of a few thousand years, this increase should be found not only in surface water foraminifera, but also in shells of species living on the ocean bottom. In two cores from the eastern Pacific, Emiliani (*4, 5*) found an average isotopic change of only 0.5 per mille in shells of benthonic species and claimed this to be an upper limit for the isotopic change of ocean water. However, the correlation between measured levels and glacial maximums and minimums was not certain. Shackleton (*7*) has later measured the isotopic variation in benthonic species in another core from the eastern Pacific and in one from the Caribbean. In these cases the isotopic composition of benthonic species varied with about the same amount as in planktonic species. It may also be noted that Emiliani's own measurements on shells of benthonic species in cores from the equatorial Atlantic showed an average increase in δ from interglacial to glacial maximums of 1.23 per mille (*4*). This is identical with our estimate of the increase in the isotopic composition of ocean water, and thus the expected change in shells of benthonic species if no appreciable change in bottom water temperature occurred.

This reinterpretation of the signification of glacial-interglacial isotopic changes in shells of foraminifera does not detract from the immense importance of Emiliani's measurements on deep-sea cores. On the contrary, if the main part of the δ variations in foraminifera is due to changes in the isotopic composition of ocean water, caused by the building-up of continental ice sheets, we have a rigid correlation between marine isotopic variations and terrestrial glacial events. This was already pointed out by Shackleton (*7*). Emiliani's generalized "paleotemperature" curve can be reread as a curve depicting the amount of continental ice in excess of (or in deficit of) the amount present today. In this sense it may be named a "paleoglaciation" curve (Fig. 2). It should be noted that in Emiliani's generalized curve the glacial-interglacial variations have been reduced by 30 percent, as we would also do if the curve should be read as a paleoglaciation curve. In Emiliani's interpretation this was the correction to be applied due to the isotopic changes of ocean water. In our interpretation it is the maximum correction to be used due to temperature changes of Atlantic surface water.

If this interpretation is correct the paleoglaciation curve shows that within the last 425,000 years we have had seven or eight major, independent glaciations of the continents, each of a magnitude similar to the maximum of the last glaciation, and each with a time spacing of the order of 40,000 to 50,000 years. With a total length of the Pleistocene of 2 to 3 million years we should expect perhaps 40 major and independent glaciations during this period, rather than the four or six subdivided glaciations usually recognized.

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21. If the water equivalent thickness of the ice sheet was 2 km, the actual thickness was 10 percent higher. At the same time, sea level was approximately 100 m lower than at present. The additional surface elevation thus amounts to 2.3 km. Part of this was counterbalanced by isostatic subsidence of the underlying bed rock. In case of equilibrium this would probably have amounted to nearly 600 m. For a rapidly expanding glacier, equilibrium will not be attained, and the maximum postglacial isostatic rebound in central Canada is of the order of only 200 to 300 m (R. F. Flint, *ibid.*, pp. 247–255). An additional average surface elevation of 2 km relative to sea level thus seems reasonable. Close to the ice divide, surface elevation must have been several hundred meters higher than the average elevation. In order to be conservative we have disregarded the effect of this.
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24 March 1969

Dredged Trachyte and Basalt from Kodiak Seamount and the Adjacent Aleutian Trench, Alaska

Abstract. *Blocky fragments of aegirine-augite trachyte (with accompanying ice-rafted gravels) were recovered from the upper slopes of Kodiak Seamount in several dredge hauls. An alkali basalt pillow segment was also dredged from a moatlike depression, at a depth of 5000 meters, near the west base of the seamount. These retrievals confirm the volcanic origin of Kodiak Seamount and further support the view of Engel, Engel, and Havens that the higher elevations of seamounts are composed of alkali basalts or related variants.*

Kodiak Seamount is located at latitude 56°52′N, longitude 146°15′W, 104 miles (167 km) southeast of Kodiak Island, in the Gulf of Alaska. It is of particular interest since it lies in the Aleutian Trench and is the northernmost seamount in the Pratt-Welker chain of seamounts and guyots. Earlier surveys had indicated that Kodiak Seamount had a flat top and was therefore a guyot or tablemount (*1*). The summit depth of Kodiak Seamount (2017 m) was considerably greater than that of adjacent guyots located beyond the south margin of the Aleutian Trench. These relations suggested to Menard and Dietz (*1*) that the formation of Kodiak Seamount and the truncation of its summit may have predated the subsidence of the Aleutian Trench.

More recently, Hamilton and von Heune (*2*) have presented precision depth recordings and seismic reflection profiles which show that Kodiak Seamount does not have a flat summit and can no longer be classified as a guyot (Fig. 1). Therefore, the age relations between the seamount subsidence of the Aleutian Trench are in doubt.

After the recovery of alkali basalt from Giacomini Seamount (*3*), which is located 100 miles south of the Aleutian Trench, we became interested in validating the volcanic character of Kodiak Seamount and retrieving dredged rock samples for petrologic study. The petrology of the volcanic rocks composing Kodiak Seamount is of particular interest because of the unique tectonic setting and the proximity of the seamount to the break in the continental slope which is believed to be coincident with the "Andesite Line" (an arbitrary petrologic boundary between oceanic and continental volcanic provinces).

During the July leg of the YALOC 66 cruise of the R.V. *Yaquina* (Oregon State University), several pipe dredge casts were attempted on the crest, upper slopes, and at the base of Kodiak Seamount. Figure 1, a contour chart of Kodiak Seamount and adjacent areas of the Aleutian Trench, as modified from Hamilton and von Heune (*2*), shows the location and heading of the ship during the successful dredge hauls.

Dredged rocks from the upper slopes and summit area of Kodiak Seamount were dominated by angular blocks of trachyte ranging in size from several millimeters to more than 25 cm in diameter. Each of these hauls also contained hundreds of ice-rafted igneous, metamorphic, and sedimentary pebbles, cobbles, and boulders similar to those dredged from the top of Giacomini Seamount (*3*). Similar gravels have been recovered from the summit areas of other seamounts and guyots in the Gulf of Alaska, as reported by Menard (*4*) and others.

The exterior surfaces of some trachyte fragments are composed of palagonitic material and most blocks are also coated by a thin layer of iron or manganese oxide, or both. The interiors of the fragments are light tan in color, and dotted by vesicles (up to 1 cm). The vesicles tend to be elongate, parallel to the preferred orientation of plagioclase laths in the trachytic groundmass.

The trachyte specimens display minor modal variations, but the fragments are characteristically composed of aegirine-augite microphenocrysts surrounded by a trachytic fabric of plagioclase (andesine) laths, interstitial palagonitic material, incipient K feldspar and clinopyroxene, and accessory apatite and opaques. Iddingsite pseudomorphs after pyroxene and olivine are also present in most samples.

Column 1 of Table 1 lists the bulk chemical composition of a representative trachyte fragment recovered from dredge haul No. 3, at a depth of 3000 to 4000 m on the west slope of Kodiak Seamount. The bulk chemical composition of this particular rock is rather similar to that presented by Engel and Engel (*5*) for a trachyte dredged from Seamount 7-N, which is located south of the Hawaiian Archipelago (column 2, Table 1). This composition is also similar to that of the average Tahitian phonolite (column 3, Table 1) as calculated by Lacroix (*6*).

Engel and Engel (*5*) have previously commented on the rarity of trachytes among the various volcanic rock types recovered in worldwide submarine dredge hauls; and these rocks are apparently the first samples of trachyte to be recovered from the Gulf of Alaska seamount province.

Several attempts were made to recover bedrock from the axis and north slope of the Aleutian Trench, north of Kodiak Seamount. These attempts were unsuccessful, with exception of dredge haul No. 6 which retrieved a pillow segment of vesicular basalt and a small amount of blue mud from a depth of 5000 m in a moatlike depression at the west base of Kodiak Seamount (Fig. 1).

The exposed interior of this pillow segment is characterized by increasing vesicle and decreasing grain size toward the margin of the pillow, and a top composed of basaltic glass encrusted by a thin rind of palagonite. Petrographically, the basalt is composed of microphenocrysts of calcic plagioclase (andesine-labradorite) and iddingsite pseudomorphs after olivine and pyroxene, surrounded by a matrix of plagioclase laths, partially devitrified glass, and opaques.

The bulk chemical composition of a slab of the pillow segment is listed in column 4, Table 1. Chemically, the

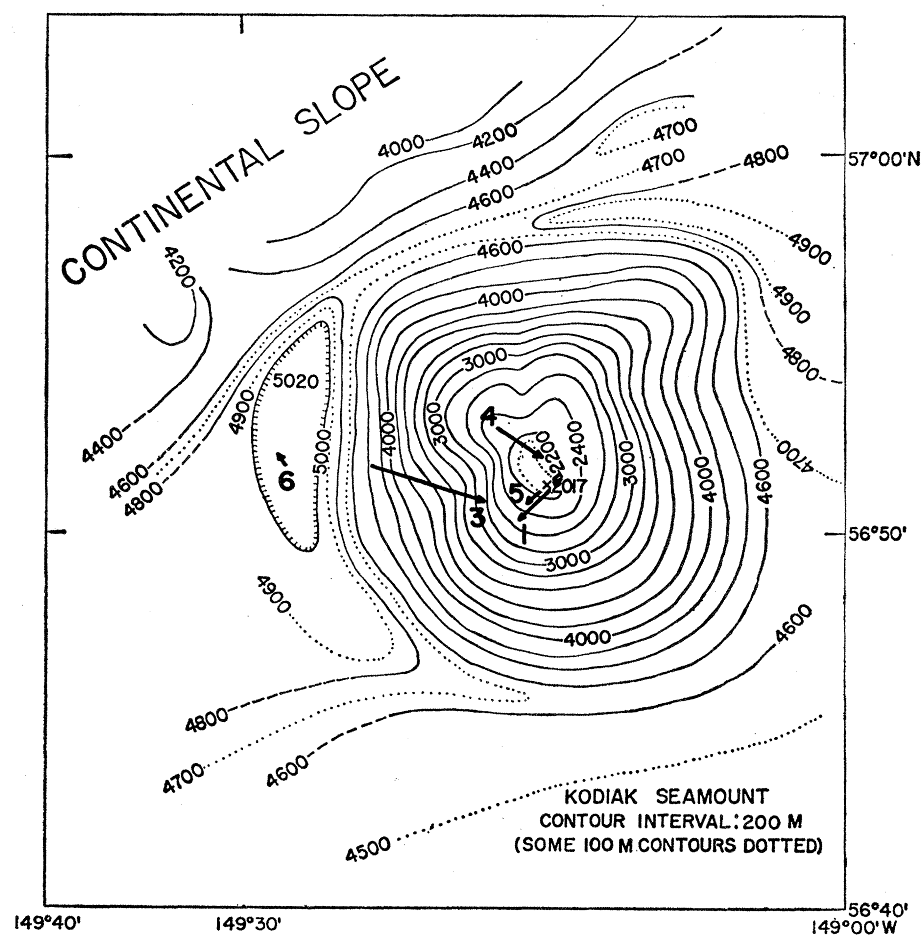

Fig. 1. Contour chart of Kodiak Seamount and adjacent areas of the Aleutian Trench, modified from Hamilton and von Heune [Fig. 1 of (*2*)]; arrows show ship positions and headings during dredge hauls.

Table 1. Comparative bulk chemical composition of dredged trachytes and basalt, and Lacroix's average Tahitian phonolite. Descriptions and locations: (1) Aegirine-augite trachyte; dredge haul (3000 to 4000 m), west slope of Kodiak Seamount; 56°53.7′N, 149°14.9′W. Analyst, H. Asari. (2) PV 320, trachyte; Dodo dredge haul 7–1 (500 m), seamount 7-N; 18°45′N, 158°15′W. Analyst, C. G. Engel (*5*). (3) Average Tahitian phonolite (*6*). (4) Alkali basalt; dredge haul (5000 m), moatlike depression adjacent to base of Kodiak Seamount; 56°24′N, 149°28′W. Analyst, H. Asari.

Constituent	Percentages (by weight)			
	(1)	(2)	(3)	(4)
SiO_2	58.57	56.12	55.47	44.08
TiO_2	0.52	0.82	1.34	3.16
Al_2O_3	18.43	18.55	19.00	16.60
Fe_2O_3	5.69	4.00	3.22	8.11
FeO	0.91	0.32	2.22	4.59
MnO	.21	.16	0.24	0.16
MgO	.64	.71	1.68	2.43
CaO	2.74	5.43	3.71	7.59
Na_2O	6.76	6.00	7.80	4.01
K_2O	3.28	4.63	4.87	1.69
$H_2O^{(+)}$	1.29	0.72		1.83
$H_2O^{(-)}$	1.32	.35		2.72
P_2O_5	0.21	1.83	0.45	1.14
Total	100.57	99.64	100.00	98.11

rock is an alkali basalt as indicated by high TiO_2, P_2O_5, total alkalies, and the low silica content. A Σ alkali/SiO_2 plot of this analysis is also located in the alkali basalt field of Fig. 2, as defined by MacDonald and Katsura (*7*). According to Hamilton and von Huene (*2*), the moat or trough on the west side of Kodiak Seamount probably formed where current scour or acceleration of turbidity currents around the base of the seamount have hindered or prevented sediment accumulation. The basalt pillow segment could have been transported into the moat by turbidity currents descending the slopes of the seamount. Therefore, this particular specimen may be from the volcanic pile of the seamount, rather than from an outcrop (volcanic?) on the floor of the Aleutian Trench.

Because of the doubtful location, the bulk composition and structure of the pillow segment cannot be applied with certainty to current arguments concerning the dominance of low K tholeiites rather than alkali basalts on abyssal floors of the oceans, as discussed by Engel and Engel (*8*) and Engel, Engel, and Havens (*9*). The occurrence of trachyte as a dominant rock type on the higher elevations of Kodiak Seamount, however, adds further support to their view that the higher elevations of seamounts, guyots, and banks in the deep ocean basins are composed of alkali basalts or related variants (*8*). The predominance of these rock types is illustrated by the relations shown in the Σ alkali/SiO_2 diagram, shown as Fig. 2, which contains the plots of published values for chemically analyzed volcanic rocks that have been dredged from higher edifices in the northeastern Pacific Ocean. Of the 17 analyzed dredged samples, only the Cobb Seamount basalt plot (*PV 37*) lies outside the alkali basalt field; and the proximity of this particular plot to the "MacDonald-Katsura" line suggests a transitional rather than tholeiitic composition.

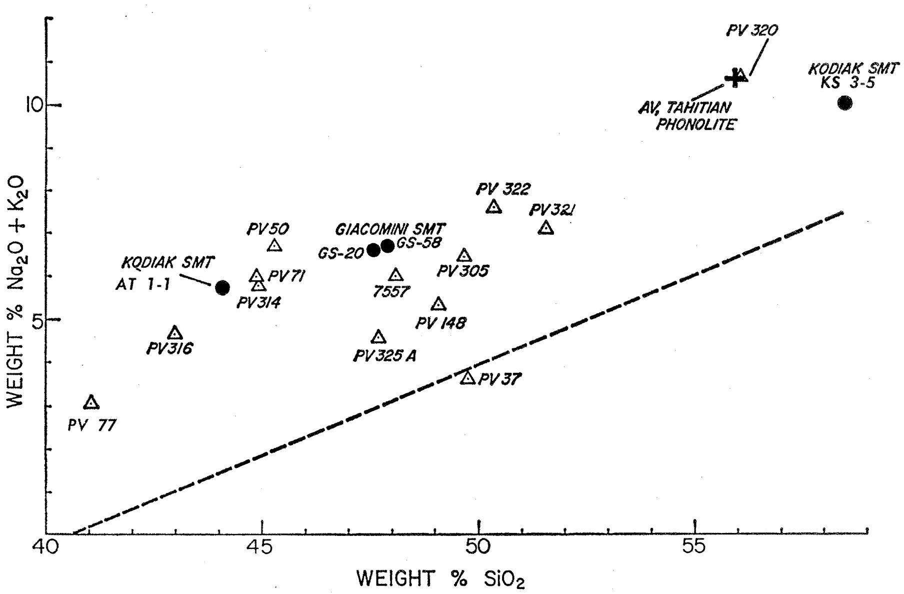

Fig. 2. A $Na_2O + K_2O/SiO_2$ variation diagram, with plots for chemically analyzed basalts and trachytes dredged from seamounts, guyots, and banks of the northeastern Pacific Ocean. Dotted line subdivides diagram into alkali and tholeiitic basalt fields, as proposed by MacDonald and Katsura (*7*). *KS 3–5*, Summit area, Kodiak Seamount, depth 3000 to 4000 m; 56°52′N, 149°15′W. *AT 1-1*, Moatlike depression adjacent to base of Kodiak Seamount, depth 5000 m; 56°54′N, 149°28′W. *GS-20*, Summit area, Giacomini Seamount, depth 790 m; 56°24′N, 146°34′W (*3*). *GS-58*, Summit area, Giacomini Seamount, depth 790 m, 56°24′N, 146°34′W (*3*). *PV 37*, Top, Cobb Seamount, depth 125 m; 47°5′N, 130°45′W (*10*). *PV 50*, Hodgkins Bank Pinnacles, depth 85 m; 53°15′N, 136°46′W (*10*). *PV 71*, Top, unnamed seamount, depth 940 m, 27°42′N, 119°17′W (*10*). *PV 77*, Top, Crest Seamount, depth 670 m, 24°36′N, 117°3′W (*10*). *PV 148*, Top, elongate bank, depth 880 m, 29°31′N, 117°17′W (*10*). *PV 305*, East slope, Clipperton Island, depth 400 m; 10°20′N, 109°15′W (*8*). *PV 314*, Unnamed seamount, depth 450 m; 4°58′N, 87°28′W (*9*). *PV 316*, West Cocos Seamount, depth 275 m; 5°28′N, 88°33′W (*9*). *PV 320*, Top, seamount 7-N, depth 500 m; 18°45′N, 158°15′W (*5*). *PV 321*, Upper slopes, seamount 1, depth 2700 m; 18°18′N, 161°46′W (*5*). *PV 322*, Upper slopes, seamount 5-W, depth 3400 to 3900 m; 19°22′N, 162°19′W (*5*). *PV 325 A*, Upper slopes and crest, seamount 2-N, depth 3170 to 4700 m; 18°47′N, 162°03′W (*5*). *7557*, Summit platform, Rodriguez Seamount, depth 675 m; 56 km west of San Miguel Island, California (*11*).

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