one light-REE enriched and other light-REE depleted; and (b) basalt from Crescent Formation showing similar, bimodal, light-REE-enriched and light-REE-depleted compositions but having less well-defined separation between these two groups (Glassley, 1974). Note that negative Eu anomaly present in some Crescent Formation REE patterns has been omitted.**

from the Siletz River area in the Oregon Coast Range (Snavely et al., 1968), have been interpreted as oceanic islands built on oceanic crust. Similar bimodal assemblages resembling oceanic ridge and oceanic island basalts have been described from the Crescent Formation in the eastern part of the Olympic Peninsula in Washington (Glassley, 1974) and from the Metchosin Volcanics on Vancouver Island (Muller, 1980). The chondrite-normalized REE patterns of Crescent Formation basalts are very similar to those from the Yakutat terrane (Fig. 4b). Clinopyroxene compositions in lavas from both suites are also similar (Fig. 5), except that the Crescent Formation shows a better developed iron-enrichment trend. The limited differentiation trend in Yakutat clinopyroxenes appears to be the result of rapid cooling, whereas many of the Crescent Formation clinopyroxenes are of coarser grained interiors of flows or intrusives. Eocene basalts with similar compositions have also been reported from the Black Hills in Washington (Globerman, 1980). The Black Hills basalts have Nb/Zr ratios very similar to those of the Yakutat terrane and form a direct linear extension with the Yakutat basalts of a progressive enrichment trend in incompatible elements (Fig. 3). Trace-element data of the Siletz River Volcanics (Snavely et al., 1968) and the Metchosin Volcanics (Muller, 1980) are not included here because they were either obtained by less precise emission spectoscopy or not analyzed for the same elements. However, FeO/MgO vs. $TiO_2$ contents of tholeiites from the lower unit of the Siletz River Volcanics, of flows and pillows from the Metchosin Volcanics, and of Crescent Formation and Black Hills basalts show a bimodal distribution similar to that of the Yakutat basalts (Fig. 2).

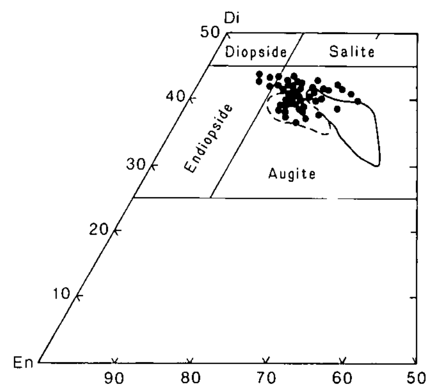


**Figure 5. Clinopyroxene compositions of Yakutat basalt on atomic Ca-Mg-Fe ternary diagram. Clinopyroxene compositions of Crescent Formation basalt, shown for comparison, show pronounced iron enrichment trend. Dashed line = field of compositions from massive flows of lower member; solid line = field of compositions from massive flows of upper member. Data from Glassley (1974).**

## DISCUSSION AND CONCLUSIONS

The Eocene basalts of the Yakutat terrane include both large ion lithophile element (LILE)–depleted tholeiites that resemble normal MORB and LILE-enriched tholeiites that resemble oceanic island basalt. The basalts were erupted, at least in part, near a continental margin and possibly close to sea level during early to middle Eocene time (Plafker et al., 1980). Basalts of Paleocene to middle Eocene age with similar petrochemistry and stratigraphic relations occur discontinuously along the Pacific Coast between southern Oregon and southern Vancouver Island. The large volumes and preponderance of light-REE–enriched lavas in

Washington and Oregon may reflect proximity to hot spots such as the Yellowstone hot spot, because seamounts generated at normal ridge segments appear to be much smaller in volume (Batiza and Vanko, 1984). Duncan (1982) showed a general age increase north and south of the Grays River Volcanics and suggested that the basalts originated as symmetrical seamount or island chains centered on the Kula-Pacific ridge. Wells et al. (1984) favored an origin along both the Kula-Pacific and Kula-Farallon ridges. Plate reconstructions for the northeast Pacific in early to middle Eocene time, based on hot-spot-track age distribution and geometry, suggest that the Kula-Farallon ridge was between central Washington and Puget Sound and moved northeastward relative to North America at velocities of about 13 to 21 cm/yr (Wells et al., 1984).

We suggest that the tholeiites of the Yakutat terrane and those in coastal Oregon, Washington, and southern Vancouver Island were accreted to North America during convergence of the Kula and North American plates and reorganization of the Kula-Farallon Ridge, which occurred from 50 to 43 Ma. In most places age of emplacement is not well documented. Intercalated and overlapping continent-derived sediment in the Yakutat terrane suggests emplacement by about 50 Ma, and a comparable emplacement date is suggested by overlap assemblages in Oregon (Wells et al., 1984; Snavely, 1984). Paleomagnetic evidence (Van Alstine et al., 1985) suggests that the Yakutat terrane was emplaced along the continental margin no farther south than Washington or Vancouver Island and could have been emplaced as far north as the latitude of Chatham Strait if about 1000 km of cumulative dextral slip on interior faults occurred in post-early to middle Eocene time (Gabrielse, 1985; Plafker, 1986). Thus the paleomagnetic data imply a northward displacement between 5° and 13°. In contrast, Bruns (1983) and Keller et al. (1984) suggested 30° northward displacement on the basis of the presence of low- and mid-latitude microfaunal assemblages. However, according to Wolfe and McCoy (1983), similar microfaunal assemblages are found in the Puget Sound area that are believed to reflect the northward extension of warmer zones in the Eocene. Similar assemblages are associated with Eocene basalts in the Washington Coast Range, for which paleomagnetic data show large rotations but no significant northward displacement (Globerman et al., 1982; Beck, 1984). Geochemistry, age relations, and paleomagnetic data suggest that the Yakutat basalts formed near the same spreading center as parts of the Crescent Formation and Black Hills basalts and that they could not have originated farther south than present-day Washington.

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